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SUSTAINABLE BIOENERGY PRODUCTION ON MARGINAL LANDS IN EUROPE: AN ECONOMIC PERSPECTIVE

(s.s.d. AGR/01)

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Figure 1. Lignite opencast mine of Welzow-Sud in Brandenburg, Germany

Sustainable Bioenergy Production on Marginal Lands in Europe: an Economic Perspective, February 2022

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Abstract

Extensive surfaces of land are currently underutilized, marginal and/or contaminated (MUC) in many EU and neighbouring countries. In the past few years, scientific research has demonstrated that bioenergy crops can potentially render this land profitable, generating income for the local populations and, at the same time, reaching the goals of the new Renewable Energy Directive (REDII) without interfering with food production. The main objective of this Thesis is to investigate the potential exploitation of MUC lands in Europe to produce biofuels and other innovative bioenergy products. First, the work assesses what the environmental, social, and economic opportunities and constraints of producing bioenergy on underutilized lands in Europe are. Secondly, the financial economic profitability and the risk of the related bioenergy investments for the selected case study (CS) sites are measured. Finally, the Thesis investigates the policies which could be introduced to overcome implementation barriers of bioenergy production on these lands. The findings of the first CS suggest that 2G ethanol would be produced at a cost of EUR 936/ ton in Italy and EUR 720/ton in Ukraine, with a substantial reduction in greenhouse gas (GHG) emissions. The results of the second CS indicated that in Italy and Ukraine, although the production of 2G ethanol would allow positive net yearly margins, the investments would not be profitable compared to the baseline scenarios. In Germany, the work shows good profitability for combined heat and power (CHP) and biochemicals, and negative NPV for investments in biomethane. The Monte Carlo simulation shows the possible economic result that could be attained once volatility is factored in. The policy landscaping shows that additional policy support from Governments is needed to address the high investment risks related to commercial-scale plants for bioenergy as well as to enable the supply of biomass feedstock for bioenergy production on MUC lands.

Declaration of Authorship

I, Lorenzo Traverso, born March 21, 1987 in Rome, declare that this thesis titled - *Exploring Investments Opportunities for Bioenergy Production on Underutilized Land in Europe* - and the work presented in it are my own. I confirm that this work was done mainly while in candidature for a research degree at the University of Tuscia, Italy.

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

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Publications

This thesis includes work by the author that has been published or accepted for publication. These publications are the own work of the author of this thesis, and the author has the permission of the publishers to reproduce the contents of these publications for academic purposes:

- L. Traverso, et al. **"Cost benefit and risk analysis of low iLUC bioenergy production in Europe using Monte Carlo simulation"** published in *MDPI Energies* **2021**, *14*, 1650 DOI: https://doi.org/10.3390/en14061650

- L. Traverso, et al. **"Opportunities and constraints for implementation of cellulosic ethanol value chains in Europe"** published in *Biomass & Bioenergy,* Elsevier **2020**, 0961-9534 DOI: https://doi.org/10.1016/j.biombioe.2020.105692

In parallel with the research activities presented in this thesis, the author collaborated as co-author in developing and publishing the following scientific articles and technical reports (FAO), which are strictly related to the main research objective of the study:

- M. Hirschmugl, et al, **"Energy from biomass: Assessing Sustainability by Geoinformation Technology"** published for 12th symposium of digital heart, Austria DOI: 10.1553/giscience2021_01_s120

- M. Hirschmugl, et al, **"Pan-European Mapping of Underutilized Land for Bioenergy Production"** published in *MDPI Land* **2021**, 10, 102. DOI: https://doi.org/10.3390/land10020102

- C. Khawaja, et al, **"Viability and Sustainability Assessment of Bioenergy Value Chains on Underutilised Lands in the EU and Ukraine"** published in *MDPI Energies* **2021**, 14, 1566. DOI: https://doi.org/10.3390/en14061566

- G. Pulighe, et al, **"Predicting streamflow and nutrient loadings in Semi-arid watershed with ephemeral streams using the SWAT model"** published in *MDPI Agronomy Journal* **2020**, 10, 2; DOI:10.3390/agronomy10010002

- C. Khawaja, et al, **"Promoting sustainable use of underutilized lands for bioenergy production through a web-base platform for Europe"** published for *EUBCE* **2019** DOI: 10.5071/27thEUBCE2019-ICO.12.3

- G. Bonati, et al, **"Ongoing and emerging issues for sustainable bioenergy feedstock production on marginal lands in the Mediterranean regions"**, published in *Renewable & Sustainable Energy Reviews, Elsevier* **2018**, 1364-0321 DOI: https://doi.org/10.1016/j.rser.2018.12.043

- G. Pulighe, et al, **"Agronomic feasibility of bioenergy crop cultivation on polluted soils in Sardinia: Insights and opportunities for land use design and environmental suitability"** published for the *Global Symposium on Soil Pollution (GSOP18)* **2018**, *DOI:* 10.13140/RG.2.2.31279.02723

- G. Pulighe, et al, **"Modelling impacts of bioenergy crops on streamflow, sediments and nutrient flows using the swat model"** published for *XXI National Conference of Agrometeorology - Italian Association of AgroMeteorology* **2018**, DOI: 10.6092/unibo/amsacta/5886

- Rita Mergner, et al, **“Fostering Sustainable Feedstock Production for Advanced Biofuels on Underutilised Land in Europe”** published for *EUBCE* **2017** DOI: 10.5071/25thEUBCE2017-1CO.5.5

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- Traverso L, Colangeli M, Morese M.M.; D3.3 – **User manual for the STEN tool** (official project deliverable H2020 project) 2021 FAO

- Traverso L, Colangeli M, Morese M.M.; D3.2 – **Database of attributes for sustainability assessment** (official project deliverable H2020 project) 2021 FAO

- Traverso L, Colangeli M, Morese M.M.; D3.1 - **Report on the harmonisation of methodologies and tools employed for bioenergy sustainability analyses in the EU** (official project deliverable H2020 project) 2020 FAO

- Morese M, Colangeli M, Traverso L; D3.3 **Final report on the sustainability assessment of the selected advanced bioenergy value chains in all the case study sites** (official project deliverable H2020 project) 2018 FAO

- Morese M, Colangeli M, Traverso L; D3.2 **Report on the design of the sustainability indicator set** (official project deliverable H2020 project) 2018 FAO

- (2017) Morese M, Colangeli M, Traverso L; D3.1 **Inventory of existing environmental, social and economic data sources in Italy, Germany and Ukraine** (official project deliverable H2020 project) 2018 FAO

Acronyms

2G	Second generation
CAP	Common Agricultural Policy
CAPEX	Capital Expenditures
CBA	Cost benefit analysis
CE	Circular Economy
CH_4	Methane
CHP	Combined Heat and Power
CIC	Bio-certificates (Italy)
CO_2	Carbon dioxide
COP	Conference of the Parties
CS	Case study
DM	Decreto Ministeriale
DM	Dry matter
EC	European Commission
EEG	Erneuerbare-Energien-Gesetz
EIO	Economic Input-Output Model
EIRR	Economic Internal Rate of Return
ENPV	Economic Net Present Value
EU	European Union
EUR	Euros
FAO	Food and Agriculture Organization of the United Nations
FIB	Forschungsinstitut für Bergbaufolgelandschaften
FIRR	Financial Internal Rate of Return
FNPV	Financial Net Present Value
FQD	Fuel Quality Directive from EU
FSTK	Feedstock
GAEZ	Global Agro-Ecological Zones
GBEP	Global Bioenergy Partnership
Gcal	Giga Calories
GDP	Gross Domestic Product

GHG	Greenhouse Gas
GIS	Geographic Information System
GSI	GBEP Sustainability Indicators for Bioenergy
GWh	Gigawatt hours
Ha	Hectares
HV	Heating Value
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change
L	Litre
LHV	Low Heating Value
MISE	Ministero dello Sviluppo Economico Italiano
MJ	Megajoule
MS	Member States
MUC	Marginal, Underutilised and Contaminated
NDC	Nationally Determined Contribution
NECP	Germany's Integrated National Energy and Climate Plan
OECD	Organization for Economic Co-operation and Development
OPEX	Operational Expenses
RED	Renewable Energy Directive from EU
REDII	Second Renewable Energy Directive from EU
SDGs	Sustainable Development Goals
SITS	Satellite Image Time Series
SMEs	Small Medium Enterprises
SRC	Short Rotation Coppice
TOC	Total Organic Carbon
Ttoe	Teratonnes of oil equivalent
TWh	Terawatt hours
EBA	European Bioenergy Association
UCO	Used Cooking Oil
UN	United Nations
USDA	United States Department of Agriculture

1 INTRODUCTION

1.1 Background of the research

Today we are living a historical period in which the attention towards our planet and its preservation is at a maximum, and this is mainly due to the increasing evidence of the effects of climate change on our natural resources, on our lives, and on the biodiversity of our planet. The media portray the climate change issue as an avoidable disaster if all governments will work together and will reverse the course of consumerism and carbon dioxide emissions by following the United Nations' (UN) guidance of the Paris Agreement. Fostering sustainable development to combat climate change have become an integral aspect of energy planning, analysis and policy making. Both the G20 of Naples and the 26th Conference of the parties (COP26) of Glasgow have recognized a fundamental role for science, on which politics must be based. And, above all, they recognize the close link between climate and energy and the need to reduce global emissions and improve mitigation and adaptation to climate change.

According to the International Panel on Climate Change (IPCC 2018), economic growth, technology developments and lifestyles are key elements to identify pathways consistent with 1.5°C of warming above pre-industrial levels. However, lack of global cooperation, lack of governance of the required energy, land transformation, and increases in resource-intensive consumption can slow down the achievement of the 1.5°C pathways. Governments do not hold all the cards: individuals, communities, civil society, companies, and investors can all make a major difference. But none have the same capacity as governments to channel investments to energy projects, by supporting innovation and by promoting long-term ambitions and policies necessary to realise them.

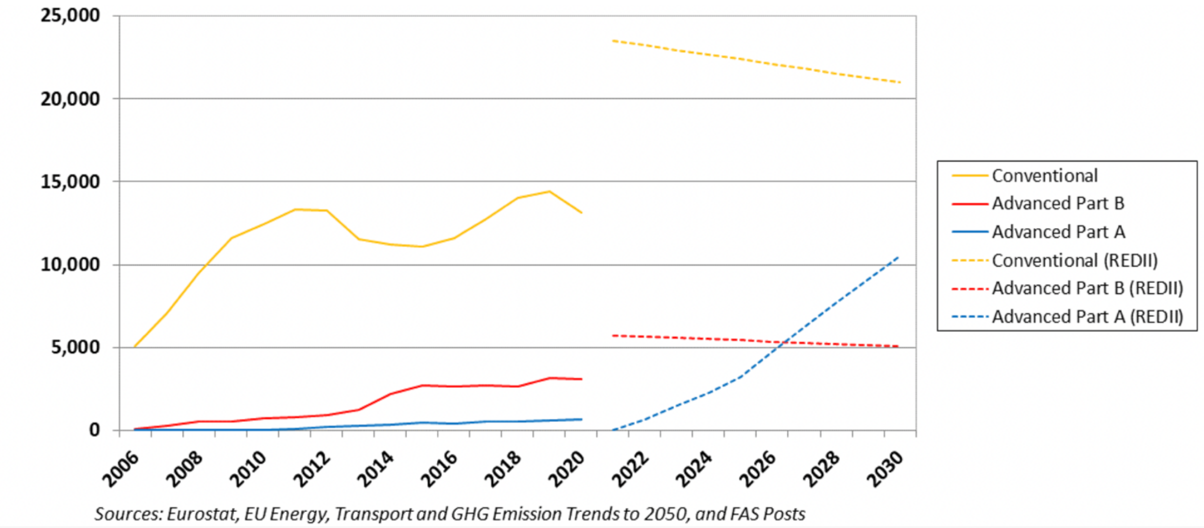
At the European level, the EU expressed its willingness to be the first climate-neutral continent in the world. To achieve this, it has committed to reduce emissions by at least 55 percent by 2030 compared to 1990 levels. With the European Green Deal (EC, 2019), the EU's growth strategy and the EU4forEnergy, Europe is taking concrete steps to decarbonise the economy (by 2050). This transformation of the European economy and societies will not only help reduce emissions, but will also stimulate innovation and investment, create more jobs, and stimulate economic growth. To achieve these targets, a holistic approach to carbon pricing and phasing out of subsidies for fossil fuels must accompany the market uptake of biofuels and sustainable renewable production of energy more generally.

Based on the proposed minimum blending rates for advanced biofuels produced with feedstocks listed in Part A of the REDII, the consumption of 2G ethanol (and in general advanced biofuels for transport) must increase significantly from 2020 (Figure 2). Although the target of 0.2 percent for advanced biofuels in 2022 equals the current consumption level, the target is set to increase to 3.5 percent in 2030, which would require approximately 10 million toe of 2G ethanol (USDA, 2018). This would entail nearly a hundred advanced biofuel plants (domestic biorefineries) with an annual capacity of around 200 million litres each. The capacity as of 2019 was about 60 million litres in the EU, although production has since been halted in Spain and Italy. According to USDA (2018), expansion of capacity has been announced in Finland (100 million litres in 2021), Slovakia (65 million litres in 2020), Romania (65 million litres in 2020) and outside the EU, in Norway (70 million litres in 2021).

According to USDA (2018), it is anticipated that the EU capacity for 2G ethanol production could increase to about 240 million litres in 2020 but the actual production is not expected to be more than 50 million litres (Figure 2). Furthermore, in recent decades, while GHG emissions decreased by 22.44 percent in EU-28 (1990–2014), for the same period, the transport sector showed inverse behaviour, increasing its emissions by 13.3 percent (Andrés & Padilla, 2018). Since 2014, GHG emissions from transport have continued to increase; by 2016, transport emissions were 26.1 percent higher relative to 1990, and preliminary estimates show that this rose to 28 percent above 1990 levels in 2017

(IRENA, 2019). As a result, transport in Europe is still one of the major sources of unsustainable energy use, accounting for most of the final energy consumption and depending almost completely on liquid fossil fuels. Given the challenging context, renewable energy technologies – especially to produce advanced biofuels for transport – represent an important opportunity to increase the share of renewable energy consumed in the EU and grant a more active role for the consumers. But the increase in advanced bioenergy production and particularly advanced transport fuels is currently held back by limited public acceptance and policy uncertainties, considered as potential risks for investors.

Figure 2. Consumption history versus EU proposal cap and minimum targets of REDII (TTOE)



Sources: USDA (2020)

Demand, supply and sustainability are all crucial aspects which describe this sector and its future developments. According to Bioenergy Europe (2021) and the European Commission, consumption of biofuels has constantly grown in the last decade. Particularly, the average share of energy from renewable sources in transport (mainly liquid biofuels and green electricity) increased from 1.6 % in 2004 to 10.2 % in 2020 and met the EU target[1]. In 2020, sustainable biofuels accounted for around 89 percent of renewable energy in transport.

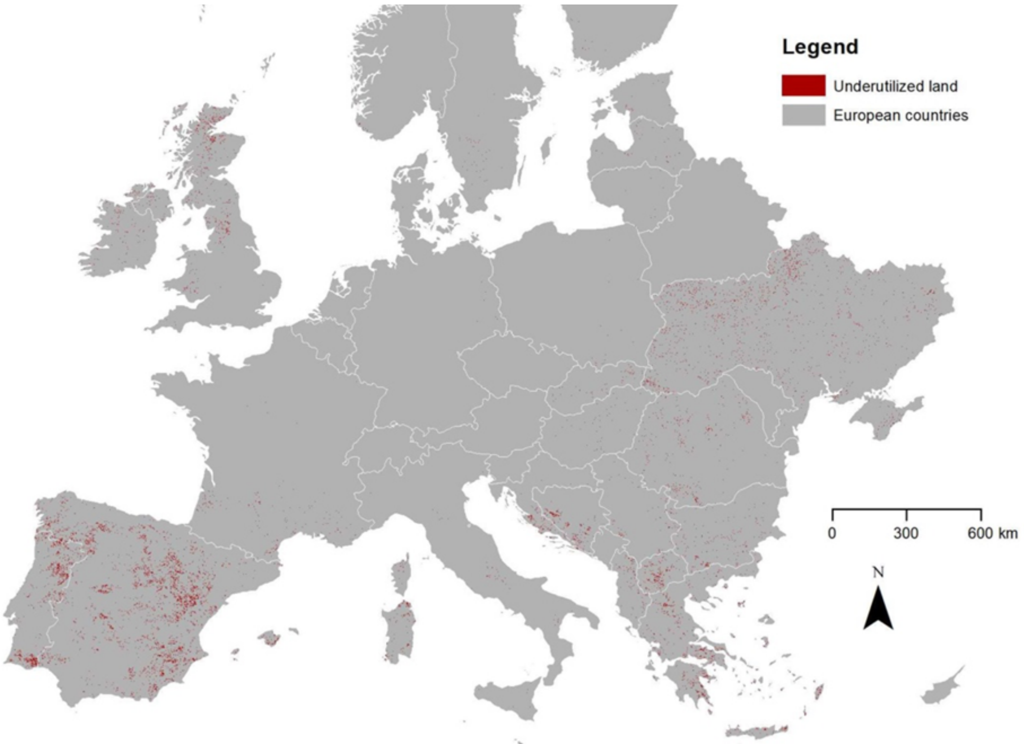
[1] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics&oldid=552113

But despite this growth, without the introduction of tailored policies which will allow a further growth in bioenergy consumption (e.g. higher blending mandates) the sector will remain heavily reliant on fossil fuels. When it comes to COVID-19, due to the reduced use of both gasoline (-13.0 percent) and diesel (-9.4 percent) caused by the pandemic, in the EU the use of bioethanol (-10.1 percent) and biodiesel also declined (-3.5 percent). However, thanks to the newly introduced blending (10 percent mandate) and the emission targets imposed by the new European Renewable Energy Directive (REDII), biofuels were not as adversely affected as fossil fuels. According to USDA, (2021), based on the minimum blending rates for advanced biofuels produced with agricultural and forestry by-products (Part A of Annex IX of the RED II), the consumption of advanced or 2G biofuels must increase significantly beyond 2020. In many countries in the EU, there is a lack of sufficient supply due to scarce feedstock availability, high capital costs of technologies and insufficient policy support. According to USDA (2021), the EU production of advanced biofuels is currently limited to roughly 4 percent of biodiesel, and five percent of bioethanol. Most of these biofuels are renewable diesels produced from tall and pine oil, bioethanol produced from food waste streams, and to a lesser extent cellulosic ethanol. Although a large portion of biofuels is produced using waste oils and fats listed in Part B of Annex IX of the REDII (nearly 30 percent of the biodiesels are produced from used cooking oil (UCO) and animal fats), increased biomass use (lignocellulosic biomass), will be essential in meeting the targets set out by the REDII. Since the increase in resource demand (food and feed crop cultivation) is leading to growing pressure and degradation of natural capital and affecting the functioning of ecosystems challenging biodiversity and soil fertility, the recovery and reuse of land and soil is necessary to secure the future provision of natural resources and ecosystem services. Finally, there is a need to continue to improve the sustainability standards of bioenergy production around the world from an environmental and socio-economic perspective (Nationally Determined Contributions (NDCs); Sustainable Development Goals of the UN (SDGs)). Ensuring the sustainability of biofuels requires consideration of socio-economic and environmental impacts along the entire value chain. Harmonized standards and certification systems are needed in Europe to assess the sustainability of advanced biofuels production and facilitate their uptake on the market.

On the other hand, although bioenergy and biofuels have great potential to reduce emissions and increase energy access, multiple trade-offs between bioenergy production, agricultural productivity, and food security exist, and managing them has presented a challenge. According to Popp, et al., (2014), Bioenergy may compete with food production, either directly, if food commodities are used as the energy source, or indirectly, if bioenergy crops are cultivated on agricultural soil that would otherwise be used for food production. Both effects may impact food prices and food security if demand for the crops or for land is significantly large. According to Costello & Ayoub (2019), the production of biomass for bioenergy affects all dimensions of food security both directly and indirectly. It is also true, however, that increased access to energy from new bioenergy production can have the potential to increase agricultural yields and accelerate the development of the local area. Furthermore, as stated by Kline et, al., (2017), bioenergy can foster social development, which is a precondition for food security and sustainability. Bioenergy provides further energy access and therefore energy security, most notably for transport and food processing. It diversifies sources of income and improves supply resilience in the event of market shocks or shortages.

In this context, a possible way to avoid trade-offs and reduce the competition with other agricultural lands is bioenergy production in currently unused areas with less impact on food production (Hasegawa et al. 2020; Meneses et al. 2019). In the EU, there are portions of land that are not used and/or cannot be used for productive activities. These lands, defined in this thesis as Marginal, Underutilized, and Contaminated (MUC) lands, are portions of land which cannot be used for food of feed production, but, in some cases, still retain the potential to produce biomass for bioenergy purposes. According to the the remote sensing time series carried out by Hirschmugl et al. (2021), a total of 5.3 million ha of underutilized land in Europe is potentially available for agricultural bioenergy production. Regarding its geographical distribution, the same study showed how the highest potentials for bioenergy feedstock production can be found in the Mediterranean and in the eastern part of the Continental region, the latter largely due to the integration of the Ukraine into the analysis. Figure 2 presents an overview of the MUC lands identified in the EU by Hirschmugl et al. (2021).

