

## Article

# Cost Benefit and Risk Analysis of Low iLUC Bioenergy Production in Europe Using Monte Carlo Simulation

Traverso L. <sup>1,\*</sup>, Mazzoli E. <sup>1</sup>, Miller C. <sup>2,†</sup>, Pulighe G. <sup>3</sup> , Perelli C. <sup>1</sup>, Morese M. M. <sup>2,†</sup>  and Branca G. <sup>1</sup> 

<sup>1</sup> Economy, Engineering, Society and Business Department (DEIM), University of Tuscia, 00100 Viterbo, Italy; enrico.mazzoli@unitus.it (M.E.); chiara.perelli@unitus.it (P.C.); branca@unitus.it (B.G.)

<sup>2</sup> Food and Agriculture Organization of the United Nations (FAO), 00153 Rome, Italy; constance.miller@fao.org (M.C.); michela.morese@fao.org (M.M.M.)

<sup>3</sup> CREA Research Centre for Agricultural Policies and Bioeconomy, 00198 Rome, Italy; giuseppe.pulighe@crea.gov.it

\* Correspondence: ltraverso@unitus.it

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**Abstract:** Extensive surfaces of land are currently under-utilized, 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 purpose of this paper is to measure net economic returns by computing benefits and costs of low indirect Land Use Change (iLUC) biofuel 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 green-house gas (GHG) emissions impact were assessed and considered for the economic analysis. The considered pathways were cellulosic or second generation (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 will not be profitable compared to the baseline scenarios. In Germany, the work showed good profitability for combined heat and power (CHP) and biochemicals. On the other hand, investments in biomethane showed negative results compared with the baseline scenarios. Finally, the Monte Carlo simulation enabled us to identify the range of possible economic results that could be attained once volatility is factored in. While for Italy the likelihood of yielding positive results remains lower than 20 percent, case studies in Ukraine and Germany showed higher certainty levels, ranging from 49 to 91 percent.

**Keywords:** advanced biofuels; low iLUC biofuels; marginal land; cost-benefit analysis; second generation ethanol; 2G ethanol; biomethane; biochemicals; CHP; Monte Carlo simulation

## 1. Introduction

The recovery and reuse of land and soil is essential to secure natural resources and ecosystem services in the future. Since the increase in resource demand generates a growing pressure and degradation of natural capital, it affects ecosystems' functions, thus provoking consequences to biodiversity and soil fertility. Therefore, the Renewable Energy Directive (REDII) of the European Union (EU) prioritizes low indirect Land Use Change (iLUC) risk bioenergy production [1–3], supporting biofuels from waste, residues and lignocellulosic feedstocks, so called “advanced” biofuels with low iLUC impact [4]. The

cascading use of renewable biomass feedstock in a bio-based economy (bioeconomy) for the production of high added-value products and energy in biorefineries is a cornerstone of Europe's Bioeconomy Strategy [5]. In this context, the cultivation of biomass to produce biofuels on under-utilized, marginal and/or contaminated (MUC) land unsuitable for food production is a viable option to minimize iLUC and maximize economic potential for rural communities.

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 up to a maximum of five years [6]. After that period of time, the land can be considered suitable to produce bioenergy without competing with food or feed production [7]. For instance, a surface of land is considered as MUC land only when satellite images time series show that there has been a lack of intensive utilization of the land for a period of more than 5 years [8]. The abandonment of these pieces of land can be due to different factors such as land marginality (biophysical or socio-economic constraints) or soil and ground water contamination.

A few recent papers have published relevant research on this specific topic in Europe and neighbouring countries. However, with the new REDII, the attention on low iLUC biofuel has increased, mainly as a consequence of the emission reduction targets imposed by the policy. According to Panuotsou [9], 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 on marginal land availability conducted by Ciria et al. [10] demonstrated how the use of marginal lands can potentially contribute to the EU policy objective to reduce green-house gas (GHG) emissions by 60% by 2030 and, in particular, to achieve the targets imposed by the REDII that promote the use of renewable energy sources. Furthermore, based on the assessment and quantification of marginal lands for biomass production developed by Gerwin et al. [11], potentially suitable areas were identified for the production of bioenergy feedstock in Europe through a Geographical Information System (GIS) analysis. Although there are several studies (and projects) demonstrating the high potential for bioenergy feedstock to be grown on MUC land from the point of view of land availability or agro-nomic 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 [12–14]. In particular, 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 [13] in which profitability of producing perennial grasses has been demonstrated. From the point of view of the processing actors (biorefineries), Yazan et al. [12] published a study on evaluating the profitability of a biorefinery in Porto Torres industrial district, in Sardinia (Italy), where large amount of MUC lands are present. The findings of the study were that a potential bio-refinery can produce economically competitive outputs with an important contribution to the region's employment market.

The scientific purpose of this paper is therefore 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 (second generation (2G) ethanol from Giant reed (*Arundo donax*) in Italy, biomethane from spontaneous grass and cultivated Lucerne (*Alpha-alfae*) with sorghum 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. All case study sites have the potential to host new advanced value chains for biofuels production, generate new employment opportunities, and to improve the value added of the areas while increasing the income of the local people. Furthermore, through the development of such value chains, both environmental and social benefits can be assured, such as the reduction of GHG emissions and air pollutants; land restoration and-or phytoremediation; and energy efficiency, access, security, and diversification.

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

The paper 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.

## 2. Materials and Methods

This paper is based on data and information collected by FAO and other project partners in the context of the “Fostering Sustainable Feedstock Production for Advanced Biofuels on Underutilised Land in Europe” (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 [15,16]. The data that were used for this research are accessible from the official project deliverables on the project website (<https://forbio-project.eu/documents>, accessed on 27 November 2018).

### 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); (iii) the Ivankiv Region of Ukraine (specifically the non-exclusion zone just south of the Chernobyl disaster area). The countries were selected in the context of the FORBIO project 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 to compare both EU and non-EU neighboring countries with different economies and regulations.

Tables 1 and 2 describe the crops and bioenergy pathways considered for this study, whilst Figure 1 shows a map of the potential bioenergy case study sites; total hectares considered for the investments are presented in Table 3.

**Table 1.** Selected crops for potential cultivation on under-utilized, marginal and/or contaminated (MUC) land.