Figure 3. Map of underutilized land in Europe



Source: Hirschmugl et al., 2021

MUC lands have proven to be potentially sustainable areas to feed modern biorefineries in several countries in the EU and neighbouring countries, if consistent and stable long-term bioenergy policies are present and are implemented. For this reason, the REDII prioritizes low iLUC risk bioenergy production (European Parliament 2018). According to Mergner et al. (2017), and subsequently corroborated by Hirschmugl et al. (2021), in the EU there are portions of MUC land that are not used and/or cannot be used for food or feed production. This is the case of MUC lands in Italy, Ukraine, and Germany (Figure 3 and 8), where industrial activities have either affected the quality of the soils in specific areas therefore impacting the possibility to carry out traditional agriculture (Mergner et al., 2017) or have been left it in a condition of marginality due to lower productivity of the soils compared to the national average (Pulighe et al., 2019).

According to Niblick et al. (2015), the use of MUC lands to produce advanced forms of bioenergy should be considered a strong part of the restorative and regenerative circular system of the sustainable economy, as well as a potential solution to reduce the risk of indirect land use change (iLUC). Furthermore, the contribution of the bioeconomy to the development of a circular economy (CE) involves several typologies of bio-based products, such as wood, residues, fibres, biofuels, among others (Corrado & Sala, 2018; Geissdoerfer et al., 2017). Since increase in resource demand is leading to growing pressure and degradation of natural capital and affecting the functioning of ecosystems, with consequences for biodiversity and soil fertility (Breure et al., 2018; Holmatov et al., 2019), the recovery and reuse of land and soil is necessary to secure the future provision of natural resources and ecosystem services.

Circular economy (CE) is a system in which the final disposal of waste, co- and by-products is minimized by promoting their reuse and valorisation) (Kirchherr et al., 2017). According to the CE framework, the environment, resources, as well as economic benefits, are all central aspects that, when viewed together, can lead to a regenerative economy and natural environment (Geissdoerfer et al., 2017; Lieder & Rashid, 2016). Therefore, the concept of CE can be successfully applied to advanced bioenergy value chains on lands not utilized for any agricultural activity or contaminated (the case of the MUC lands in our research), thus not useable for traditional agricultural productions.

1.2 Recognised definitions of MUC lands

Among a variety of definitions, The Food and Agriculture Organization of the United Nations (FAO) defines "fallow land" as agricultural land that is not seeded for one or more growing seasons (FAO, 2018a). According to this definition, the maximum idle period is usually less than five years and past these five years, land can be reclassified (FAO, 2018a). The reclassification of these lands was the novel approach adopted by FAO to identify the suitable lands that could be used to produce bioenergy without competing with other lands suitable for food production. It led to the identification of MUC land through the definition of three different land typologies, which are also used in this work: underutilized land; marginal land; and contaminated land.

"Underutilized land" includes agricultural land that has not shown signs of human activity (including grazing) over the last five years, and therefore cannot be classified as fallow land anymore. In other words, a surface of land is considered underutilized only when satellite image time series (SITS) show that there has been a lack of intensive utilization of the land for a period of more than 5 years.

Land marginality could depend on both biophysical constraints (e.g. low fertility, poor drainage, shallowness, salinity, unfavourable climate), and socio-economic ones (e.g. absence of markets, difficult land access, restrictive land tenure, small holdings, poor infrastructure, unfavourable output/input ratios). Marginal land is thus not automatically catalogued as underutilized land; if an area is considered marginal because it has poor soil performance but there is some form of land use (e.g. agriculture, even if low productivity) it is not considered underutilized. Similarly, if an area is classified as agricultural land but satellite image time series show no sign of utilization over the last 5+ years, the area is considered underutilized.

Soil contamination is defined as the occurrence of pollutants in the soil above a certain level, causing deterioration or loss of one or more soil functions (Panagos et al., 2013). It can be considered as the presence of chemicals or other alterations in the natural soil environment resulting from anthropogenic activities. This type of contamination typically arises from the rupture of underground storage tanks, application of pesticides, mining activities, military operations, deposition of heavy metals from industrial emissions, or direct discharge of industrial wastes into the soil (Tóth, 2016). The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, and lead and other heavy metals. Consequently, the occurrence of contamination is directly correlated with the degree of industrialization and intensity of chemical usage in an area.

1.3 Selected potential bioenergy pathways on MUC lands

This thesis investigates why the use of marginal sites for sustainable biofuels and bioenergy production from energy crops should be supported and promoted. The following paragraph provides a short overview of the advanced bioenergy pathways and feedstocks considered for this study, their main characteristics, and their market in the EU.

1.3.1 Cellulosic ethanol from lignocellulosic feedstock

Two bioenergy feedstocks were considered for this study to potentially produce cellulosic or second-generation ethanol (hereinafter referred to as 2G ethanol) on MUC lands. These are: i) willow (*Salix viminalis L.*) cultivated under a Short Rotation Coppice (SRC) regime in Ukraine, and ii) giant reed (*Arundo donax L.*) under irrigated and rainfed regime in Italy. 2G ethanol is a biofuel that is manufactured by converting vegetation into ethyl alcohol (ethanol). Whereas first generation ethanol uses edible feedstock such as corn (maize), 2G ethanol can be produced by using raw materials such as wood, perennial grass, or nonedible plant residues. This allows 2G ethanol to have a lower impact on the food chain than first generation biofuels because it can be produced on lands that are only marginally useful for food production. According to USDA (2021), the commercialization of 2G ethanol is lagging behind the development of other advanced biofuels (e.g. HVO). High research and production costs and regulatory uncertainty are the main factors that prevent operators from investing in cellulosic ethanol.

1.3.2 Biomethane, CHP and Biochemicals from low iLUC risk feedstock and grasslands

For the advanced biomethane pathway, two feedstocks were selected as potential sources of biomass on MUC lands in Germany. These are Lucerne (Alpha-alfae) and Sorghum potentially grown on post-mining reclamation sites. Biomethane (also known as "renewable natural gas") is a near-pure source of methane mainly produced by "upgrading" biogas (around 90% of total biomethane produced worldwide). Although biogas is considered a first-generation form of energy, by upgrading it to biomethane, the pathway becomes an advanced (or second generation) way to produce energy. According to the European Biogas Association EBA (2020), biomethane production is growing in Europe. In 2020, 32 TWh of biomethane was produced. As of August 2021, 992 upgrading plants were in operation (+13% in 2021). Biomethane demand continues to grow in the industry and transport sectors to replace fossil-based alternatives as a climate-neutral energy carrier or feedstock.

Surplus grassland has a remarkable bioenergy potential, and biomass supply for energy or biobased products is regarded as one suitable way to make use of it. Grasslands on the former sewage irrigation fields in the surroundings of Berlin in Germany were considered for this study. The former irrigation fields fall under the category of "polluted areas" or "potentially contaminated sites" and therefore were considered as MUC lands potentially available for sustainable bioenergy proposes. For the biochemicals pathway, a grass biorefinery transforms biomass into a spectrum of marketable products (chemicals and materials, food and feed ingredients) and energy (fuels, power, heat) where fresh grass or grass-silage is used as input material. In the

CS, production of biochemicals (amino acids and lactic acids) was selected as an innovative promising option.

Miscanthus is a perennial grass crop with high biomass production potential and low input requirements. This study investigated whether growing miscanthus on underutilized lands could be a good option to combine remediation of soils with sustainable bioenergy production in areas that are not available for food production due to health reasons. Cultivation of miscanthus as a biomass feedstock for energy production is increasing due to its agronomical properties. The lignocellulosic biomass of miscanthus can be used for 2G ethanol production, however it is mostly utilized as raw material to produce electricity or heat by direct combustion process. Dried biomass from miscanthus can be combusted for electricity and heat production in Combined Heat and Power (CHP) plants.

1.4 Existing projects on MUC land in Europe

This paragraph introduces the link between this Thesis and national or international research and innovation activities in EU (mainly funded by the H2020 Program) that have investigated the market uptake of bioenergy and particularly the feasibility of developing biomass for bioenergy production on marginal lands in EU. The projects are listed in Table 1.

The FORBIO project demonstrated the viability of using land in EU Member States for sustainable bioenergy feedstock production that does not affect the supply of food and feed, in addition to not interfering with land currently used for recreational and/or conservation purposes.

The aim of the SEEMLA Project was the establishment of suitable innovative land-use strategies for a sustainable production of plant-based energy on marginal lands while improving general ecosystem services. The premise of the project was that the use of marginal lands could contribute to the mitigation of the fast-growing competition between traditional food production and production of renewable bio-resources on arable lands

BIOPLAT-EU promoted the market uptake of sustainable bioenergy in Europe using MUC lands for non-food biomass production through the provision of a web-based platform that serves as a decision support tool.

MAGIC aimed to promote the sustainable development of resource-efficient and economically profitable industrial crops grown on marginal lands.

MISCOMAR is a joint initiative between the European Commission and a partnership of 15 countries in the framework of the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI).

The OPTIMA project explored the potentialities of perennial grasses on underutilized or abandoned marginal lands.

Finally, the BIKE project focuses on low ILUC risk biofuels, bioliquids and biomass fuels.

Table 1. Link with national or international research and innovation activities

Acronym	Name
FORBIO	Fostering Sustainable Feedstock Production for Advanced Biofuels on Underutilized Land in Europe
SEEMLA	Sustainable Exploitation of Biomass for Bioenergy from Marginal Lands
MAGIC	Marginal lands for Growing Industrial Crops: Turning a burden into an opportunity
BIOPLAT-EU	Promoting sustainable use of underutilized lands for bioenergy production through a web-based platform for Europe
MISCOMAR	Miscanthus biomass options for contaminated and marginal land: quality, quantity and soil interactions
OPTIMA	Optimization of Perennial Grasses for Biomass Production
BIOVILL	Bioenergy Villages Increasing the Market Uptake of Sustainable Bioenergy
BIKE	Biofuels production at low - ILUC risk for European sustainable bioeconomy

1.5 Objectives and structure of the Thesis

This study analysed the feasibility of producing a series of advanced bioenergy productions (mainly biofuels), assessing their environmental, social, and economic sustainability, and calculating the financial and economic profitability of the related investments. The following research questions are analysed:

I. What are the environmental, social and economic opportunities and constraints of producing bioenergy on underutilized lands in Europe?

II. What is the financial economic profitability and what is the risk of the selected bioenergy investments on underutilized lands in Europe?

III. What policies could be introduced to overcome implementation barriers of bioenergy production on MUC land?

The Thesis is structured as follow: Chapter 1 and 2, the introduction and the literature review, provide an overview of the research field, the objectives of the Thesis, and *a description of* the relevant considered literature, its gaps and weak areas. The following chapters, Chapters 3 and 4, present the two case studies of the Thesis, which comprise the core of the research activity, and are based on the two published scientific articles presented in the Publication section (Page xii). The two articles were published in the second and third year of the PhD activities and they answer the first two research questions of the Thesis. Particularly, Chapter 3 analyses the main agronomic and techno-economic aspects affecting the uptake of 2G ethanol production on MUC lands in the Ivankiv Region of Ukraine, a lower-middle income country, and in the Sulcis area of Sardinia in Italy, a high-income country. In those countries, the use of MUC lands to produce 2G ethanol mitigates negative impacts on food security by reducing the risk of indirect land use change (iLUC). The findings suggest that 2G ethanol would be produced at a cost of EUR 936/tonne in Italy and EUR 720/tonne in Ukraine, with a substantial reduction in greenhouse gas (GHG) emissions. The second CS, presented in Chapter 4, further investigates the findings of the previous scientific work, including Germany as a suitable country for the analysis. The work measured the net economic returns for six potential investments in Italy, Ukraine, and Germany by computing benefits and costs of low iLUC biofuel and bioenergy production on MUC land from the perspective of both the private investors and social welfare. A standard cost-benefit technique was applied to analyse and compare net returns of different advanced bioenergy value-chains in monetary terms. Productivity, economic feasibility, and GHG emissions impact were assessed and considered for the economic analysis. The considered pathways were: 2G ethanol from Giant reed (*Arundo donax*) in Italy; electricity from miscanthus, biochemicals from spontaneous grass, and cultivated Lucerne (*Alpha-alfae*) with sorghum for biomethane in Germany; and 2G ethanol from Willow (*Salix viminalis*) in Ukraine. For the risk assessment, Monte Carlo simulation was applied. The results indicated that in Italy and Ukraine, although the production of 2G ethanol would allow positive net yearly margins, the investments would not be profitable compared to the baseline scenarios. In Germany, the work showed good profitability for CHP and biochemicals. On the other hand, investments in biomethane showed negative results compared with the baseline scenarios. Finally, the Monte Carlo simulation enabled the study to identify the range of possible economic results that could be attained once volatility is factored in. Finally, Chapter 5 provides the policy review and implications to answer the third and last research question of the Thesis. Chapter 5 also describes the main barriers and obstacles to the development of the studied value chains and analyses the effects of existing policies on the economic feasibility of the fuel production in the countries. The study highlights the need to provide consistent and stable long-term bioenergy policies, including but not limited to financial support, to facilitate market penetration and competitiveness. Chapter 6 provides the general conclusions of the Thesis.

2 LITERATURE REVIEW

The literature review undertaken during the research activity is presented in this chapter.

Concerning the characterisation and availability of MUC land in Europe, there is still the need to develop new methodologies to allow possible comparisons between the existing studies. According to Hirschmugl et al. (2021), in the past, only a few studies on the classification of underutilized or abandoned land using Earth Observation data had been developed for Eastern Europe (mainly large abandoned agricultural areas). Currently, several research projects (Section 1.5 of this thesis), and the related scientific publications, have started investigating MUC land availability using accurate satellite data and time series, but further work should be done.

Particularly, Hirschmugl et al. (2021) developed and published a study to identify underutilized land potentially suitable for bioenergy production in Europe by means of remote sensing time series analysis named ***"Pan-European Mapping of Underutilized Land for Bioenergy Production"***. This study provided valuable information on the European-wide availability of underutilized lands potentially usable for bioenergy feedstock production, as well as delivering insight into their geographical distribution. The study was able to validate the presence of MUC land in Italy, Ukraine and Germany, as per the potential sites proposed in this Thesis. This study reenforced the assessment and quantification of marginal lands for biomass production developed by Gerwin et al. (2018), where potentially suitable areas were identified to produce bioenergy feedstock in Europe through a Geographical Information System (GIS) analysis. Furthermore, the study on marginal land availability ***"Identification of Arable Marginal Lands under Rainfed Conditions for Bioenergy Purposes in Spain"*** conducted by Ciria et al. (2019), demonstrated how the use of marginal lands can potentially contribute to the EU policy objective to reduce GHG emissions by 60 percent by 2030 and to achieve the targets imposed by the REDII that promote the use of renewable energy sources.

A study on MUC lands for bioenergy production is made by Khawaja et al. (2021), named ***"Viability and Sustainability Assessment of Bioenergy Value Chains on Underutilised Lands in the EU and Ukraine"***. The study described how marginal land has received wide attention for its potential to produce bioenergy feedstocks, minimizing diversion of productive agricultural land from food crop production. The aim of the research was to promote biomass production for bioenergy purposes by exploring new lands that were not previously considered for this purpose. A gap in this approach was the absence of financial and economic analyses of the selected investments. This Thesis has provided these analyses for some of the case studies assessed by Khawaja et al. (2021), thus enhancing the original research.

A previous but similar study by Pulighe et al. (2018), named ***"Ongoing and emerging issues for sustainable bioenergy production on marginal lands in the Mediterranean regions"*** assessed, through a qualitative methodology, the effectiveness of eight critical issues that bioenergy developers, scholars and policymakers should consider in terms of agronomic, techno-economic and methodological practices for growing bioenergy feedstock. As per the previous study, the results of Pulighe's research proved the feasibility of using marginal land for bioenergy production; this was done through assessing their sustainability and agronomic convenience, without an analysis of the financial and economic aspects of such potential investments. This Thesis augments the findings provided by Pulighe et al. (2018), developing further analyses to prove the effective profitability of investing in bioenergy on MUC lands in the Mediterranean region.

The study by Yazan et al. (2017) ***"Environmental and economic sustainability of integrated production in bio-refineries: The thistle case in Sardinia"*** assessed, through an input-output (EIO) model, material/energy/waste flows, then modelled to compute the economic performance of a potential bioenergy biorefinery. The empirical CS is based on a (under-construction) biorefinery in the Porto Torres industrial district, Sardinia (Italy). The CS considered the marginal land available in the area as part of its feedstock availability estimates. The study does not include a financial or economic analysis of the proposed investment. The findings of the study were that a potential biorefinery can produce economically competitive outputs with an important contribution to the region's employment market. The study was included in the literature review for its findings, and especially for the CS site, which is very close the one analysed in this Thesis.

A detailed analysis of investment and operating costs of the production of giant reed, miscanthus and switchgrass in marginal lands of South Europe has been given by Soldatos (2016), ***"Economic Aspects of Bioenergy Production from Perennial Grasses in Marginal Lands of South Europe"***, in which a Life Cost Cycle of producing perennial grasses has been developed. The study proved that under current economic and climatic conditions in South Europe, perennial grass production cost in marginal lands is significantly affected by the degree of land marginality. Furthermore, a study on low iLUC risk biofuel production done by Panuotsou & Chiaramonti (2020), ***"Economic Aspects of Bioenergy Production from Perennial Grasses in Marginal Lands of South Europe"***, proved that there are opportunities to generate employment and create financial profit from cultivation and supply of Miscanthus and other lignocellulosic feedstock using low-quality, marginal land in Europe. The study followed an EIO methodology and uses an econometric model to investigate the impact of crop yield performance and marginal land on jobs and profit from the cultivation and supply of Miscanthus in low quality, marginal land in Italy and Greece. The study provided a useful range of definitions for the characterization of the marginal/unused lands. Both of these studies proved the added value that a new value chain could provide to a marginal area but did not provide any financial or economic analysis on the potential investments.

Testa et al. (2015) published a study, ***"Giant reed as energy crop for Southern Italy: An economic feasibility study"***, where a financial analysis was conducted to evaluate the economic feasibility of the introduction of giant reed as an energy crop in southern Italy. The applied methodology was a structured financial cost benefit analysis which only considered the feedstock production phase, without including the potential investments for the processing of the biomass into energy. Results showed that introduction of a biomass giant reed plantation (both for woodchip and chopped forage production) in Italy (Sicily), could have a higher economic return for farmers with respect to traditional crops.

The policies that provide support to bioenergy production and a list of social and techno-economic barriers were identified through an existing literature review and thanks to the information obtained from the results of the multi-stakeholder discussions provided by the FORBIO's technical reports. At EU level, the methodology proposed by Panoutsou & Singh (2020), ***"A value chain approach to improve biomass policy formation"***, inspired the selection of suitable policies for bioenergy where the following aspects were considered: i) the main issues the policy regulates, and ii) the policy scope, objectives, and instruments, which include regulations, financing mechanisms and soft measures. Following Panoutsou & Singh's (2020) methodology, the policy analysis was done at different stages of the value chain. At national level, for the Italian, Ukrainian, and German cases, the literature review was able to provide useful information on financial mechanisms that facilitate the market penetration and competitiveness of the studied value chains in the countries. The methodology was similar to the one applied for the EU level analysis, and the literature was mainly composed of official Government publications.

In conclusion, as proved by the literature review, in general and even more for the European context, although there are several studies and related projects demonstrating the high potential for bioenergy feedstock to be grown on MUC land from the point of view of land availability, sustainability, and agronomic feasibility, few comprehensive financial and economic profitability studies have been published with the aim to investigate and assess their economic feasibility from both the private investors and the public point of view. The first reason behind this lack of accurate studies on financial and economic investments analysis could be due to the innovative nature of this research area. A second reason could be related to the high technological level of the advanced bioenergy processing plants. The literature demonstrates how MUC lands are well suited to be used for cellulosic dedicated crops or extensive oil crop productions. However, these types of crops often follow advanced bioenergy pathways (e.g. 2G Ethanol, Hydrotreated Vegetable Oils (HVO), Gasification for electricity or synthetic fuels, etc.) for which accurate information is still confidential and therefore detailed analyses are not available due to competition issues within private industrial actors.

3 Feasibility and sustainability assessment: ethanol from lignocellulosic feedstock in Italy and Ukraine[2]

3.1 Introduction

The objective of this chapter is to assess the economic feasibility and the environmental sustainability of producing 2G ethanol on MUC land in different socio-economic contexts, and to discuss its policy implications. Although several examples of such socio-economic and environmental assessments, in both high- and low-income countries, exist (Thurlow et al., 2016; Dauber et al., 2012; Branca et al., 2016), this chapter adopts an innovative approach by assessing the feasibility of developing innovative and advanced bioenergy value chains in two different income-level countries.

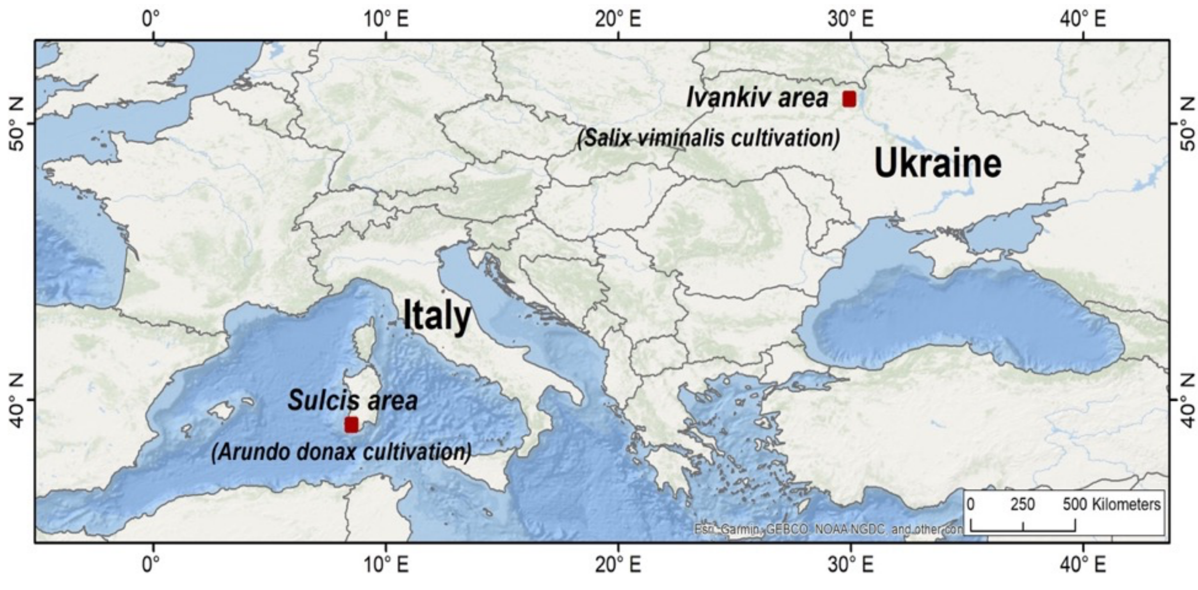
The chapter focuses on the case of Ukraine and Italy (Figure 4) as examples of countries with a bioenergy production potential. The two countries were selected based on their different income level. Ukraine, a lower-middle income country, and Italy, a high-income country. In Ukraine, the study area is located in the south-west of the Ivankiv region in the northern part of the Kyiv oblast District, while in Italy the study area is the Sulcis-Iglesiente catchment located in South–western Sardinia. The Ivankiv Region was selected primarily because of the high availability of MUC lands (e.g. marginal lands with low rental price), which represent an interesting opportunity for the deployment of modern bioenergy value chains. Furthermore, the strategic position of Ukraine at the crossroads of Europe and Asia, plus the increase in market price of natural gas due to recent geopolitical tensions, make the area suitable to evaluate alternative energy scenarios of bioenergy production. Similarly, the Sulcis area presents a large area of MUC lands that are available for bioenergy

[2] Traverso, L.; Colangeli, M.; Morese, M.; Pulighe, G.; Branca, G. Opportunities and constraints for implementation of cellulosic ethanol value chains in Europe. *Biomass Bioenergy*, *141*, 105692. https://doi.org/10.1016/j.biombioe.2020.105692. **2020.**

production. Furthermore, as already mentioned, the difficult climatic and social conditions of Sulcis make the cultivation of energy crops and subsequent biomass upgrading in a local biorefinery a valuable opportunity for job creation and economic diversification for the region.

The chapter is organized as follows: the first section analyses the agronomic feasibility of producing 2G ethanol in both countries, also calculating the production costs (financial feasibility) of bioenergy feedstock and 2G ethanol productions, respectively. Then, the chapter provides a picture of the potentials of these 2G ethanol value chains in terms of GHG emission reduction. Other results related to the sustainability assessments have been presented and discussed by Pulighe et al. (2019 and FAO (2018b), however, no scientific publications have been published taking into consideration the economic results of the project and assessing them at the European level, distinguishing between different countries with different levels of income and bioenergy policy contexts.

Figure 4. Potential bioenergy sites and crops considered for the analysis



An example of contaminated land comes from the CS site of Carbonia in the Sulcis Iglesiente in Italy, where the land has been affected by chemical contamination and therefore all agricultural activities banned by both local and National Government, except some illegal agriculture and pasture uses (Di Lucia & Ribeiro, 2018; Di Lucia et al., 2019). This undesirable scenario has mainly been driven by the difficult climatic conditions faced by local farmers – mainly drought – and the high unemployment level generated by the cessation of previous prosperous industrial and mining activities (Di Lucia et al., 2019). As a result, this illegal agricultural production can lead to unsafe conditions of animal nutrition or in the worst cases human health. The contaminated lands under illegal agricultural activities should be considered as available for bioenergy production, but the delicate situation defers action. A possible solution remains to stimulate the conversion from feed or food crops to biomass feedstock production through economic incentives allocated to farmers at local or sub-national level.

3.2 Materials and methods

3.2.1 Data collection and study areas

This chapter is based on data and information collected by FAO and other project partners in the context of the FORBIO project. All analyses and assessment developed during implementation of the project were based on a combination of existing tools developed and/or implemented by the partners of the consortium, using both primary and secondary data.

For the agronomic aspects of feedstock production, the financial feasibility study and the environmental assessment, data, collected from on-going and completed projects, public sources, and accessible databases, were reported in the project deliverables. Particularly, for the Italian CS site, two project deliverables have been published for the agricultural (Biochemtex, 2016a) and the techno-economic assessment (Biochemtex, 2016b), respectively. The same official deliverables are available for the Ukrainian CS (SECBiomass, 2016; Biochemtex, 2017). For the sustainability assessment, FAO published a final report including both countries (FAO, 2018a). The deliverables are publicly available and downloadable from the project website[3].

A special focus was put on cellulosic biomass crops in the CS sites, including annual and perennial energy crops (fibre sorghum, forages, giant reed, miscanthus, switchgrass), cellulosic agricultural residues (wheat straw, corn stover) and short rotation plantations (Populus spp., Salix spp., Black Locust (*Robinia pseudoacacia L.*)). All available information about land contamination was collected and elaborated into a harmonized, user-friendly database. However, most of the information regarding soil contamination was fragmented, and scattered in various reports and studies that are often still not digitalized (SECBiomass, 2016; Biochemtex, 2017). Particularly, for the Italian CS site, all data were collected and aggregated into a GIS model, which was verified in situ by involving all relevant stakeholders such as research centres, universities, National and Regional Agencies for the Environment and SMEs (Biochemtex, 2016a).

Figure 5. Arundo donax cultivation trial in Sardinia, Italy

[3] https://forbio-project.eu/documents

In Italy, there are notable examples of MUC land due to biophysical limitations, soil contamination or due to economic/profitability limitations. The area of the Sulcis Iglesiente (Sardinia Region) (Fig. 3) is located in the largest contaminated "Sites of National Interest" in Italy (about 36,000 ha, of which around 18,000 ha of agricultural land), polluted by heavy metals from industrial flumes derived from coal power generation, aluminium production, as well as by the past centuries-old mining activities (Pulighe et al., 2016). Moreover, the economic decline of the cereal-based rotations and water scarcity have contributed to land abandonment and underutilization. A recent study revealed that, among the tested energy crops (Table 2), giant reed (*Arundo donax* L.) could have the highest potential to effectively support biomass energy value chains (Pulighe et al., 2016). Figure 5 shows an experimental field of *Arundo donax* in Sardinia.

The study revealed that in the Sulcis area, giant reed cultivation could supply enough biomass to a 2G ethanol plant to produce 40,000 tonnes of ethanol per year.

Table 2. Summary of the different typologies of bioenergy crops analysed in the context of the FORBIO project in Italy

Typology	**Herbaceous plant**		**Woody plants**
	Annual	**Perennial**	
Lignocellulosic crops	Globe-artichoke Milk thistle	Gian reed Miscanthus Switchgrass Smilo grass Tall fescue Ryegrass Cocksfoot Cardoon	Eucalyptus
Oleaginous crops	Rapeseed	Ethiopian Mustard	
Starch crops	Sweet-Sorghum Maize Durum-Wheat Triticale		

In Ukraine, there are at least 4 million ha of agricultural land that are underutilized or set aside due to low productivity for cultivation of food crops, as well as low demand for agricultural products in the internal market and the distance of these areas from major European markets (Mergner et al., 2017). Part of this area could be used to produce advanced biofuels from willow or used to produce solid biofuels and biogas (SECBiomass, 2016). The area studied in the project (21,350 ha site in the Ivankiv region, of which 16,720 ha of agricultural underutilized land) (Fig. 3) is located outside the Exclusion Zone of Chernobyl. Therefore, at least in principle, these soils are not contaminated, and the agricultural land is unused due to limitations other than health risks.

Existing field trials among the tested energy crops (Table 3), show that willow (*Salix viminalis L.*) cultivation under a Short Rotation Coppice (SRC) regime has the potential to produce high quality biomass that could be used to produce electricity and heat in CHP plants and roughly 33,440 tonnes of 2G ethanol (SECBiomass, 2016).

Table 3. Summary of the different typologies of bioenergy crops analysed in the context of the FORBIO project in Ukraine

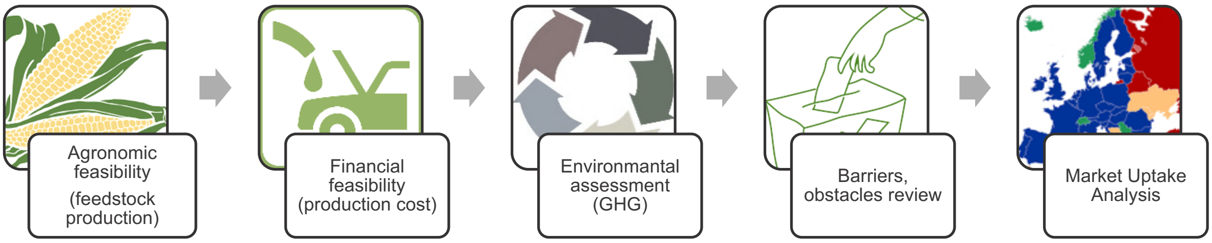
Typology	**Herbaceous plant**		**Woody plants**
	Annual	**Perennial**	
Lignocellulosic crops	Mallow (*Malva meluca graben*)	Miscanthus Switchgrass Sida Cup plant	Poplar Willow Scots pine Black locust
Oleaginous crops	Rapeseed Amaranth Turnip x wild Cabbage hybrid Rocket-cress Camelina	Ethiopian Mustard	
Sugar crops	Sweet sorghum Jerusalem artichoke	Columbian grass	
Starch crops		Sorrel	

This potential production suits the Ukrainian context, where the Biomass Association of Ukraine estimated that about 400,000 ha of under-utilized agricultural land could be devoted to the production of lignocellulosic biomass, thus increasing the market uptake of sustainable bioenergy without interfering with other uses of the land (Mergner et al. 2017; SECBiomass, 2016; OECD, 2015).

3.2.2 Methodology

To assess the feasibility of the production of 2G ethanol on MUC lands, a multidisciplinary approach has been developed and applied (Fig. 6). Steps 1, 2 and 3 (Agronomic aspects of 2G ethanol production on MUC lands; study or the production costs of 2G ethanol in the case studies; and Environmental analysis based on a GHG assessment developed by FAO, respectively) are described in this section (Section 3.2.2), while steps 4 and 5 are further discussed and presented in chapter 5.

Figure 6. Market Uptake of Advanced Biofuels analysis



3.2.2.1 *Agronomic and financial assessment*

To identify the most promising bioenergy crops for advanced biofuel production, agronomic feasibility studies were conducted. Agronomic performances in different climatic zones, soil conditions, land morphology, availability of irrigation infrastructures and limitations due to soil contamination and to different marginality factors were considered. Detailed databases were developed for assessing the most promising cellulosic biomass crops, based on existing literature data and field trial results in both countries. The databases contain a series of observations of agronomic trials (e.g. crop yield, humidity, input requirements, etc.) as well as data on soil characterization. Finally, the agronomic characteristics and biomass yield potentials of the selected crops were compared to identify the most suitable crops for the selected value chains (Biochemtex, 2016a; SECBiomass, 2016).

Furthermore, as financial aspects play a fundamental role in ensuring the feasibility of all bioenergy value chains, the production cost of 2G ethanol in both CS sites was calculated at different steps of the chain. First, the feedstock cost was estimated using the data collected from the agronomic assessments for both Italy and Ukraine. For this estimation, the following costs were taken into consideration for the analysis: (I) landowner fee, (II) irrigation fee, (III) fertilization costs, (IV) annual operations, (V) harvesting cost, (VI) yearly installation + eradication costs, (VII) yearly irrigation costs, (VIII) capital remuneration, (IX) supply chain management, and (X) bioenergy feedstock transport cost.

Subsequently, the production cost of 2G ethanol was calculated considering the following assumptions:

- Technology: Lignocellulosic (2G) ethanol technology for fuel production
- Plant Capacity: 40,000 tonnes/year Italy; 33,440 tonnes/year Ukraine
- Collection radius from the plant: 40 km Italy; 50 km Ukraine
- CAPEX: Capital expenditures (CAPEX) represent the investment required to design, construct, and commission the bioenergy plant and include the buildings, platforms, facilities, equipment, pipelines, and everything else with a lifetime greater than one year. CAPEX was included in the production costs for both areas because plants do not currently exist within the collection radius.

The cost of 2G ethanol in EUR per tonne of fuel was calculated using the formula below:

Equation 1. Cost of 2G ethanol calculation

$$Cost\ of\ cellulosic\ ethanol\ per\ ton = \frac{\frac{CAPEX}{X\ number\ of\ years} + \sum OPEX}{Ethanol\ plant\ production\ per\ year} \quad (1)$$

In this approach, the CAPEX was distributed over 20 years of planned investment and summed to all operational expenses (OPEX). The result was divided by the annual ethanol production of the plant (plant capacity). The OPEX that were considered for this analysis were: feedstock expenditures, salaries for feedstock transport, salaries and inputs for feedstock processing into fuel, and salaries for fuel transport.

3.2.2.2 *Environmental assessment*

For the assessment of sustainability of the potential CS investments in bioenergy in Italy and Ukraine, the study relied on the most widely accepted tools for sustainability assessment of bioenergy, including the 24 GBEP Sustainability Indicators for bioenergy and the FAO Integrated Food and Energy Systems Appraisal Tool. These instruments have been developed to present a national level overview of the impacts of existing bioenergy production and use on several environmental, social and technoeconomic aspects. Particularly, for the environmental aspects, this paragraph presents the methodology developed to assess the GHG emissions at the value chain level (FAO, 2020b), with the aim to support the financial analysis with an overview of possible environmental benefits of such value chains. Environmental aspects provide another interesting point of view and enhance the analysis, especially considering the recent REDII targets. The framework of the GHG assessment included the following steps: the analysis of traditional fuel used by the fleet for the comparison with the replaced fuel; the GHGs covered and the Global Warming potential; the identification of the biomass availability and the land use change; and the analysis of GHG emissions along the whole value chain (biomass production and transport, biomass processing into fuel and transport of fuel). The efficiency impacts on fleet mileage have not been included because in Europe significant differences exist among national fleets and these differences in the technology of internal combustion engines are make regional averages difficult to obtain. Thus, the system boundaries of the value chain comprise all activities from feedstock production to fuel distribution at the fuel stations, without considering the final use of the fuel by customers. All inventory data are available from (FAO, 2018a; FAO, 2020b).

A specific area – the target area – has been defined for each CS site to assess the sustainability impacts of the different scenarios of bioenergy value chains simulated. The target area is the smallest area of land as defined by subnational boundaries of A) physical, B) political, and/or C) cultural origin that is concerned with the bioenergy production and use operation and that contains all the direct interactions deriving from the bioenergy value chain (FAO, 2020b). In other words, the definition of the reference system at local (sub-national) level was originally proposed as the area delimited by those municipalities or watersheds touched upon by the production of the biomass and its transport to the processing plant. The area itself is, therefore, the minimum surface in ha (delimited by existing physical or political borders) that has relevance to the bioenergy value chain simulated.

The final environmental assessment was structured as the analysis of the difference in impacts caused by two (or more) reference scenario projections: *baseline vs target* scenarios projections.

Equation 2. Impact assessment methodology

$$\boldsymbol{Iv = TSv - BSv} \qquad \textbf{(2)}$$

Where:

Iv is the Indicator's Value,

TSv is the Target Scenario Value, and

BSv is the Baseline Scenario Value.

The GHG assessment compares the emissions produced by the 2G ethanol value chains (target scenario) with the baseline scenarios based on fossil fuels. The baseline situation is represented by the fuel currently used by the passenger car fleet in each country which would be partially substituted by the 2G ethanol produced in the target area. It is common practice in GHG assessments to measure the sustainability impact of bioenergy production and use based on GHG emission intensity per unit of energy. The GHG emission intensity is therefore expressed in grams of carbon dioxide equivalent per megajoule of bioenergy produced (gCO2eq/MJ) (FAO, 2020b).

In the baseline scenario, the reference fuel is petrol. The emission intensity of European petrol is 83.3 gCO2eq/MJ (FAO, 2020b). In the target scenario, the emission intensity of 2G ethanol produced in the target area was therefore compared to the emission intensity of the reference fuel, and the relative (in percentage) and absolute (in g, Kg, or tCO2eq) change is reported. The total surface of land (target area) for the Italian and the Ukrainian CS sites were 35,745 ha and 180,000 ha, respectively. The main contributors and components of the GHG assessment of biofuel production and use were: (I) feedstock production; (II) feedstock transport; (III) feedstock processing; and (IV) fuel transport/distribution.

Concerning the processing phase, the simulations included a scenario in which a 2G ethanol plant was built in each CS site. The technology selected for the simulation was the PROESA[4] process (steam- explosion, Enzymatic liquefaction, Simultaneous Saccharification and Fermentation SSF)[5]. The PROESA technology foresees the production of by- and co-products of the

[4] http://biochemtex.st.e-one.it/en/proesa

[5] The PROESA technology is patented by Biochemtex, a partner of the FORBIO project and technology provider of the first-of-its-kind commercial scale 2G ethanol biorefinery in Europe, in the municipality of Crescentino, in Italy.

ethanol value chain and thus an allocation among the various products was performed.

The principal co-product of this processing technology is lignin, which is used to fuel a CHP boiler to fulfil the internal needs of the biorefinery and produce some 104 GWh of excess electricity. In the simulation, the electricity surplus is sold to the grid while the potential production of 2G ethanol is obtained considering a 40,000 tonne/year biorefinery using PROESA cellulosic sugar expertise. Although the allocation of co-products is often calculated taking in consideration the economic value of the outputs, particularly when it comes to crop production and livestock feed supply chains (Mackenzie et al., 2017), the analysis considered a more biophysical approach for the advanced biofuels value chain; the results were allocated considering the energy output in MJ from both the ethanol and the combustion of the lignin (electricity production).

Furthermore, not all stages of the supply chain generate emissions that require allocation. This is the case, for instance, of the biomass processing into fuel, for which large quantities of enzymes and yeast are needed to treat the lignocellulosic biomass and produce fermentable sugars; the emissions linked to the production of enzymes and catalysts were not attributed to the surplus electricity but solely to the production of fermentable sugars and therefore ethanol (FAO, 2018a).

3.3 Results and discussion

3.3.1 Agronomic and financial assessment

Below, the results of the analysis conducted for the different parts of the value chain are reported: feedstock production, feedstock processing into fuel, and the production and sale of co-products to local market.

3.3.1.1 *Feedstock production*

In the Sulcis area (Sardinia, Italy), from the field trials of two experimental sites of the target area (Arca, 2016), giant reed has been selected as a valuable bioenergy crop due to its comparatively high biomass yield and the good conversion rate into ethanol. Results showed that giant reed under irrigated management systems represents the best option to obtain average high yields of 25 tonne of dry biomass per hectare per year (Table 4) (Di Lucia & Ribeiro, 2018; Arca, 2016). However, of the hypothetical 7,000 ha needed to supply enough biomass to produce 40,000 tonne of 2G ethanol, only 1,000 ha were equipped with the necessary irrigation infrastructure. In a rainfed scenario, around 18,000 ha would be necessary to feed the biorefinery.

Table 4. Average yield and feedstock (FSTK) conversion to fuel of giant reed in Italy and willow in Ukraine field trials

Bioenergy crop	Irrigated	Rainfed
Giant reed		
Average yield (tonnes of dry biomass per hectare per year)	25	10
Conversion rate (tonnes of FSTK per ton of fuel produced)	4.5	4.5
Willow		
Average yield (tonnes of dry biomass per hectare per year)	-	10
Conversion rate (tonnes of FSTK per ton of fuel produced)	-	5

Source: FORBIO, Techno-economic assessment Italy and Ukraine

For the Ukrainian CS site (Table 4), field trials conducted in the Ivankiv Region showed that rainfed willow was the most promising cellulosic bioenergy crop and a valid candidate for the ethanol biorefinery in this CS area due to the yields obtainable: up to 10 tonnes of dry biomass per ha per year (SECBiomas, 2016). As shown in Table 5, the final cost at plant gate for the feedstock produced in Italy (irrigated giant reed) was calculated at EUR 71 per tonne of dry biomass as a sum of the following technical field costs: landowner fee (24 EUR/tonne), irrigation fee (8.4 EUR/tonne), fertilization costs (4 EUR/tonne), annual operations (3.2 EUR/tonne), harvesting (single pass with 2 tractors) (13.3 EUR/tonne), per year installation + eradication costs (0.6 EUR/tonne), per year drip irrigation investments (5.3 EUR/tonne), capital remuneration 2.5 percent (0.1 EUR/tonne), and supply chain management (2 EUR/tonne).

Table 5. Biomass cost delivered at plant gate in Italy and Ukraine (EUR/dry tonne)

Item	Italy	Ukraine
Landowner fee	24	1.3
Irrigation fee	8.4	-
Fertilization cost	4	13.9
Annual operations	3.2	3.5
Harvesting	13.3	3.2
Pro-anno installation + eradication costs	0.6	13.9
Pro-anno drip irrigation investments	5.3	-
Capital remuneration 2.5%	0.1	3.5
Supply chain management	2	-
Technical field cost	**61**	**25.2**
Biomass handling and transport	10	3.5
Final cost at plant gate	**71**	**28.7**

Source: FORBIO, Agronomic and techno-economic feasibility study

The transport cost for biomass (40 Km) was calculated as EUR 10 per tonne of dry biomass. In Ukraine, following the same model, the final cost at plant gate for the delivered biomass was calculated as EUR 28.7 per tonne of dry biomass, while the technical field cost was 25.2 EUR per tonne of dry biomass. Table 5 provides a list of costs for both countries.

3.3.1.2 *2G ethanol production from lignocellulosic biomass feedstock*

The estimate of the production cost of 2G ethanol was performed by local partners of the FORBIO project through calculations and data obtained both from direct communication with the biorefinery and information found in the specialized literature. The components that make up production cost are CAPEX and OPEX. The CAPEX was quickly estimated for the hypothetical biorefinery in Italy based on the information obtained from the project partner in Italy (FAO, 2018a). It is important to underline that, due to a confidentiality issue, the industrial partner in Italy provided information about CAPEX in an aggregated way. Therefore, as shown in Table 6, a total initial investment of EUR 150 million was considered adequate for the construction and running of a 40,000-tonne 2G ethanol plant using the PROESA technology, while a reduced investment was estimated for the 33,400-tonne 2G ethanol plant of Ivankiv region in Ukraine. The OPEX in EUR per year that have been taken into consideration are the feedstock expenditure, inputs required for the feedstock processing into fuel (e.g. enzymes, yeast, catalysts, etc.) (Chudziak, 2017), salaries of the employees of the bioenergy plant, plus other miscellaneous costs.

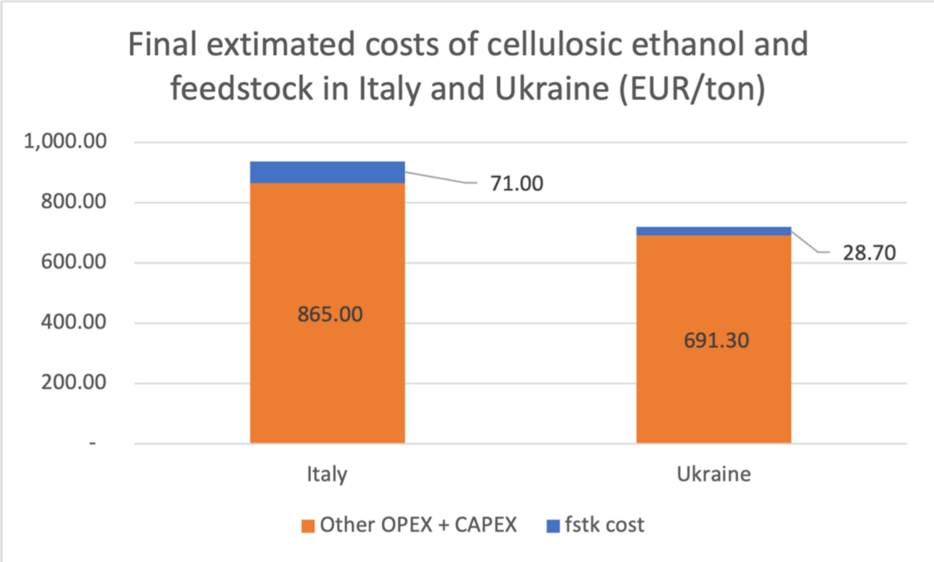
Table 6. Capital and Operational expenditures of the studied 2G ethanol plants in Italy and Ukraine (Thousands of EUR per year)

Item	Italy	Ukraine
CAPEX	**7,500**	**6,250**
Feedstock expenditure	12,780	4,681.1
Inputs	13,000	10,790
Salaries	2,952	2,592
Miscellaneous	1,200	1,000
Tot. OPEX	**29,932**	**19,063**

Source: FORBIO, Techno-economic feasibility study, Italy and Ukraine

As presented in Fig. 6, in total, for the Italian CS, the production cost of 2G ethanol is calculated at EUR 936 per tonne. This value was compared to and resulted in line with the range of cost for 2G ethanol – between EUR 940 and 1010 per tonne – provided by Chudziak (2017) in a special report for the European Commission on this theme. In Ukraine, the final cost of 2G ethanol has been estimated to be EUR 720 per tonne (Fig. 7). The expected cost of production in Ukraine is lower than the cost provided by Chudziak (2017) and this is mainly due to the lower feedstock price.

Figure 7. Final estimated costs of 2G ethanol and feedstock produced in Italy and Ukraine (EUR/tonne)



Source: Data from the FORBIO project deliverables

3.3.1.3 *Economic viability of 2G ethanol production*

In Italy, both 1G and 2G ethanol are subject to an excise if the product is not at least partially denaturized. This excise is 10.35 EUR/m^3 ethanol and producers must comply with the denaturation process if they intend to stay in business (FAO, 2018b). According to ICIS 2019 (Pennington, 2018), the European price for ethanol is around 424 EUR/m^3 (534 EUR/t). According to Table 7, at EU market prices, sales of ethanol from a 40,000 tonne/year biorefinery would generate some 21,360,000 EUR/year in the Italian CS. In addition to ethanol production, the surplus electricity produced in the hypothetical biorefinery could reach some 104 GWh of electricity per year. It is crucial to underline the importance of this production of surplus electricity sold to the grid in the economic feasibility of the PROESA technology, as the price per unit of electricity generated is as much of a key aspect in evaluating the economics of a 2G ethanol biorefinery as the price paid per tonne of ethanol. In fact, at the current price of electricity for large scale biomass-fuelled power plants in Italy of 115 EUR/MWh as per Decreto Ministeriale (DM) July 26, 2016 (MISE, 2016), revenues from the 2G ethanol plant in Sardinia for the generation of the surplus of electricity would amount to EUR 11,960,000 per year (FAO, 2018a). Total revenues for a 40,000 tonne/year biorefinery at current market conditions would then be EUR 33,320,000 per year (Table 7). However, since the total production cost of 2G ethanol in Sardinia would be around 936 EUR/tonne or 37,440,000 EUR/year, given the current market conditions, the Gross Value Added of a 2G biorefinery would be negative by some EUR 4,120,000 per year (FAO, 2018b).

Table 7. Gross Value Added (GVA) of Cellulosic ethanol production in Italy and Ukraine

Item	Italy	Ukraine	Unit
Ethanol EU Market price	534	534	€ per ton
Revenues from ethanol	21,360,000	17,835,600	€ year
Revenues from Electricity surplus	11,960,000	10,779,300	€ year
Revenues from heat generation	0	4,905,252	€ year
Total revenues	**33,320,000**	**33,520,152**	**€ year**
Ethanol Cost of production	940	720	€ per ton
Total cost of production	**37,440,000**	**24,048,000**	**€ year**
GVA	**-4,120,000**	**9,472,152**	**€ year**

Source: Data from the FORBIO project deliverables

Considering the EU market prices mentioned above, sales of ethanol for a 33,400 tonne/year biorefinery in Ukraine would generate some 17,835,600 EUR/year in revenue. The price per unit of electricity generated (around 87 GWh per year) is a contributor to the overall balance of the 2G ethanol value chain (FAO, 2018a). The current price of electricity for large scale biomass-fuelled power plants in Ukraine is the equivalent of 123.9 EUR/MWh as per Article 20 of Law "On Heat Energy Supply", and therefore revenues for the generation of electricity would amount to around EUR 10,779,300 per year for the entire lifetime of the biorefinery (20 years). Total revenues for a 33,400 tonne/year biorefinery at current market conditions would then be EUR 33,520,152 per year (Table 7). In addition, the generation of heat as a co-product of the biofuel production for about 28,030 households in the country would deliver additional 4,905,252 EUR/year. This is calculated against total production cost of 2G ethanol in Ukraine of 720 EUR/tonne or 24,048,000 EUR/year (FAO, 2018a). Thus, given the EU market conditions, the Gross Value Added of a 2G biorefinery would be positive by some 9,457,152 EUR/year (Table 7).

3.3.2 Environmental assessment

In Italy, giant reed under both irrigated and rainfed management systems were considered as sources of feedstock for the analysis of the sustainability of the production of 2G ethanol. Overall, the sustainability assessment demonstrated that a potential production of sustainable 2G ethanol in the Sardinia Region is feasible albeit with some environmental and techno-economic bottlenecks.

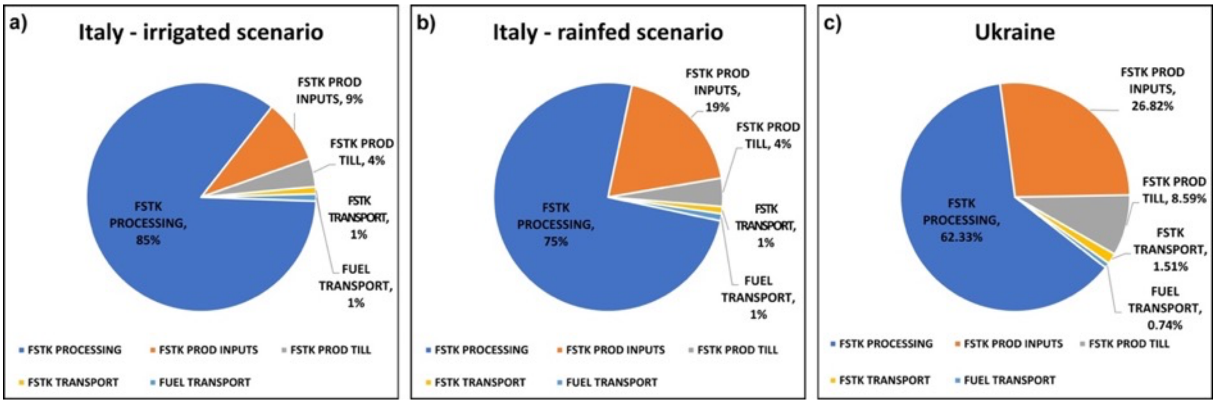
In terms of air emissions, emissions of GHG and non-GHG air pollutants were measured. The baseline scenario considered the emission intensity of petrol of 83.3 gCO2eq/MJ (FAO, 2020b). For the 2G ethanol obtained from irrigated giant reed, the emission intensity (allocated results) was 26.36 gCO2eq/MJ, while the emission reduction in comparison to the baseline scenario (petrol) was 68.54 percent. The avoided emissions were then calculated to be 61,227 tonnes of CO2eq per year (FAO, 2018a). When the feedstock is cultivated in a rainfed management system, the 2G ethanol emission intensity was calculated to be 30.19 gCO2eq/MJ, the emission reduction compared to baseline was 63.97 percent and the avoided emissions were 57,147 tonnes of CO2eq per year (FAO, 2018a), considering the petrol emission intensity in the baseline scenario for the comparison. The reference engine for the passenger vehicles selected for this GHG assessment was a 1.6 L in-line 4 turbocharged EURO 6 engine. According to Eurostat (2019), in 2017 in Italy, 25.9 percent of petrol passenger cars had a displacement between 1.4 and 2.0 L, followed by 21.9 percent displacing less than 1.4 L. The reference engine selection was made based on the assumption that a 1.6-L turbocharged engine could be considered the average engine for displacement and technology in current EU fleets. Admittedly, not much emphasis was given to this choice since the GHG assessment was only one of the several aspects of interest in the assessment made and the level of accuracy of such choices has been considered adequate for the scope.

Emissions avoided were calculated considering only the substitution of petrol due to the additional 2G ethanol produced and blended. The efficiency impacts on fleet mileage have not been included. However, we can consider that, on the one hand, ethanol blends have lower LHV than pure petrol by unit of volume, and on the other hand, high ethanol blends increase the octane number of the fuel and in the case of high compression ratio spark-ignited engines, this increases overall efficiency. Downsizing and turbocharging a spark-ignited engine is becoming an important strategy in the engine industry for improving the efficiency of gasoline engines (Jo et al., 2014). This action has been the main response to the stricter emission limits imposed by the EURO 6 protocol for car manufacturers selling new vehicles in Europe. According to Jo et al. (2014), the increasing presence of these vehicles in modern fleets has shown a significant increase in efficiency when high octane fuels are used. Evaluating the incidence of these efficiency gains against the decreased energy density of gasoline-ethanol blends was outside the scope of this paper and it was assumed that the positive and negative effects evened out.

For the Italian CS site, Fig. 8a and Fig. 8b show a comparison between the GHG emissions (tot gCO2eq/MJ produced) in percentage under irrigated and rainfed conditions, respectively, considering all different stages of the fuel production phase. In terms of agricultural inputs, the feedstock produced under rainfed management accounts for 19 percent of the total value, while when the same feedstock is grown under irrigated management, it accounted for only the 4 percent of the total share (Fig. 8).

In Ukraine (Fig. 8c), in terms of emission of GHGs, as for the Italian CS site, petrol (83.3 gCO2eq/MJ) was considered as the baseline scenario for the comparison with the potential 2G ethanol obtained from willow in the Ivankiv region. The emission intensity (allocated results) was 36.10 gCO2eq/MJ, while the emission reduction compared to baseline was calculated at 56.67 percent (FAO, 2018a). In total, considering the 896,526,400 MJ of the 33,440 tonnes of total fuel production, the assessed avoided emissions could be 42,319 tonnes of CO2eq per year. In addition to this calculation, to further reduce emissions, on-site enzyme production could diminish by a further 22.4 gCO2eq/MJ the carbon intensity of the ethanol, resulting in a reduction of about 83 percent when compared to the baseline (FAO, 2018a).

Figure 8. Share of GHG emissions due to each component of feedstock (FSTK)production - allocated results for (a) Italy, irrigated management system; (b) Italy, rainfed management system; and (c) Ukraine, rainfed management system



Source: FORBIO, Final report on sustainability assessment

Figure 9. The ethanol plant of Crescentino, Italy

4 Cost Benefit and Risk Analysis of six bioenergy investments on MUC lands[6]

4.1 Introduction

The scientific purpose of this chapter is to calculate and compare the cost and benefit of advanced biofuel production on MUC land in three countries compared to baseline scenarios, and to evaluate the risks to profits. The considered pathways (2G ethanol from Giant reed in Italy, biomethane from cultivated Lucerne (Alpha-alfae) and sorghum in Germany, biochemicals from spontaneous grass in Germany, Miscanthus for combustion in Germany, and 2G ethanol from Willow (Salix viminalis) in Ukraine) were chosen to assess their profitability and compare their competitiveness in the framework of bioeconomy.

The chapter investigates the following research questions: (i) What are the financial costs and benefits of the proposed investments in advanced biofuels production in the selected CS sites? (ii) what are the economic costs and benefits of producing advanced biofuels in the selected CS sites and therefore the contribution of such investments to social welfare? And (iii) what are the risks that environmental, social, and economic factors can have on the proposed investments?

The chapter is organized as follows: the first section analyses the financial profitability of the selected value chains; the second section assesses the economic contribution of such value chains to welfare; and finally, the third section describes the risks through a risk assessment for each of the planned value chains.

[6] Traverso, L.; Mazzoli, E.; Miller, C.; Pulighe, G.; Perelli, C.; Morese, M.; Branca, G. Cost Benefit and Risk Analysis of Low iLUC Bioenergy Production in Europe Using Monte Carlo Simulation. 14, 1650. https://doi.org/10.3390/en14061650. Energies, **2021**.

4.2 Materials and methods

The work is based on data and information collected by FAO and other project partners in the context of the FORBIO project. All the analysis and assessment developed during the implementation of the project were based on a combination of existing tools developed and/or implemented by the partners of the consortium, using both primary and secondary data (FAO, 2020b; FAO, 2018a). The data that were used for this research are accessible from the official project deliverables on the project website. A range of secondary data sources served as the key bibliographic tools for identifying relevant work for the financial, economic and risk analyses. Particularly, the literature behind the methodology adopted in this study followed the ***"Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014–2020"*** of the European Commission, and the approach suggested by Boardman et al., (2014) in their ***"Cost-Benefit Analysis manual: Concepts and Practice"***. For the economic analysis, the calculation of shadow prices was carried out using National Input-Output matrices retrieved from the OECD database following OECD (2015) ***"Introduction to shadow pricing in a semi-input-output approach"***, and Londero (2003) ***"Shadow Prices for Project Appraisal"***.

4.2.1 Case Study Sites

The reference countries for this analysis are Italy, Germany and Ukraine. The areas considered by this study are as follows:

(i) the Sulcis area in the south-western part of the island of Sardinia, Italy (a known Site of National Interest due to the presence of contaminants in the soils, particularly heavy metals);

(ii) two study areas located in Brandenburg, north-eastern part of Germany (the former sewage irrigation fields near the city of Berlin and the lignite reclamation sites in Lusatia); and

(iii) the Ivankiv Region of Ukraine (specifically the non-exclusion zone just south of the Chernobyl disaster area).

The countries were selected as examples of countries with a bioenergy production potential allowed by the large amount of available MUC land. Furthermore, the three countries were also selected based on their different income level: Ukraine is a lower-middle income country, and Germany and Italy are high-income countries. This allowed a comparison of both EU and non-EU neighbouring countries with different economies and regulations.

Tables 8 and 9 describe the crops and bioenergy pathways considered for this study, whilst Figure 10 shows a map of the potential bioenergy CS sites; total hectares considered for the investments are presented in Table 10.

Table 8. Selected crops for potential cultivation on under-utilized, marginal and/or contaminated (MUC) land.

CS	Crop Name	Management	Site	Site Features	Bioenergy Pathway	WoP * Scenario
IT-ARUNDO	Giant reed (*Arundo donax* L.)	Irrigated	Sardinia, Italy	Polluted due to mining and industrial activity	2G ethanol	Durum wheat
GE-MISC	Miscanthus (M. x *giganteus*)	Rainfed	Germany	Sewage irrigation fields	CHP	Sugar beet
GE-GRASS	Spontaneous grass	Rainfed	Germany	Sewage irrigation fields	Biochemicals	Forage
GE-L	Lucerne (*Alpha-alfae);*	Rainfed	Germany	Lignite reclamation site	Biomethane	Sugar beet
GE-S	Sorghum	Rainfed	Germany	Lignite reclamation site	Biomethane	Sugar beet
UAH-SALIX	Salix (*Salix* spp.)	Rainfed	Ukraine	Chernobyl non-exclusion zone	2G ethanol	Winter wheat

* Without Project.

Table 9. Feedstock production and relative cost for the selected investments.

CS	Biomass Yield (Tonnes of DM ha⁻¹ Yr⁻¹)	FSTK Production Cost (€ Tonne⁻¹)	Potential FSTK Production (Tonnes yr⁻¹)	Feedstock Price (€ Tonne⁻¹)	Potential Annual Net Benefits of FSTK Production (€ ha⁻¹) 2018
IT-ARUNDO	25	70.9	180,000	100	727.5
GE-MISC	15	31.76	17,100	80	723.6
GE-GRASS	3	25.83	9900	60	102.5
GE-L	5	50.87	18,240	140	445.65
GE-S	10	31.25	24,310	130	987.5
UAH-SALIX	10	28.6	167,200	70	414

CS = Case Study; FSTK = Feedstock; DM = Dry matter.

Figure 10. Potential bioenergy sites identified for the analysis.

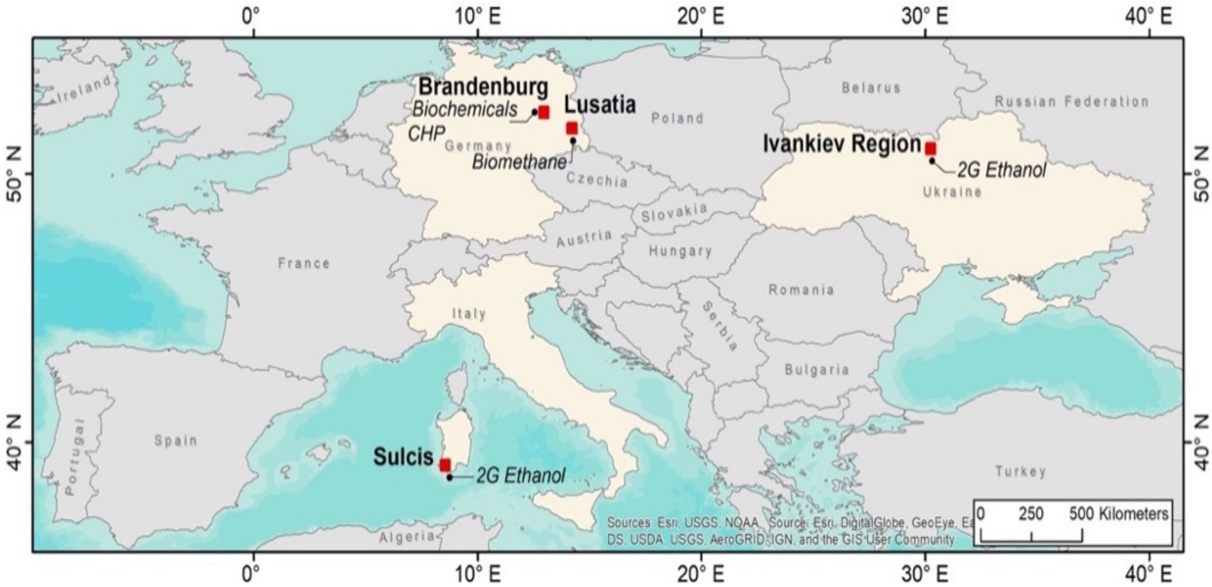


Table 10. Total hectares and Capital (CAPEX) and operation (OPEX) expenditures of the selected investment.

Pathway	Total Hectares Considered	CAPEX (Thousands of €) 2018	OPEX (Thousands of €) 2018
Italy—2G ethanol	7200	150,000	29,914
Germany—CHP	1140	18,000	1343
Germany—Biochemicals	3300	800	422
Germany—Biomethane	3648 + 2431	9700	2930
Ukraine—2G ethanol	16,720	125,000	19,524

As shown in Table 8, in Italy, the CS site was the contaminated land in Carbonia in the Sulcis area, where the land has been affected by chemical contamination, and therefore all agricultural activities are banned by both local and National Government (although some illegal agriculture and pasture use occurs) (Di Lucia et al., 2019; Di Lucia & Ribeiro, 2018). Irrigated Giant reed was considered to produce 2G ethanol and electricity as co-product with an average yield of 25 tonnes/ha/yr of dry matter (DM). Around 7200 ha were considered to feed a hypothetical biorefinery with capacity of 40,000 tonnes.

In Germany, the identified potential for the cultivation of *Miscanthus x giganteus* on the former sewage irrigation fields in the surroundings of Berlin was 1140 ha (FIB, 2020; Mergner et al., 2017). According to Mergner et al. (2017), miscanthus has the potential to remediate the contamination of heavy metal in soils and possibly render this land suitable for food production. According to Pogrzeba et al. (2013), miscanthus grown on contaminated soils can accumulate up to 5 mg Cd kg^{-1} and 150 mg Pb kg^{-1} in its biomass, as well as 700 mg Zn kg^{-1}, making it a promising crop for phytoremediation. The considered yield for miscanthus production was 15 tonnes/ha/yr of DM. Miscanthus production was considered for CHP production from combustion.

The cultivation of spontaneous grasslands on the former sewage irrigation fields in the surroundings of Berlin was also analysed. Nowadays in Germany, grassland is mainly used for cattle farming; however, during the last decades, notable changes in grassland use can be noted (Mergner et al., 2017). According to Thumm et al. (2014), there are new options to use grassland biomass for energy purposes as well as for biobased products. Based on FIB (2020), the potential yield of grass was identified to be around 3 tonnes per ha per year of DM.

Post-mining reclamation sites in Germany were also assessed. According to Mergner et al. (2017), the identified potential for the cultivation of Lucerne and Sorghum was approximately 7,295 ha. The considered yields for Sorghum and Lucerne selected to produce biomethane were 5 and 10 tonnes DM/ha/yr, respectively.

For the Chernobyl non-exclusion zone in the Ivankiv Region in the Ukraine, the identified potential for the cultivation of Salix was 16,720 ha, with an identified yield of around 10 tonnes DM/ha/yr (SECBiomass, 2016). As for the Italian CS site, in Ukraine, Salix biomass was considered for 2G ethanol production.

Table 9 shows the yield and the production cost of the bioenergy crops considered for the analysis. Potential production in tonnes per year is estimated considering the total hectares identified in each CS site. Furthermore, although the biomass produced is not sold to the market, national market prices of feedstock and potential income at farm gate are provided to show the possible income obtainable by farmers from the sale of the biomass.

4.2.2 Financial Analysis

A financial analysis was carried out, where a standard cost benefit analysis (CBA) approach was applied to demonstrate net profits. This analysis was included to compute the investment's financial performance indicators (EC, 2014) and was carried out in order to:

- Assess the consolidated investment's profitability, With Project (WP) vs Without Project (WoP) scenarios;
- Assess the profitability for the investor(s); and
- Outline the cash flows which support the calculation of the socio-economic costs and benefits.

Following the CBA framework defined by the European Commission (Thumm et al., 2014), impact categories were identified and associated with the WP scenario where biofuels are produced in the countries. The impact outside the countries' borders was not considered (e.g., no global market distortion).

Reference values, conversion factors, prices and other relevant information considered for the analysis are presented in Tables 22–25 of Appendix A. Particularly, prices for the financial analysis are presented in Table 25.

Annual financial net benefits of producing biofuels are given by:

Equation 3. Annual financial net benefits equation

$$\pi\mathrm{b}(Qb) = Pb(Qb) - (\mathrm{wLb} + \mathrm{fFb} + \mathrm{nNb} + \mathrm{eUb} - \mathrm{mMb}) \quad 3)$$

where:

b: *corresponds to the bioenergy pathways (e.g., 2G ethanol from Giant reed (Arundo donax) in Italy, biomethane from spontaneous grass and cultivated Alfalfa (Alpha-alfae) in Germany, and 2G ethanol from Willow (Salix viminalis) in Ukraine)*

πb(Qi): *annual net benefits of the biofuel pathway*

Pb: the price of biofuels as final product in the market

w: *unit wages*

Lb: *quantity of labour force (salary)*

f: *unit price of feedstock*

Fb: *amount of feedstock used to extract per unit biofuel*

n: *per unit cost of chemical*

Nb: *related chemicals such as sulphuric acid, methanol etc. (inputs)*

e: *the price of utilities, e.g., electricity, biogas and coal*

Ub: amount of utilities, e.g., electricity, biogas and/or coal (inputs and Miscellaneous)

m: the market price of by-products

Mb: amount of by-products produced during conversion process

The cost and benefits listed above were obtained in an aggregated form from FAO (2020b) and FAO (2018a). These data were directly provided by industrial bioenergy processors (e.g., Biochemtex) to FAO. This was mainly due to the difficult availability of detailed information about processing costs and technologies for advanced biofuels and biochemical biorefineries (e.g., 2G ethanol or lactic acid plants). Furthermore, for consistency, the same aggregation was applied to the analysis of conventional bioenergy such as CHP.

Following the method described by the Guide to cost-benefit analysis of investment project of the European Commission (EC, 2014) and Boardman et al. (2014), determination of investment revenues and expenditures enables the assessment of the project profitability, which is measured by financial net present value (FNPV) and financial internal rate of return (FIRR) on investment. A 5 percent financial discount rate was considered as per Commission Implementing Regulation (EU) 2015/207 of 20 January 2015, and 8 percent for Ukraine as a neighbouring country, as suggested by EC (2015a). The reference period of the analysis was 20 years, n = 20. Salvage values for key investments contribute to determining the FNPV and are accounted for in the last year cash flow (Sn).

The FNPV is given by the following equation:

Equation 4. Financial Net Present Value (FNPV) equation

$$FNPV = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n} \quad (4)$$

While the FIRR is given by the following equation:

Equation 5. Financial Internal rate of return FIRR equation

$$0 = \sum \frac{S_t}{(1 + FIRR)^t} \qquad (5)$$

where:

S: *annual financial net benefit*

t: *time*

a_t: *financial discount factor*

i: *financial discount rate*

Information on capital expenditures (CAPEX) for the selected investments was collected from specific literature. As presented in Table 11, for the 2G ethanol production in Italy and Ukraine, a plant capacity of 40,000 and 33,000 tonnes was assumed, respectively. The relative CAPEX for the two cellulosic plants was EUR 150 and 125 million, respectively (FAO, 2018a). In Germany, EUR 18 million were considered for building a new CHP biomass power plant (3.6 MW) for the combustion of miscanthus chips for heat and electricity production (Mergner et al., 2017). The total investment cost considered for a modern green biorefinery to produce biochemicals was EUR 800,000. As green biorefinery concepts are rather new, no exact data on full investment costs is available; EUR 800,000 is a realistic indication, but more information needs to be collected in the future (Mergner et al., 2017).

Finally, for the biomethane investment, a CAPEX of EUR 7 million plus 2 million for the upgrading of biogas to biomethane was considered for a total initial investment of EUR 9.7 million (Mergner et al., 2017).

The operation costs (OPEX), as presented in Equation (3), include the feedstock expenditures, the input costs of production (e.g., enzymes, electricity, etc), and other miscellaneous costs. As per the CAPEX values, the OPEX costs were taken from the official deliverable of the FORBIO Project. The total OPEX costs are provided in Table 5. The average lifetime of the investment is assumed to equal 30 years. The analysis considers residual values based upon the double-declining method with an R factor equal to two. The adopted method allows us to account for a mid-point estimate between the maximum salvage value provided under the straight-line method and the minimum residual value provided under the declining balance method (Table 24).

Table 11 shows the crops and relative income per hectares that were considered for the WoP. These values were used to calculate a WoP FNPV that was compared with the WP FNPV to calculate the final incremental FNPV. The WoP scenarios were selected as the most representative existing alternatives (in the area) to the potential studied bioenergy productions.

Table 11. Reference scenarios (WoP) considered for the analysis

Reference Pathway	WoP Production	Yield (Tonnes ha^{-1})	Production Cost (€)	Market price (€ $Tonne^{-1}$)	CAP Incentives € ha^{-1}	Annual Revenue € ha^{-1}	Annual Net Benefit € ha^{-1}
Italy—2G ethanol	Durum Wheat	3.5	992	270.0	200	1145	153
Germany—CHP	Sugar beet	60.3	1417	30.7	0	1851	434
Germany—Biochemicals	Forage	3	300	75.0	250	475	175
Germany—Biomethane	Sugar beet	60.3	1417	30.7	0	1851	434
Ukraine—2G ethanol	Winter Wheat	3.8	600	200.0	0	760	160

4.2.3 Economic Analysis

An economic analysis was developed considering the environmental benefits from replacing fossil fuels and environmental remediation, therefore appraising the investments' contribution to welfare. According to EC (2014), Boardman et al. (2014), and Naureen (2013), biofuel production projects—and more generally various types of projects for energy production—can be associated with different impact categories and their related direct benefits and externalities. In this study, the impact is associated with a series of environmental variables.

Table 23 of Appendix A presents the direct benefits and externalities that were considered for the proposed investments. Following the standard approach suggested by EC (2014) and Boardman et al. (2014), starting from the account for the return-on-investment calculation, the adjustments were as follows:

(i) fiscal corrections;

(ii) conversion from market to shadow prices; and

(iii) evaluation of non-market impacts and correction for externalities.

Shadow prices were used to reflect the social opportunity cost of goods and services instead of prices observed in the market, which may be distorted (EC, 2014). The calculation of shadow prices is carried out using National Input-Output matrices retrieved from the OECD database (Weiss, 1988; Londero, 2003). Table 22 of Appendix A shows the conversion factors calculated for the analyses.

For the positive externalities, as shown in Table 23, five additional benefits were monetized for the analysis. The calculations were done using data collected from FAO literature (FAO, 2018a, FAO, 2018b). Particularly, the reduction of CO2eq was obtained as result of a series of Life Cycle Analyses (LCA) done ex-ante for the potential investments. The net reduction was then calculated as a comparison between a fossil fuel alternative scenario (petrol or diesel) and the results of the LCA. The tonnes of CO2eq were associated with the EU market price for carbon dioxide.

The Total Organic Carbon (TOC) stored in soil was also obtained from FAO (2018a). The TOC was then converted to CO2eq following the methodology provided by Luske (2010), and the CO2eq was monetized as for the benefits from the emissions reduction.

For the land restoration component, phytoremediation capability was considered for Arundo donax and Miscanthus. The amounts of lead and zinc were obtained from FAO (2018a), FIB (2020), Biochemtex (2016a) and Arca (2016), and monetized following the method provided by Jiang et al. (2015) and Lewandowski et al. (2006), in which the cost of alternative remediation and the value of the metal were considered. Finally, the heat produced by the CHP was considered as potential benefit for the local municipality and included in the analysis.

Following the methodology for carrying out CBAs provided by the EU (EC, 2015a), the considered social discount rate (SDR) was 3 percent for Italy and Germany (as defined by EU for major projects in Cohesion countries) and 5 percent for Ukraine, as a neighbouring country, as suggested. The project economic performance was measured calculating the Economic Net Present Value (ENPV) and the Economic Internal Rate of Return (EIRR). As for the financial analysis, the economic ENPV and EIRR obtained are both WP and incremental and were calculated based on the difference between the project scenario and the WoP scenario.

The ENPV is given by the following equation:

Equation 6. Economic Net Present Value (ENPV) equation

$$ENPV = \sum_{t=0}^{n} k_t S_t = \frac{V_0}{(1+r)^0} + \frac{V_1}{(1+r)^1} + \cdots + \frac{V_n}{(1+r)^n} \qquad (6)$$

While the EIRR is given by the following equation:

Equation 7. Economic Internal rate of return EIRR equation

$$0 = \sum \frac{V_t}{(1 + EIRR)^t} \quad (7)$$

Where:

V: *annual economic net benefit*

t: *time*

k_t: *economic discount factor*

r: *economic discount rate*

4.2.4 Risk Assessment

A risk assessment was included in the CBA, based on the results obtained from the financial and economic analyses. The risk assessment deals with the uncertainty that always permeates investment projects, including the risk that the adverse impacts of climate change may have on the project (EC, 2014).

Following the methodology described by EC (2014) and Boardman et al. (2014), the considered steps for assessing the project risks were:

(i) sensitivity analysis;

(ii) qualitative risk analysis;

(iii) probabilistic risk analysis; and

(iv) risk prevention and mitigation.

The sensitivity analysis allowed for the identification of the critical variables with the largest impact (positive and negative) on the project. A variable is defined as critical when a variation of ±1 percent in its initial value gives rise to a variation of more than ±1 percent in the value of the NPV (EC, 2014). Switching values were calculated and a scenario analysis was completed combining the critical values.

Subsequently, qualitative risk analysis considered a list of adverse events, and a risk matrix was developed and interpretated. For the probabilistic risk analysis, a Monte Carlo simulation was developed following the method applied by Rayner et al. (2002), providing the probability distribution of the NPV and Internal Rate of Return (IRR). Where possible, probability distribution functions for key variables were modelled based on historical data (i.e., bootstrapping and fitting).

As suggested by Rayner et al. (2002), the application of the Monte Carlo simulation provides more comprehensive information about the risk profile of a project and allows for the analysis of results based on the risk and uncertainty modelled within the study. Table 25 shows the assumptions that have been considered for the market prices. Finally, the results of the previous steps were discussed and analysed in the risk prevention and mitigation assessment.

4.2.5 Adoption barriers

This paragraph presents the finding of a comprehensive and participated multi-stakeholder discussion which was carried out in each of the CS sites to analyse the barriers to the uptake of the proposed value chains and discuss their incidence as limiting factors. The discussions were held during workshops organized ad-hoc by FAO in Italy, Ukraine, and Germany, and further information can be found by consulting the technical report of the FORBIO project (FAO, 2018b).

During each of the workshops, the moderated discussions around the identified and perceived economic and non-economic barriers to the market uptake of advanced bioenergy value chains in the CS areas were successfully held. The findings from the project analyses were proposed to the audience of the workshops as elements for debate and further aspects that might have represented a barrier were raised by the participants in each of the events. During each of the discussions, the findings were summarized into a questionnaire presented as a list of questions and the participants were asked to express their opinion on such barriers. During the discussion moderated by FAO, all possible constraints and opportunities for the sustainable market uptake of the value chains studied were discussed. More details concerning the multi-stakeholder analyses are available from FAO (2018b).

4.3 Results

In this section, the results of the data analysis are presented in accordance with the theoretical framework described in the previous section. The results are presented in suitable tables and charts to compare different scenarios of CBAs and risk analysis.

4.3.1 Financial Analysis

Table 12 shows the results of the financial CBA, including WP annual net benefits, FNPV and FIRR for all CS investments. The WP scenario is compared with the WoP scenario to calculate the incremental NPV and IRR.

Table 12. With Project (WP), Without Project (WoP), and incremental financial FNPV and FIRR results.

Item (Thousands of €)	ITA-ARUNDO	GE-MISC	GE-GRASS	GE-L + S	UAH-SALIX
Annual financial net benefit (full regime)	4126	3054	829	1055	9716
FNPV (WP)	−96,314	17,352	9368	4021	−37,156
FIRR (WP)	−3.26%	13.34%	91.25%	9.36%	4.21%
Annual financial net benefit Without project scenario	1102	495	578	495	2675
NPV (WoP)	14,830	6664	7774	6664	28,941
FIRR (WoP)	n.a.	n.a.	n.a.	n.a.	n.a.
Annual financial incremental net benefit (with-without)	3024	2559	251	560	7041
FNPV (incremental)	−111,144	10,689	1593	−2643	−66,097
FIRR (incremental)	−4.83%	10.19%	15.24%	1.90%	1.02%

In Germany, the analyses showed positive results in terms of WP and incremental FNPV for both CHP and biochemicals production, while for the biomethane production, although the WP result was positive, the investment was not profitable in comparison with the WoP scenario.

In Italy and Ukraine, the production of cellulosic ethanol resulted in a negative FNPV, regardless of whether the WoP scenario was considered.

4.3.2 Economic Analysis

Table 13 presents the economic analysis of the five CS sites. In Germany, the ENPV is positive for all case studies. The ENPV for the biomethane scenario is therefore different from the FNPV due to monitorization of the positive externalities of the project.

Table 13. WP, WoP and incremental economic ENPV and EIRR results.

Item (Thousands of € and Percentage)	ITA-ARUNDO	GE-MISC	GE-GRASS	GE-L + S	UAH-SALIX
Annual economic net benefit (full regime)	7130	5586	747.9	1734	15,912
ENPV (WP)	−70,965	61,843	10,127	15,136	51,114
EIRR (WP)	−1.37%	26.03%	80.00%	14.78%	8.71%
Annual economic net benefit Without project scenario	1091	478.7	558.5	478.7	2630
ENPV (WoP)	17,325	7602	8869	7602	35,405
EIRR (WoP)	n.a.	n.a.	n.a.	n.a.	n.a.
Annual economic incremental net benefit (with-without)	6039	5108	189	1255	13,282
ENPV (incremental)	−88,290	54,241	1258	7534	15,708
EIRR (incremental)	−2.57%	23.01%	10.29%	9.02%	6.16%

The economic analysis also shows that there are differences between the 2G ethanol investments in the Italian and the Ukrainian CS sites. In Italy, the results show that, although the introduction of economic benefits (derived from the CO2eq emissions reduction, the land restoration potential, and the application of the economic conversion factors) significantly increases the NPV, the investment still has a negative economic return with a negative EIRR.

On the other hand, in Ukraine, the 2G ethanol production would have sufficient social returns with a positive ENPV and a positive EIRR, higher than the social discount considered for the country (i.e., 5 percent).

4.3.3 Risk Analysis

Figure 11 provides a straightforward comparison of financial results through the juxtaposition of the probability density functions obtained through the Monte Carlo simulation. Results indicate a lower and less volatile range of results for Italy and Ukraine— positioned to the left-hand side of the horizontal axis—and higher but more volatile results for Germany.

In the overlay chart of Figure 12, the economic results present a similar positioning to that noted in Figure 11, although volatility across results appears to be slightly reduced. Furthermore, while results for the Italian CS have not improved, the Ukraine and Germany (CHP) probability distribution functions have transitioned to the right-hand side of the chart, denoting an improvement in the economic profitability indicators.

For each profitability indicator, the entire range of uncertainty is identified, as well as certainty levels linked to positive results. Figures 13-15 provide a comparison across financial and economic NPVs under each model. Within each plot, red-shaded areas denote negative results while blue-shaded areas indicate positive results. Table 14 below summarizes the estimates concerning certainty levels, or rather the likelihood of achieving positive results.

The ranking and comparison of the relevant importance of variables in determining a change in profitability are shown in Figures 16-18 of Appendix A. For 2G ethanol production in Italy and Ukraine, the most crucial variable in the system is the international (EU) price of the ethanol, followed by total hectares available for cultivation and the biomass yield. In Germany, for all case studies, the most important variables in the system were the counterfactual price and yield of WoP feedstock.

Figure 11. Overlay chart of financial internal rate of return (FIRR) of the selected investments.

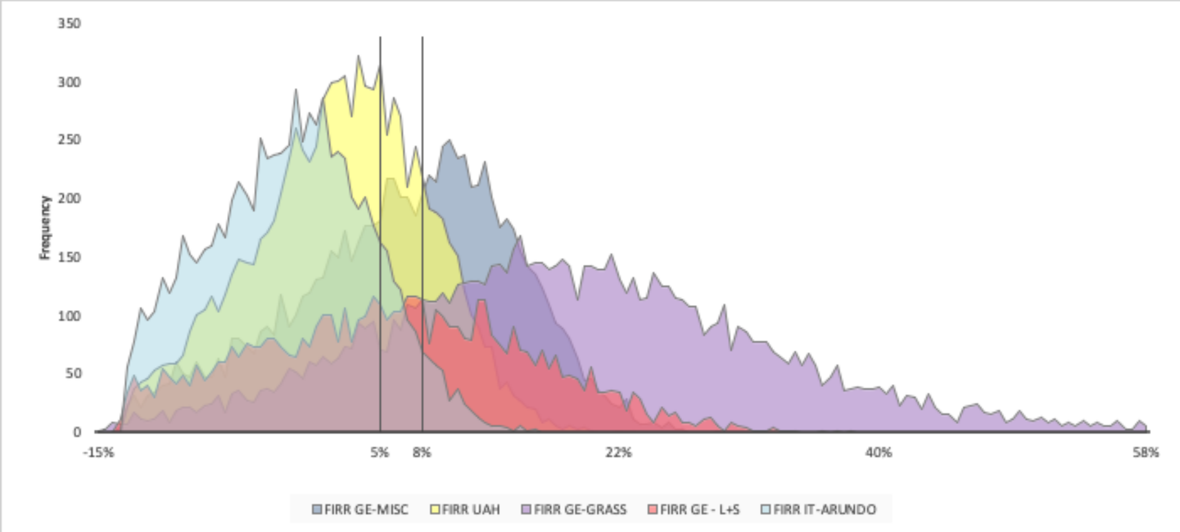


Figure 12. Overlay chart of Economic Internal Rate of Return (EIRR) of the selected investments.

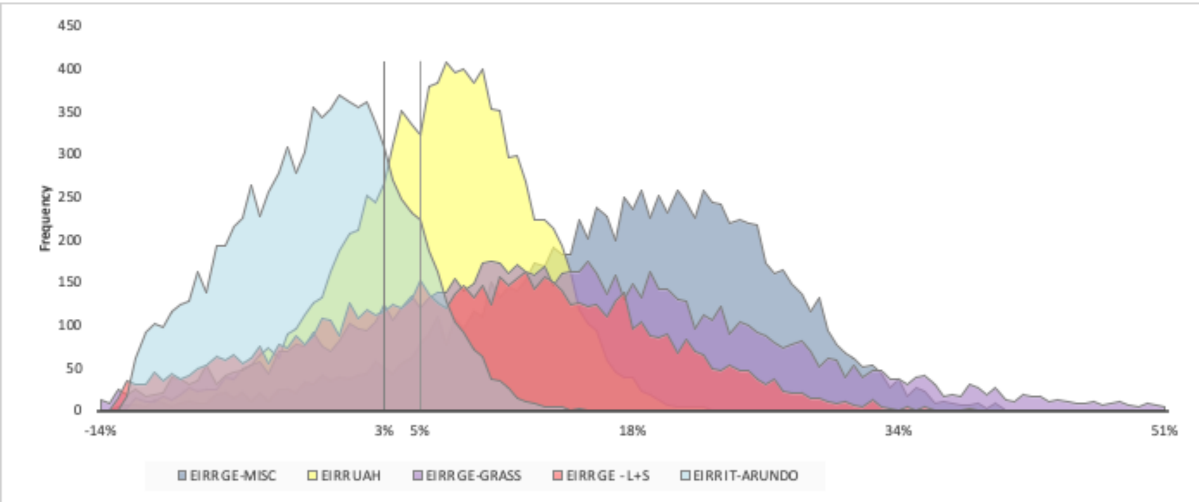


Table 14. Certainty levels by profitability indicator and investment

Reference Pathway	**Certainty Levels (NPV > 0)**	
	FNPV	**ENPV**
IT-ARUNDO	9%	19%
GE-MISC	51%	91%
GE-GRASS	80%	73%
GE-L + S	28%	49%
UAH-SALIX	17%	59%

4.3.4 Barriers, obstacles, and framework conditions

This paragraph presents the national barriers identified during the multi-stakeholder consultation. Table 15 summarises the main findings which are discussed below.

Table 15. Barriers and Obstacles to Market Uptake

Barrier/Obstacle	Italy	Ukraine	Germany
High CAPEX	+++	+++	+
Feedstock production cost	+	-	
Blanding mandates penalties	+++	-	n.a.
Bioenergy product national demand	-	+++	-
Market price of bioenergy product	+++	+++	-
Denaturation fee	+++	-	n.a.
Land tenure	++	+++	+++
Scarcity of subsidies and incentives for bioenergy products, fossil fuel taxation	+++	+++	+++
Absence of long-term policy support	+++	+++	+++

n.a: Not applicable

In Italy the main determinant of the production cost of 2G ethanol is represented by the high CAPEX to deploy the modern biorefineries rather than the cost of feedstock.

In Italy there is a penalty system for non-compliance of suppliers with the blending mandate, which is equal to EUR 750 per missing certificate (one certificate for each 10 Gcal for 1G biofuels or 5 Gcal for the 2G biofuels) (EC, 2018). This is equivalent to EUR 0.38 per litre of fossil fuel equivalent for 1G biofuels and EUR 0.76 per litre of fossil fuel equivalent for 2G biofuels. This penalty can be reduced if supply on the market is less than 20 percent of the mandated quantity. Furthermore, the penalty of EUR 750 can be reduced to EUR 250 if the supplier pays within 30 days (EC, 2018). For 1G ethanol, 10 Gcal amount to approximately 1.57 tonnes of biofuel, while for 2G ethanol, 5 Gcal amount to approximately 0.78 tonnes. Producing 1 tonnes of 2G ethanol in the Italian CS scenario would cost approximately EUR 950. Therefore, 10 Gcal would cost about EUR 1491. These figures suggest that, at present, suppliers who prefer to pay the penalty instead of blending ethanol into petrol save around EUR 741 utilizing the first-generation ethanol or spend EUR 4.25 per certificate when utilizing 2G ethanol. As a result, the need for a clear review of the penalty system related to 1G biofuels seems compelling. Furthermore, albeit to a lesser extent, for 2G biofuels (including biomethane) and particularly 2G ethanol production, a higher penalty would be desirable to drive the suppliers not to choose the faster solution for the market that is also the worst for the environment.

Finally, ethanol and even 2G ethanol, are subject to an excise if the product is not at least partially denaturized. In Italy, this excise is 10,350 EUR/m^3 and producers must comply with the denaturation process if they intend to stay in business.

As per the Italian CS, in Ukraine the main determinant of the production cost of 2G ethanol is represented by the high CAPEX to deploy the modern biorefineries rather than the cost of feedstock. One of the main identified barriers was the low demand for liquid biofuels in the domestic market. Another barrier concerns land tenure: the land tenure system in Ukraine is not as well defined, modern, and organized as in most European countries. The system is not informatized and access to information is often difficult. It was reported by entrepreneurs and farmers that if an interested user wishes to access maps and obtain information on the ownership type of a specific parcel of land, the process is tedious and complex and the results uncertain. In fact, it was reported that sometimes parcels of land unused for a long period of time remain in a sort of ownership limbo from which it is hard to escape because interested entrepreneurs are not able to access the owner's name to purchase the land.

After a fast development of the biomethane production following the incentives of a biogas upgrading bonus of 2009-2018, all investments have been reduced in recent years. A main barrier for the development of biomethane projects like the one proposed in this study is that currently, not only in Germany but at European level, the preference is given to farming residues and municipal wastes over energy crops, leading to a stagnation in biogas production. Furthermore, as revealed through the multistakeholder consultation held by FAO (FAO, 2018b) in the context of the FORBIO project, the public acceptance for a further expansion of biogas units in the region is very low (only 39 %), in contrast to, for instance, solar systems (75 % according to Forsa, 2009). Furthermore, the size and scattered ownership of the fields in the former sewage irrigation area makes the planning of a single large investment challenging and the formation of consortia also seems quite complex but not unrealistic (FAO, 2018b).

4.4 Discussion

For the 2G ethanol production in Italy and Ukraine, the annual financial net benefits of potential investments on these marginal lands are negative, as expected; the obtained results were also corroborated by Traverso et al. (2020). The reason for this is clearer when the sensitivity analysis is considered; the international (EU) price of the ethanol represents a crucial factor for the development of the 2G ethanol value chains in both Italy and Ukraine. This is easily understandable since, on the international market, 2G ethanol competes with first generation biofuels (i.e., ethanol from maize or sugarcane) and petrol, which are both often subsidized (albeit indirectly), leading to a lower, more competitive market price than the advanced biofuel alternative. Policies that stabilise the price paid for 2G ethanol could therefore improve investment prospects (Markel et al., 2018). The outcome of the financial CBA also illustrates that the total hectares available for cultivation and the biomass yield are crucial variables of the system. This is expected since such investments require a considerable biomass supply.

For the economic analysis, in Italy, the benefit attained by society through the reduction in imported fossil fuel and the remediation activities on contaminated soil made by the production of 2G ethanol is not enough to compensate the production costs. Conversely, in Ukraine, where the result of the financial analysis is slightly higher, the economic CBA showed a positive performance (Ukraine reached a 59 percent certainly level, far beyond its Italian cousin with a certainty level of 19 percent). The Ukrainian CS is the perfect example of why positive externalities must be valued when running economic profitability analyses and the influence of mechanisms of government support. One potential mechanism could be to include economic instruments such as the internalisation of externalities in energy prices, so that state support for both fossil and renewable energy is better tailored to reflect the true societal costs and benefits.

These results from Italy and Ukraine suggest that on marginal land where no competition with food crops is expected and where large areas of land are available, the production of 2G ethanol could fulfil the need for low iLUC production to meet the target imposed by European policies. However, the environment for positive net benefit investments is required and governments should therefore move towards new and stable incentive systems that can promote the development of advanced and low carbon value chains while encouraging national and foreign investors to participate in the European Green Deal.

In Germany, the positive results obtained from both the CBA and the risk analysis show a good environment for the development of low iLUC bioenergy on MUC lands. The benefits of electricity from Miscanthus as well as those from biomethane from Lucerne and Sorghum presented a strong dependence on the counterfactual price and yield of the WoP feedstock. Although the production of sugar beet was chosen because it was considered appropriate as an alternative value chain in the area, these results suggest that a more accurate analysis with different baseline scenarios could be done to validate the profitability of such investments. Availability of feedstock and high cost of production for the project scenarios are also critical variables. It is expected that governments will provide sufficient support (e.g., through grants and loan guarantees) that addresses the high investment risks related to commercial-scale plants for bioenergy as well as providing sufficient support to enable the supply of biomass feedstock for bioenergy production on MUC land in the EU. For the economic analysis, the CBA of the German investments underlines the high impact of environmental externalities to social welfare, as they greatly increase the certainty levels of the investments. The positive NPVs suggest that in the long-term, policies can be developed aiming to adjust economic incentives over time, as biofuels move towards competitiveness with fossil counterparts.

5 POLICY REVIEW AND IMPLICATIONS

5.1 Introduction

Although bioenergy contributes significantly towards the share of renewable energies in Europe, according to Schmid et al. (2019), it is considered highly challenging for Governments and Institutions to prepare sound bioenergy policies. This is mainly due to several aspects such as the competition for biomass with other utilisation pathways like food or feed, the challenging interactions with further sectors like forestry or waste management, the involvement of a large number of actors and stakeholders, the ecological impacts, and, particularly, the large variety of usable feedstock, conversion pathways, energy carriers, and value-added chains, which lead to different environmental, social and economic impacts on the countries (Kaltschmitt et al., 2016; Thrän, 2015; Clancy et al., 2018). Furthermore, in many cases, the proposed government mechanisms and instruments were revealed to be insufficient, representing policy bottlenecks for the market uptake of those advanced bioenergy value chains in the EU. This perception increases when high CAPEX investment projects and high technological and innovative value chains are considered.

Nowadays, the major challenge confronting the EU and its member states is how to accelerate the implementation of bioenergy systems to meet the targets for sustainability and emission reductions imposed by the new energy directives and the Green Deal. Several EU and National policies that provide support to modern bioenergy and biofuel productions exists, but their instruments and measure are not always able to cover all steps of the value chain, and additional instruments are still required to reduce investments risk and to incentive clean and renewable bioenergy productions to replace fossil fuels (Singh et al., 2020).

The scope of this chapter is to provide a review of policies impacting the possible bioenergy production on MUC lands in Europe and assess the policy support to the studied CS value chains. The central question that motivated this approach is: "How could policies support bioenergy productions on MUC lands and what could be a brief strategy to overcome a list of barriers and policy gaps identified by the research?" The answer to this question is provided in the following paragraphs where the main bioenergy- and biomass production-related policies, at EU and national level, are reviewed and discussed. The results of a series of multistakeholder consultations held by FAO in the context of the FORBIO project are presented and discussed. This allowed an understanding of existing barriers and obstacles to the development of the potential investments studied and to formulate a solid roadmap of recommendations.

5.2 Methodology

The policy landscaping proposed in this chapter presents a structured review of current existing EU and national policy mechanisms that support the competitiveness of the studied bioenergy productions with relevance to the potential assessed investments.

For each policy, following the methodology provided by Panoutsou & Singh (2020), the following aspects were considered: i) the main issues the policy regulate, and ii) the policy scope, objectives and instruments, which include regulations, financing mechanisms and soft measures. The analysis was done at different stages: biomass production (agriculture, forestry, waste/residues), bioenergy production, and sustainability stage. The analysis allowed an understanding, in general terms, of their relevance to the bioenergy productions, quantified as: + low relevance; ++ medium relevance; +++ high relevance. Policies which do not present any relevance were not included in the review. The analysis was done assessing the policies based on their number of sub measures and instruments which were relevant for the bioenergy productions. The policy review was discussed during the stakeholder consultation with all actors involved in the value chain. The findings of the review are presented in Tables 16-18. Particularly, the scoring was always (each case study site) done in a group (face-to-face), and all group members discussed the scores (three levels) and agree on each one. The presence of a project facilitator or leader from the research team was helpful in clarifying the criteria and discussing the nuances of the scoring. Nuances of the received scoring were discussed – for example some support on a specific policy measure may be seen as a positive factor for a certain typology of stakeholder but could be perceived as a negative factor for others. For example, the CAP is shown to support both the biomass production and the sustainability of the studied value chains with high relevance (+++). Through a series of specific measures (e.g. Greening measures), it supports sustainable land management for both agriculture and forest lands, and soil quality and health. Furthermore, the CAP had some changes (2018), proposed by the European Commission, which introduces a more flexible, performance- and results-based approach that takes into account local conditions and needs, while increasing EU level ambitions in terms of sustainability.

At national level, for the Italian, Ukrainian, and German cases, the chapter presents possible financial mechanisms that facilitate the market penetration and competitiveness of the studied value chains in the countries. Following the approach presented above, the analysis focused on tariffs (and the penalties system) and incentives, and on existing instruments to sustain by- and co-products, identified as possible sources of income to promote the viability of the bioenergy productions.

5.3 Policy landscaping

5.3.1 EU policy, regulatory, and institutional landscape

The first typology of policies that was considered for supporting the promotion and market uptake of advanced bioenergy and biofuel value chains at EU level involved policies that directly impact the feedstock production for bioenergy production and therefore the agriculture, forestry, and waste/residues sectors. These policies mainly focus on land use, and biomass production. Examples of land use policies could be policies for land acquisition (e.g. incentivising production on MUC lands or prohibiting the use of certain sensitive land types of soil). In addition, there are policies addressing land use management, protection of soil quality and rehabilitation of deteriorated soils (Singh et al., 2020).

When it comes to biomass production and sustainability, the review focuses on policies which provide rules and financial support to biomass production providing and supporting actions related to sustainable natural resource management, mitigation of agricultural and soil management practices, including reducing pollutants and GHG emissions, research and innovation to increase resource efficiency, as well as mobilisation of waste to improve the circularity of biomass.

Table 16 presents a list of land use- and biomass-related policies that have the potential for supporting the production of bioenergy on MUC land. Policies are selected and assessed based on their relevance to the potential bioenergy production on MUC lands.

As showed in table 16, the new CAP (2023-2028) and the Indirect Land Use Change (ILUC) Directive appear particularly important for supporting potential biomass production on MUC lands. The CAP 'greening measures' allow farmers to receive the green direct payment if they comply with three mandatory practices that benefit the environment. This can be linked to additional biomass production through agronomic practices suitable to the climate. The REDII also provides substantial support through its carbon credits scheme and the focus on land use change. Both instruments are strongly related to potential MUC land exploitation. Soil conservation measures are provided by the Farm to Fork Strategy as part of the EU Green deal (EC, 2019) and the Soil Thematic Strategy. The common concept behind these policies and their mechanisms is that soil is essentially a non-renewable resource and a very dynamic system that performs many functions and delivers services vital to human activities and ecosystems survival. Measures that promote the conservation and rehabilitation of soils can be considered very important when biomass productions are planned to be done on MUC lands. Particularly, the Farm to Fork Strategy supports the transition to sustainable agricultural systems and aims to reduce soil deterioration by implementing targets of reducing fertiliser and pesticide use, nutrient losses, and antimicrobial applications (EC, 2020).

Table 16. Agriculture, forestry, and waste/residues policies

Policy	Measure	Relevance - support	Relevance
Common Agricultural Policy (CAP) 2021-2027 (EC, 2018c),	Preamble 26; Title VI Part 94;	Support sustainable land management for both agriculture and forest lands, and soil quality and health through greening measures.	+++
A Farm to Fork Strategy COM (2020/381) (EC, 2020),	Section 2.1, Chapter 2 Section 1	Reduce soil deterioration by implementing targets of reducing fertiliser and pesticide use, nutrient losses, and antimicrobial applications.	++
EU Forest Strategy (EC, 2018e),		Sustainable use of forest biomass in EU.	+
New EU Biodiversity Strategy 2020 and Waste Framework Directive (WFD) 2008/ 98/EC (EC, 2008).	Section 2.2.2 and 4.2.2 Trade policy	Conservation of biodiversity and natural habitat to minimise the ecological costs of land-based biomass production.	++
The Indirect Land Use Change (ILUC) Directive 2015/1513 (EC, 2009)	Explanatory memorandum, annexes	Promote the exploitation of unused and severely degraded land by monitoring land use changes and associated GHG emissions and prohibiting the use of land with high biodiversity value, peatland, and land with high carbon stock.	+++
Renewable Energy Directive (RED II) (EC, 2018f)	Article 28 Paragraph 6	Unused land conversions may be eligible for significant carbon intensity credit; any biofuel project, including low-ILUC projects, must account for emissions from land use change	+++
Land use and forestry		Provides accounting and governance rules for the reduction of GHG from	+

regulation for 2021-2030 (LULUCF) 2018/841 (EC, 2018e)	relevant sectors to achieve the long-term climate goals of the Paris Agreement	
Soil Thematic Strategy (EU, 2012)	Provides support to regulate soil quality protection by limiting the leaching of toxic substances, preventing soil erosion, and improving land use practices and soil organic content.	++

As second step of the review (Table 17), considered the EU policies that directly support the bioenergy processing and consumption, and therefore the three main market sectors: the energy sector, the transport sector and the industrial sector. As shown in Table 17, in general high-level support is provided through research programmes that support innovation in bioenergy production and consumption. First, the programme Horizon Europe (formerly Horizon 2020), through its cluster 6 on Food, Bioeconomy, Natural Resources, Agriculture and Environment; the programme aims to reduce environmental degradation, reversing the decline of biodiversity on land, air and water.

Table 17. Bioenergy and biofuels processing policies

Policy	**Relevance - support**	**Relevance**
Horizon2020 and Horizon Europe	Funding research and development (R&D) and Innovation and demonstration activities and infrastructural development at all levels of the value chain.	+++
Environmental Technologies Action Plan (ETAP)(ETAP, 2004)	Support eco-innovative projects for clean products and decarbonize energy- intensive sectors through funding research and development (R&D) activities and infrastructural development	++
Energy Taxation Directive 2003/96/EC (ETD) (EC, 2003)	Support the uptake of bio-based products by establishing a harmonised tax on energy products to avoid distortions in trade.	++
EU Energy Union Strategy (EC, 2015b)	The Strategy is centred around five dimensions: i) energy security, solidarity, and trust; ii) A fully integrated internal energy market; iii) Energy efficiency; iv) Decarbonisation of the economy; v) Research, innovation and competitiveness	++
Bio-based Industries Joint Undertaking (BBI-JU) (EC, 2013)	Adopt low carbon technologies and products, reduce GHG emissions, and take part in the global climate change mitigation effort. Promotes investment for bio-	+++

Innovative bioenergy and biofuel production are supported at different development levels. Research and innovation activities under cluster 6 contribute to and work in parallel with the European Green Deal related to the Biodiversity Strategy to 2030, the Farm to Fork strategy, the European Climate act and initiatives under sustainable industry and eliminating pollution, as well as the long-term vision for rural areas, and the Sustainable Development Goals. Second, the Bio-based Industries (BBI) program aimed to demonstrate new technologies to fill the gap in value chains, to develop business models integrating all economic actors along the value chain, to set-up flagship biorefinery plants deploying business models & technologies to keep investment in EU through a series of research and innovation, and demonstrate funding opportunities for the EU industrial partners.

Finally, the policies that are related to sustainability of bioenergy production and consumption were reviewed and are presented in Table 18. As shown in the table, the European Green Deal and the REDII represent the two selected mechanisms that mainly support the sustainability of bioenergy productions in EU. This is also thanks to the wide financial support available under these programmes.

The CAP reform, proposed by the European Commission in June 2018, introduces a more flexible, performance- and results-based approach that increases the EU level of ambition in terms of sustainability. Based on this approach, the CAP reform proposal was compatible with the Green Deal's ambitions and opened the way to the new CAP 2023-2028. According to CAP (2018), the agricultural practices beneficial for the climate and the environment shall be the following: crop diversification measures, maintaining existing permanent grassland, as well as having ecological focus area on the agricultural area.

Table 18. Bioenergy sustainability policies

Policy	Measure	Relevance - support	Relevance
Renewable Energy Directive (RED II) (EC, 2018f)	Article 25, Paragraph 1, Sub-paragraph 2; Article 28 Paragraph 6; Annex VIII Part A	Sustainability criteria for biofuels, bioliquids and biomass. GHG reduction criteria, sustainability criteria, and low and high iLUC risk factors for biomass feedstock. Reduction of competition with land and water resources for food production.	+++
CAP Reform 2018		Proposed by the European Commission in June 2018, introduces a more flexible, performance and results-based approach that takes into account local conditions and needs, while increasing EU level ambitions in terms of sustainability.	+++
Fuel Quality Directive (FQD) (2009/30/EC) (EC, 2006)	Recital 14	Regulation of the GHG emissions from biofuel and sustainability of the feedstock used for biofuels	++
Horizon2020 and Horizon Europe	Cluster 6 and section 2	Funding research projects on sustainability of bioenergy and biofuels production.	++
Clean Air Programme for Europe COM/2013/0918 (EC, 2013b)		Contribute significantly to the achievement of the necessary emissions reductions; implement support measures at all political levels, with priority areas including urban air pollution, research and innovation, and the international dimension of air policy.	++
Environmental Technologies Action Plan (ETAP, 2009)		Support eco-innovative projects for clean products and decarbonise energy-intensive sectors through funding research and development (R&D) activities and infrastructural development.	+
European Green Deal Investment Plan (EC, 2019).		Boost the efficient use of resources by moving to a clean, circular economy and stop climate change, revert biodiversity loss and cut pollution.	+++
EU Standards CEN/TC 383 (ETIP, 2013)		Produce biomass sustainably under specific emission thresholds and adopt BAT to minimise environmental impacts.	+
EU Biodiversity Strategy for 2030	Section 3.3.3. Measuring and integrating the value of nature	Criteria and standards to describe the essential features of biodiversity, its services, values, and sustainable use.	
EU Energy Union Strategy [118]		The Strategy is centred around five dimensions: i) energy security, solidarity, and trust; ii) A fully integrated internal energy market; iii) Energy efficiency; iv)	++

		Decarbonisation of the economy; v) Research, innovation, and competitiveness	

5.3.2 National support policies for 2G ethanol in Italy and Ukraine

In Italy, between 1995 and 2010, the first instrument to promote the use of biofuels was the tax/excise reduction (Basili & Rossi, 2020). Since its revocation in 2010, ethanol and petrol have had the same tax imposition, thus consumers do not see any advantage or incentive in purchasing different blended fuels (E5 or E10) for their vehicles. After 2010, a system of bio-certificates (CIC) was introduced. This system expects that subjects releasing petrol are required to also release a quota of biofuels calculated on the amount of calorific value of the petrol. Nowadays, the transport sector mainly complies with the relative EU Directives. In addition, the Italian Government published a new decree in March 2018 (MISE, 2018), establishing an obligation for advanced biofuels starting at 0.6 percent in 2018 and rising to 1.85 percent by 2022. Moreover, the advanced biofuel target is further subdivided between a 75 percent for advanced biomethane and 25 percent by other advanced biofuels.

In Ukraine, even though no valuable policies for advanced biofuels market uptake have been established, the policy environment appears favourable for the generation of electricity and heat from renewable sources in contrast to the natural gas import affected by the limitations imposed by the ongoing conflict with the Russian Federation. In fact, with the aim to limit its dependency on energy imports (mainly from Russian Federation), Ukraine has put in place a comprehensive set of strategic and policy measures to diversify sourcing and complement the energy mix.

Table 19. Italian and Ukrainian National policies

Policy	Measure	Relevance - support	Relevance
		Italy	

"Biocertificates for consumption of biofuels" (CIC)"	D.M 2 March 2018	Obligation on petrol and diesel suppliers	+++
		Ukraine	
"Heat and Energy Supply"	Article 20	Support to the production of RE and heat	+++
Energy Strategy of Ukraine until 2035 (ESU 2035)		(1) building an energy-efficient society, (2) ensuring energy independence, and the reliability and sustainability of the fuel and energy complex (FEC), (3) strengthening market development, (4) enhancing the sector's investment attractiveness, (5) promoting network integration, and (6) establishing a "Modern Management System"	++

Particular importance is given to the promotion of energy efficiency and renewable energy through the Law on "Heat and Energy Supply", which, as shown in the economic analysis, allows the production of 2G ethanol to be feasible in the country. In Ukraine, a new energy strategy to 2030 has been proposed by the Government but is still being revised by the Organization for Economic Co-operation and Development (OECD). The strategy, divided in six strategic objectives (Table 19), aims to address "the needs of society and economy for fuel and energy in a technically-reliable, safe, economically-efficient and environmentally-friendly way, in order to guarantee the improvement of social well-being".

5.3.3 National support policies for Biomethane and CHP in Germany

In Germany, biogas, biomethane, and electricity production (CHP) are supported by the Government through the latest version of the Renewable Energy Sources Act (EEG, 2017) (Table 20), where the support system was switched from feed-in tariffs (FiT) to the auction model (pay-as-bid). According to Gustafsson et al. (2020), both the newly built biogas plants (with an installed electrical capacity of more than 150 kWe) and already existing biogas plants can participate in the auctions.

In addition to the EEG, Germany's Integrated National Energy and Climate Plan (NECP) contributes to the achievement of the EU energy targets of 2030 (REDII and Green Deal) by increasing the energy efficiency through a reduction of the primary energy consumption (by 30% by 2030 compared to 2008), and by expanding the share of renewable energies to 30% of gross final energy consumption in 2030 (Table 20). According to BMU (2020) and BMWi (2019), the NECP confirms the national GHG emission reduction target for 2030 of at least 55% compared to 1990, and the commitment to pursue GHG neutrality as a long-term goal by 2050. Specific biogas-related targets included in NECP are: i) a 30% manure digestion by 2025, and ii) a gas-tight storage of manure on up to 70% of biogas plants (Lievetrau et al., 2020).

Table 20. German National policies

Policy	Measure	Relevance - support	Relevance
Renewable Energy Sources Act (EEG 2017)	Part 3	The feed-in tariffs (FiT) to the auction model (pay-as-bid)	+++
Germany's Integrated National Energy and Climate Plan (NECP)	Section A national plan	GHG emission reduction target for 2030 of at least 55%; neutrality 2050	+++

5.4 Policy implication

In Italy, thanks to the Crescentino plant, 2G ethanol technology has been proven at the pre-commercial scale, but, as in the rest of the EU, the industry still faces challenges in scaling up the production to full commercial scale. Bridging the gap requires longer and more stable policy timeframes, greater policy stability, and financial support from instruments in terms of grants and loan guarantees, especially for countries where large areas of land are available for cultivation of feedstock for 2G biofuels production. It is of crucial importance that investors give priority to advanced technologies to develop a modern bioenergy market and reduce capital costs. For this reason, licensing, taxes, and construction costs of 2G facilities should be reduced, whilst introducing some form of direct or indirect public support to encourage their take-off.

Investors would show interest in a biorefinery provided that the conditions exist for the investment to be profitable over the long run (FAO, 2018b). Since the economic lifetime of a biorefinery is typically 20–25 years, investments should be spread over such a lifetime. Therefore, policies that mandate a certain blend for only a decade (as it was the case with the RED and now the REDII) may not represent a sufficient incentive to support long-term bankability of investments in this sector (FAO, 2018b).

In the CS area of Ukraine, concrete potential exists to enable an efficient and sustainable value chain where the co-production of electricity and heat from 2G ethanol can close the loop and achieve the standards of sustainable development. In other words, thanks to the above-mentioned Law on "Heat and Energy Supply", the generation and sale of the surplus electricity and heat generated by the hypothetical 2G ethanol biorefinery, would enable the economic sustainability of the Ukrainian 2G ethanol production. Considering the identified low demand of liquid biofuels in Ukraine, it is key that high-level discussions between Ukraine and European Member States start to devise commercial agreements for the supply of 2G ethanol to Europe and contribute to meeting the REDII mandate by sustaining the existing Law on Heat and Energy Supply in Ukraine. Ukraine is expected to receive active support from the EU as per the Union's development strategies for low- and middle-income and EU neighbouring countries. The framework of the European Neighbourhood Policy is one example of this cooperation. Development projects that promote business opportunities and interregional integration are required to promote stability, leverage local private investments, and support small-scale stakeholders, especially in rural areas. Development of social and economic infrastructures to increase energy security, along with several environmental benefits, are an indispensable strategy to promote economic growth in EU neighbouring countries. It is therefore paramount that the EU continues to support the development of innovation projects on advanced biofuels (e.g. the Bio Based Industries instrument) in those countries in order to reduce the high capital expenditures of modern 2G ethanol biorefineries with the aim to promote economies of scale and to expand international markets.

The rising levels of 2G ethanol production, and in general advanced biofuels for transport, foreseen for the new European targets will considerably increase demand for lignocellulosic biomass feedstocks. To support the development of the feedstock supply and make it available in a sustainable way, without competing with other lands possibly suitable for food production, threatening the environment or limiting smallholders' access to land, a sound policy framework is needed. To promote the supply of biomass feedstock to ensure the production of advanced biofuels, the European Commission, European Council and European Parliament are negotiating the next Common Agricultural Policy (CAP), which programs all EU-wide funding for agricultural and rural development. On 1 June 2018, the EC released its legislative proposal for CAP post-2020 that is currently under scrutiny from legislators. The EC's legislative proposals suggested voluntary coupled support for sectors that would decrease dependence on fossil fuels. When it comes to Germany, although there is no specific policy available for the development of bioenergy value chains on underutilized lands, the analysis has proven that the production of CHP from lignocellulosic feedstocks, biochemicals, or biomethane from dedicated crops can be profitable. In this context, policies which promote rural development (e.g. CAP) should include the sustainable grassland management of the former irrigation sewage fields and the dedicate crop production on brownfields within the regimes of the land management that are eligible for receiving subsidies. A strategy to overcome the scattered land tenure issue, could be the planning of small uses of the biomass, in a few pilot plants, which could be upscaled to one or two medium-size biorefineries that produce power and use it for internal demand, while the surplus is sold.

Based on the environmental and financial analyses, the policy review, and the assessment of the barriers for the studied value chains, Table 21 shows a list of identified roadmap actions that could facilitate the market uptake of

2G ethanol and other advanced bioenergy value chains. As already discussed, the creation of longer and more stable policy timeframes, greater policy stability, and financial support from economic instruments is a fundamental element in fostering the deployment of advanced bioenergy productions in the longer term and would help considerably to improve competitiveness. Financial support (grants and loan) could be applied to reduce investment risks and support the construction of pilot and demo plants.

Access to credit is likely to be necessary for most of the stakeholders involved in the advanced biofuel value chain and particularly for farmers. This aspect is strictly linked to the financial security over time guaranteed by long-lasting contracts and agreements among the actors within the value chains. To date, in Ukraine there is an adequate credit system and access to credit is reasonable for Agri holdings. However, linked to the novel nature of advanced biofuel value chains, and from areas disadvantaged due to contamination or other aspects that limit their utilization, the access to credit could be more difficult, particularly for unorganized individual farmers. Furthermore, considering the disadvantaged conditions of the area where the proposed value chain would occur, specific incentives would be necessary to provide investors with tools for embarking on investments needed to create the value chain. The incentives would not necessarily have to be in the form of subsidies, but there is a need to support the uptake of these technologies that are not yet economically competitive. Another crucial aspect concerns the support to new and effective Life Cycle Assessments (LCAs) and GHG analyses that can incentivize and promote the most efficient biomass feedstock productions and advanced biofuel technologies. As demonstrated in Italy and Ukraine, a sustainable feedstock production would be feasible in terms of environmental sustainability, provided that the policy scenario would allow the final product to be competitive on the market (Banja et al., 2019).

Table 21. Proposed roadmap actions for 2G ethanol value chain deployment

Proposed roadmap actions

Create a stable, long-term policy framework for advanced bioenergy, to increase investor confidence and allow for the expansion of biofuel production.
Provide sufficient support (e.g. through grants and loan guarantees) that addresses the high investment risks related to commercial-scale advanced biofuel plants.
Provide sufficient support to enable the supply of biomass feedstock to produce 2G ethanol and advanced biomethane.
Promote the supply of 2G ethanol to EU-Member States
Promote financial support schemes for the sustainable performance of fuels (e.g. GHG emissions).
Adjust economic incentives over time, as biofuels move towards competitiveness with fossil counterparts.

6 CONCLUSION

The study recognised the important role that more innovative and efficient forms of bioenergy and biofuels produced from feedstock cultivated on MUC lands could play in decarbonising the energy and transport sectors, increasing the access to sustainable energy productions. In the last few years, several international research and development studies have started investigating the effective availability of MUC lands in the EU and in the neighbouring countries, using GIS systems and other valuable verified approaches. The demonstrated availability of these lands allows farmer and investors to explore bioenergy productions relying on biomass produced with no competition with food and with higher consumer acceptance. However, still few comprehensive feasibility and profitability studies have been published with the aim to investigate investment options on those lands from both the private investors' and the public's point of view. In addition, MUC lands used to produce alternative fuel options could represent a credible solution for achieving the strong commitment of the EU in decarbonising its sectors, by investing in realistic technological solutions, empowering citizens, and promoting marginal and abandoned areas in line with the goal of the new Green Deal. However, although advanced bioenergy and biofuel technologies are available at industrial scale, and both private and public finance is potentially available for investments, there is still a lack in consistent long-term policies in support of advanced bioenergy production demand and/or incentives to production and/or direct support to high-capex technology development. A real taxation for fossil fuels is also not in place and taxes on the most polluting fuels are zero or close to zero. As a consequence, in the EU there is still little incentive to change and to shift to low-carbon alternatives as suggested by the REDII and the European Green Dean.

It is probable that future agricultural production will have to grow faster than population growth and largely on existing agricultural land. Therefore, innovative productions on MUC lands may offer an alternative, preventing intensification and further soil degradation, and their environmental, social, and economic sustainability should be further assessed in parallel with the financial and economic profitability.

The results of the first CS proved how in both case studies, the production of 2G ethanol has high potential to reduce GHG emissions as compared to fossil fuel scenarios, even though the uncertainty regarding environmental sustainability of producing biofuels could represent a strong non-economic barrier. The on-site production of enzymes has shown a high potential for further GHG emission reductions and should be better supported by adequate incentives. Concerning feedstock and fuel generation, biomass production from lignocellulosic crops in Italy proved to be efficient and to represent an asset for the sustainable development of underutilized and marginal areas of Sardinia. Unfortunately, the low market price of ethanol and the high production cost of feedstock do not allow the production to be competitive. Ukraine is the perfect candidate for the mutual benefits from achieving the REDII mandate and fostering sustainable development and economic growth. The production of 2G ethanol from willow is to be considered feasible due to the lower cost of feedstock production when compared to the Italian CS. The amount of underutilized land and the low cost of feedstock production found in this neighbouring country should push the Ukrainian Government to move toward a reform of the national incentive system that can promote development of 2G ethanol value chains and encourage national and foreign investors to participate in the market development of this advanced biofuel. In this context, the role played by the Global Bioenergy Partnership (GBEP) Sustainability Indicators for Bioenergy was crucial for assessing the environmental, social, and economic sustainability of bioenergy value chains specifically on MUC lands. The GBEP work has proved that, when bioenergy crops are grown in appropriate places and under sustainable conditions, several benefits are provided, and feasible businesses exist. The reduction of GHG emissions and other environmental benefits, such as soil remediation and improvement, biodiversity increase, are all feasible goals that can be achieved if biomass and biofuels are produced adopting best practices and preserving the area. The creation of new value chains on lands where abandonment is high, and infrastructures are not sufficiently developed could support Governments to invest in socio-economic development and the creation of local employment and skills. New investments could help create the necessary enabling environment and business connections to restore economical activities in less developed rural areas. Indirect employment can be generated by industries supplying goods and services to the bioenergy sector. Energy access in marginal and abandoned areas (for example, the electricity obtained from co- and by-products) can be counted as an increase of the local access of basic resources. District heating and district cooling can be captured and supplied to householders and businesses. All these measurable factors have demonstrated how bioenergy value chains on MUC lands, if developed in a sustainable way, can contribute to the social and economic development of the areas. And at the same time, by reducing the GHG emissions and increasing the share of renewable energy sources at local, national, and European level, these productions can have substantial impact on the environment in accordance with the goals of decarbonisation.

But what is the financial economic profitability of investing on MUC lands in Europe? The research activities conducted in the second CS led to different conclusions about the performances of the studied bioenergy investments. In general terms, for the investments in cellulosic ethanol, although this study demonstrated a sustainable way to overcome the obstacle of lignocellulosic feedstock costs and availability by using MUC land for biomass production, the high capital investment required and the low market ethanol selling price (and demand), does not allow investments to be financially profitable. Insufficient incentives and subsidies do not allow the achievement of competitive financial returns. Only in the case that market becomes mature, and the governments provide measures to eliminate/reduce the risk and uncertainty and provide sufficient financial support, investment banks, for instance, can bring together investors and meet the required high capex by financing new biorefineries.

When it comes to economic analyses, the study proved that, if sufficient financial support is not provided, positive externalities and fiscal correction may not be sufficient to justify the proposed high technological investments.

For biomethane and low iLUC feedstock CHP productions, where lower CAPEX are required, although investments are sensitive to counterfactual prices, the available feedstock produced on MUC lands showed how the investments may be profitable under both financial and economic point of view. In this case, self-financing can be an asset and a large company can invest their capital supported by fair government policies.

Finally, the study demonstrated the need for introducing appropriate incentives to support the bioenergy development in both low- and a medium-income countries. In Italy and Ukraine, uptake and commercialization of advanced bioenergy productions is challenged by competing demands and policies. The current European and national policy setting does not contain sufficient instruments for supporting a strong domestic demand for ethanol and, more broadly, advanced biofuels. It is paramount that research efforts on feedstocks and land availability mapping (especially for MUC lands) will be increased to identify the most promising lignocellulosic feedstock and locations for future scale-up. In parallel, the reduction (or eventual abolition) of tariffs and other trade barriers to enhance sustainable biomass and biofuel trade will be necessary. The collaboration among European Member States is fundamental and so is the establishment of cross-border agreements with Countries that can support the renewable revolution initiated by the RED II and the European Green Deal.

As shown by the study, policy coherence and stability would help mobilise the investments needed to meet the EU's long-term decarbonisation objectives, but still a lack of sufficient policies was identified to support the value chain development and the investments in advanced bioenergy and biofuel production in the EU. The creation of a stable, long-term policy framework for advanced bioenergy can increase investor confidence and allow for the expansion of biofuel production. Currently, market conditions for advanced biofuels are not attractive, mainly because they cannot compete with fossil fuel and even with conventional biofuel productions. This is also because insufficient specific incentives exist for advanced biofuels. It is mandatory for the EU and its member states to adjust economic incentives over time, as biofuels move towards competitiveness with fossil counterparts and less developed forms of bioenergy. Concerning the support to technological development and market scale-up of advanced bioenergy technology, this study showed that in the EU, there are several EU programmes in place. These programmes, such as BBI, Horizon Europe, ETIP, etc., provide support (e.g. through grants) to research activities to addresses the high investment risks related to commercial-scale advanced biofuel plants. These support programmes are essential to provide project and investment development support. Finally, financial advice is also required by investors to enhance companies' abilities to access adequate sources of financing. Increased levels of guidance and training on how access finance and use of EU funds should be incentivised by ad-hoc EU programmes and support mechanisms.

This study may have some limitations. Given that the project on which this study is based finished in 2018, the data used were mostly from literature from that year. Moreover, in many cases, the data that can be gathered from biorefineries are aggregated and not specific in terms of processes due to their confidential nature; this limits the number and accuracy of the variables in the analysis. A further potential limitation is in the economic analysis, in that it included only the environmental positive externalities (i.e., CO2eq air emissions; CO2 from C stored in soil; Pb, Zn removals from soil; and heat production). Further studies could evaluate the effects of other direct benefits of these investments, such as job creation, increase and diversification of energy supply, and increase in security and reliability of energy supply, to name a few.

In conclusion, this study proved how sustainable advanced bioenergy and biofuels productions can be done by cultivating dedicated crops on marginal, underutilized, and contaminated lands in the EU. But, in most of the cases, capital costs are high and little certainty exists that produced fuels can be sold to the market at a fair price. Considering the key role these productions may possibly play in decarbonising the transport and energy sectors, continuous effort should be put into developing innovative technologies and transforming the policy environment to reduce investment risk and allow investors to support the replacement of fossil fuels.

Annex_ Appendix A_ Additional data and results of Chapter 4:

Table 22. Conversion factors for the economic analysis

Item	Italy 2G Ethanol		Germany CHP		Ukraine 2G Ethanol	
	Value	**Justification**	**Value**	**Justification**	**Value**	**Justification**
Capital expenditures (CAPEX)	0.98	Construction sector	0.97	Construction sector	0.94	Construction sector
Feedstock expenditures	0.99	Agriculture, forestry and fishing	0.94	Agriculture, forestry and fishing	1.03	Agriculture, forestry and fishing
Inputs cost (processing)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Salaries (processing)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Miscellaneous cost (processing)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Revenues—fuel production	0.99	Agriculture, forestry and fishing	0.94	Agriculture, forestry and fishing	1.03	Agriculture, forestry and fishing
Revenues—electricity production	0.96	Electricity, gas, … remediation	0.96	Electricity, gas, … remediation services	1.01	Electricity, gas, … remediation
Revenues—lactic acid production	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Revenues—biomethane (grid)	0.99	Standard conversion factor (SCF)	0.96	Electricity, gas, … remediation services	0.98	Standard conversion factor (SCF)
Incentives per ha (CAP)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Benefits from heat (externalities)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Benerfits CO_2 reduction (externalities)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Market value of lead (externalities)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)
Market value of Zinc (externalities)	0.99	Standard conversion factor (SCF)	0.97	Standard conversion factor (SCF)	0.98	Standard conversion factor (SCF)

Table 23. Positive externalities considered by the study per each of the selected investment

Pathway	ha	Air Emission	CO$_2$ from Carbon Stored in Soil		Pb, Zn Removals from Soil		Heat Production
		Tonnes of CO$_2$eq Reduction/yr	Tonnes of C/yr	Tonnes CO$_2$eq/yr	Tonnes of Pb/yr	Tonnes of Zn/yr	GWh
1	7200	61,227	3240	11,664	0.24	0.00	156
2	1140	13,905	730	2627	2.57	11.97	44.32
3	3300	0	0	0	0.00	0.00	0
4	3648	1461	84	302	0.00	0.00	0
4'	2431	1276	7050	25,380	0.00	0.00	0
5	16,720	42,319	5250	18,900	0.00	0.00	130

Table 24. NPV parameters for capital investments

Model	Initial Value of CAPEX ('000 Euro)	Asset Economic Life (Years)	Straight Line	Declining Balance	Double Declining	Sum of Year Digits
Italy—2G ethanol	150,000	30	50,000	0	18,810	17,742
Germany—CHP	18,000	30	6000	0	2257	2129
Germany—Biochemicals	800	30	267	0	100	95
Germany—Biomethane	9700	30	3233	0	1216	1147
Ukraine—2G ethanol	125,000	30	41,667	0	15,675	14,785

Table 25. Market prices and assumptions considered by the study

Variable	Price	Unit	Assumption	Variable	Price	Unit	Assumption
Ethanol	552	€ ton	Weibull distribution	Arundo donax price	100	€ ton	Triangular distribution
Electricity price (ITA)	115,000	€ GJ	Beta distribution	Salix spp price	70	€ ton	Triangular distribution
Electricity price (UKR)	124,000	€ GJ	Min extreme distribution	Miscanthus price	80	€ ton	Triangular distribution
Electricity Price (DE)	148,800	€ GJ	Min extreme distribution	Spontaneous grass price	60	€ ton	Triangular distribution
Heat price (ITA)	50,000	€ GJ	Triangular distribution	Lucerne price	140	€ ton	Poisson distribution
Heat price (UKR)	10,000	€ GJ	Triangular distribution	Sorghum price	130	€ ton	Triangular distribution
Heat price (DE)	30,000	€ GJ	Triangular distribution	Ton of CO2e price	25	€ ton	Triangular distribution
Biomethane price	0.073	€ kWh	Lognormal distribution	Lead price	1800	€ ton	Min extreme distribution
Amino acids price	4000	€ ton	Beta distribution	Zinc Price	2500	€ ton	Triangular distribution
Lactic acids price	600	€ ton	Beta distribution				

Figure 13. Probability distribution of FNPV (upper) and ENPV (lower) resulting from Monte Carlo simulation

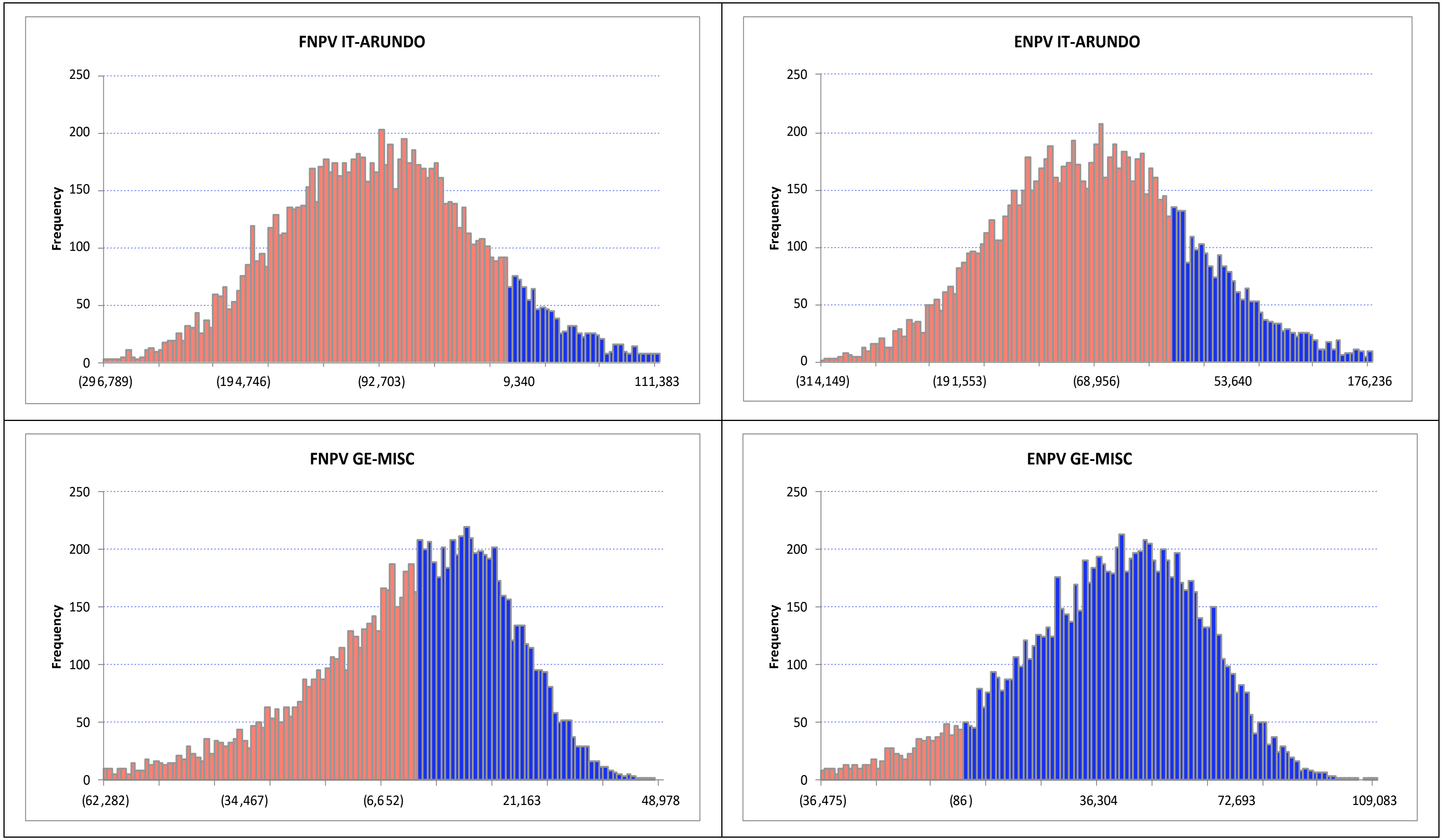


Figure 14. Probability distribution of FNPV (upper) and ENPV (lower) resulting from Monte Carlo simulation

Figure 15. Probability distribution of FNPV (upper) and ENPV (lower) resulting from Monte Carlo simulation

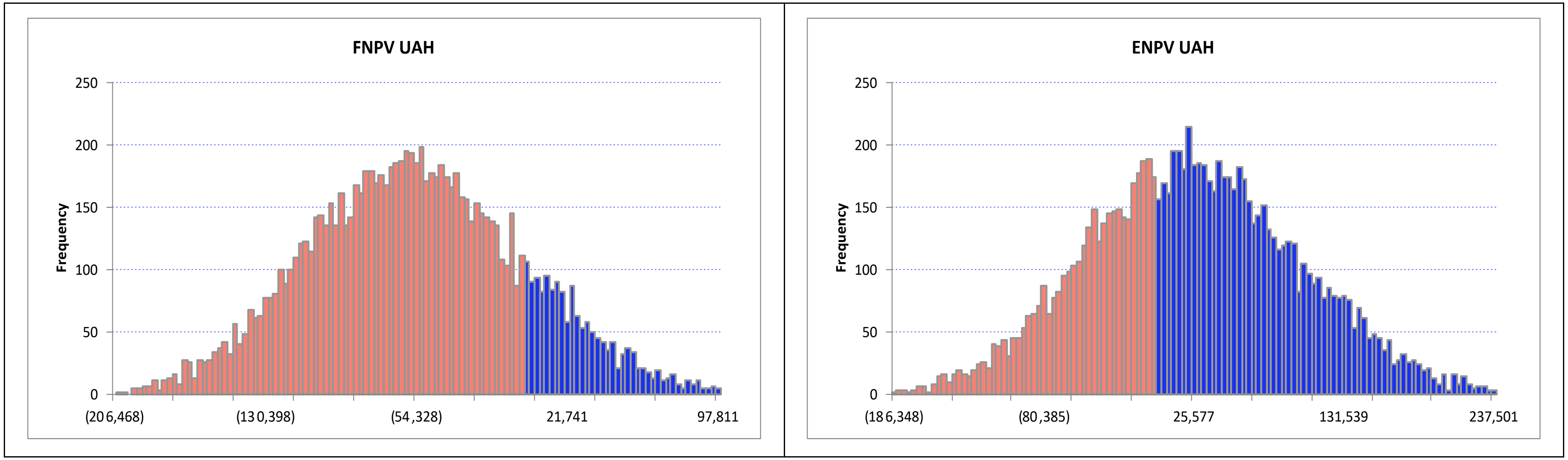


Figure 16. Tornado plot sensitivity analysis of selected investments

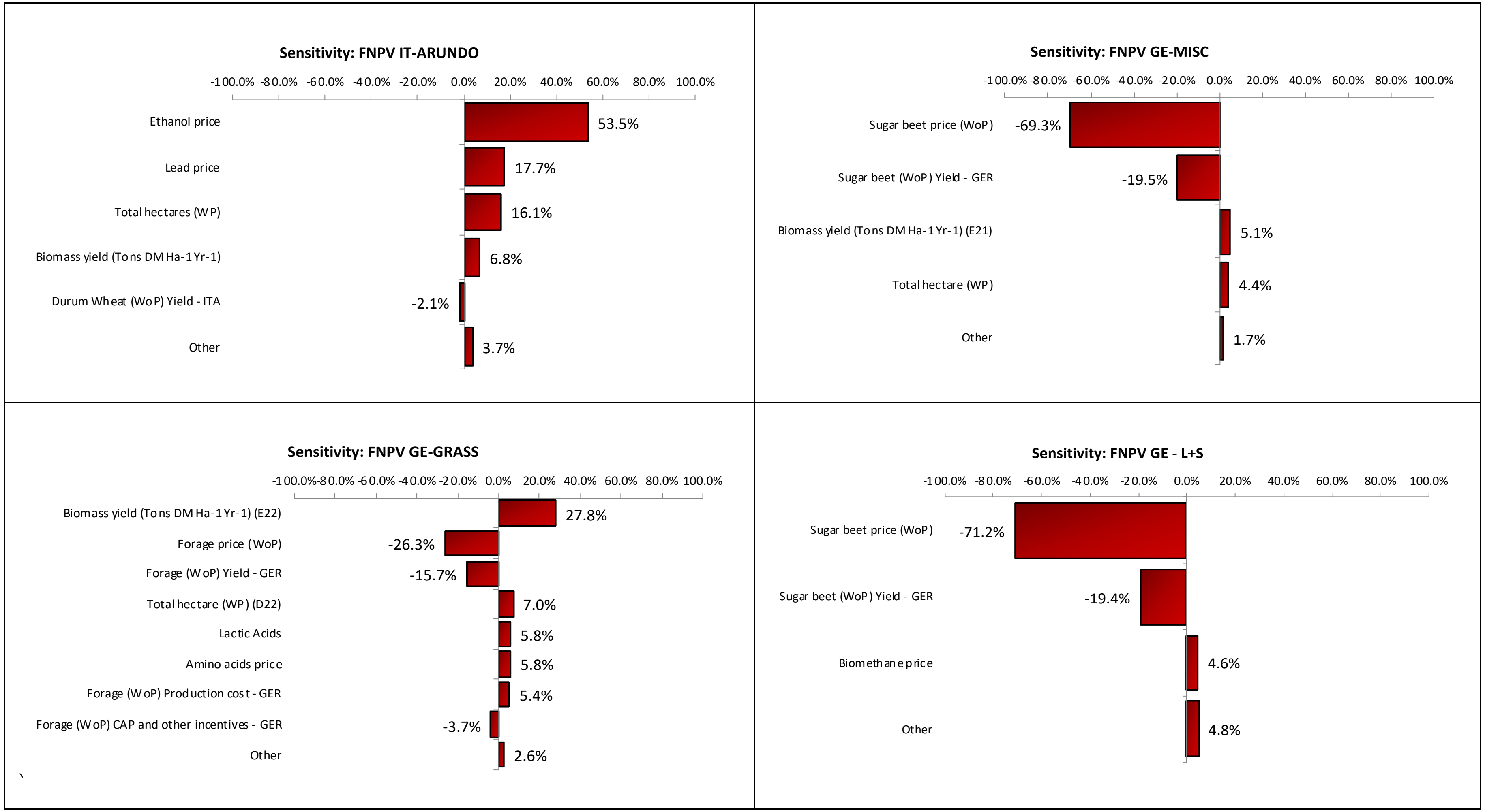


Figure 17. Tornado plot sensitivity analysis of selected investments

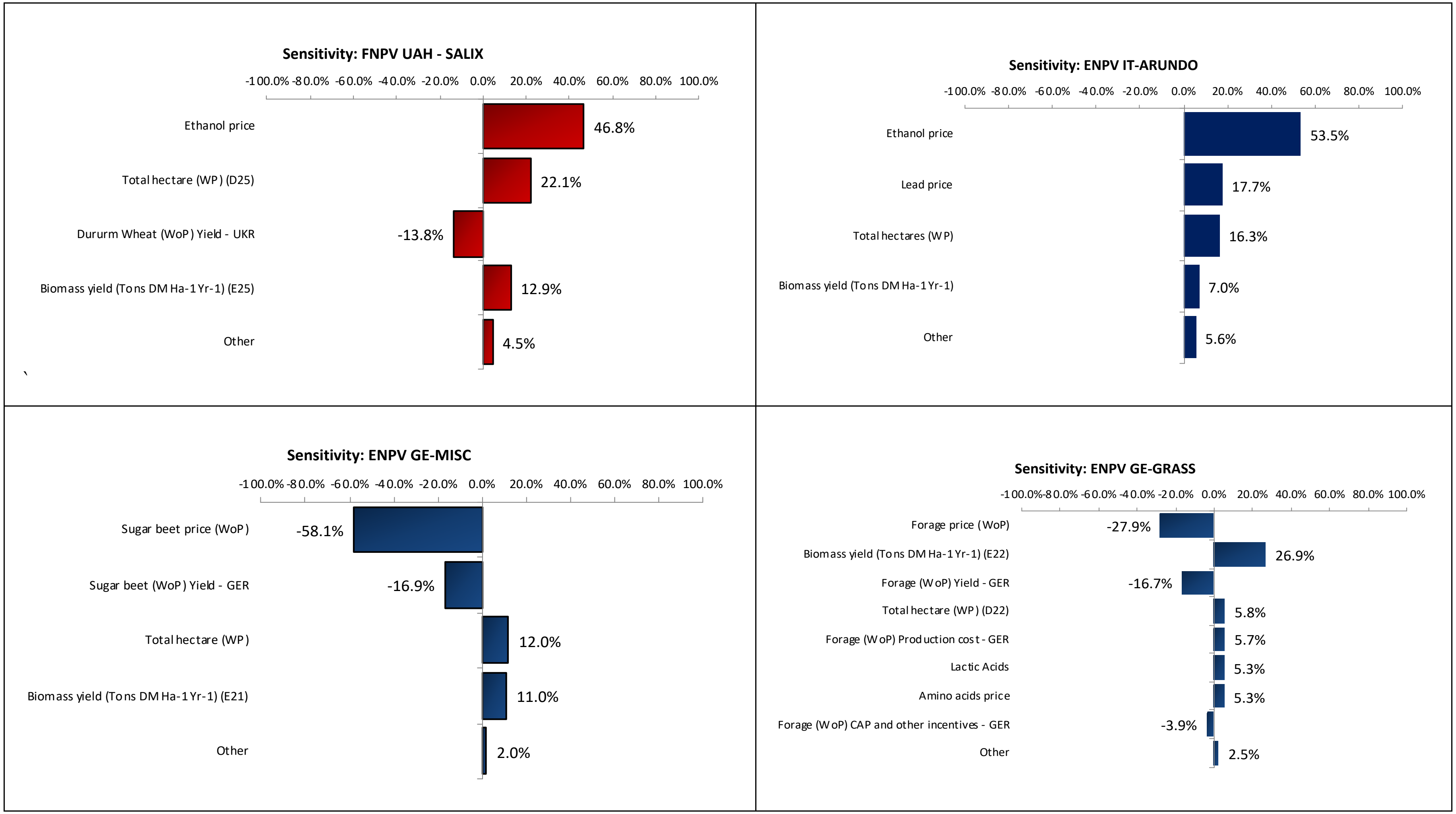
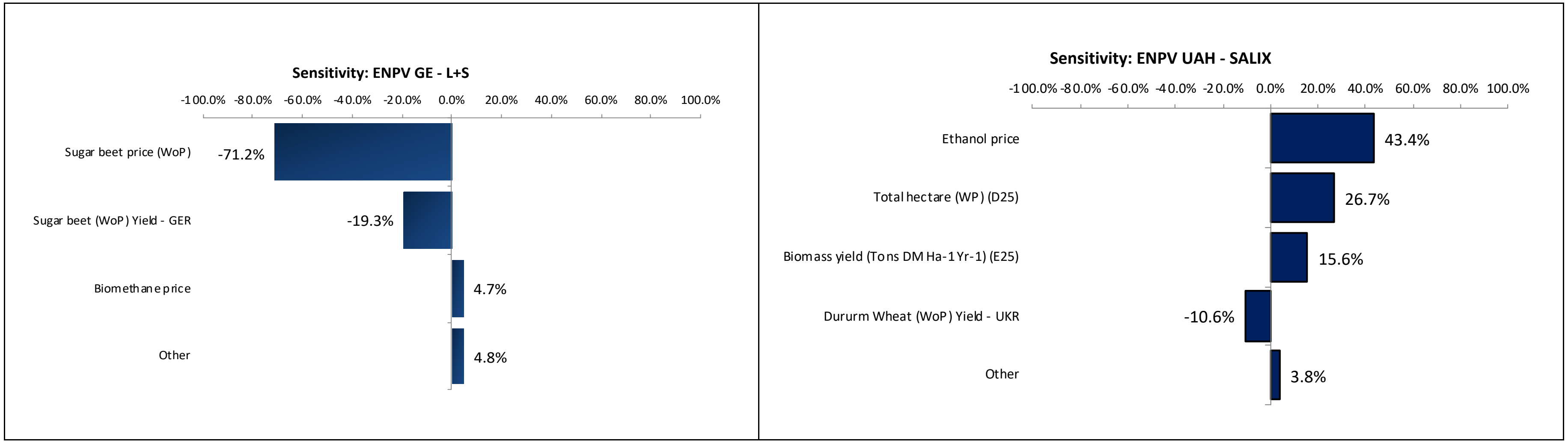


Figure 18. Tornado plot sensitivity analysis of selected investments



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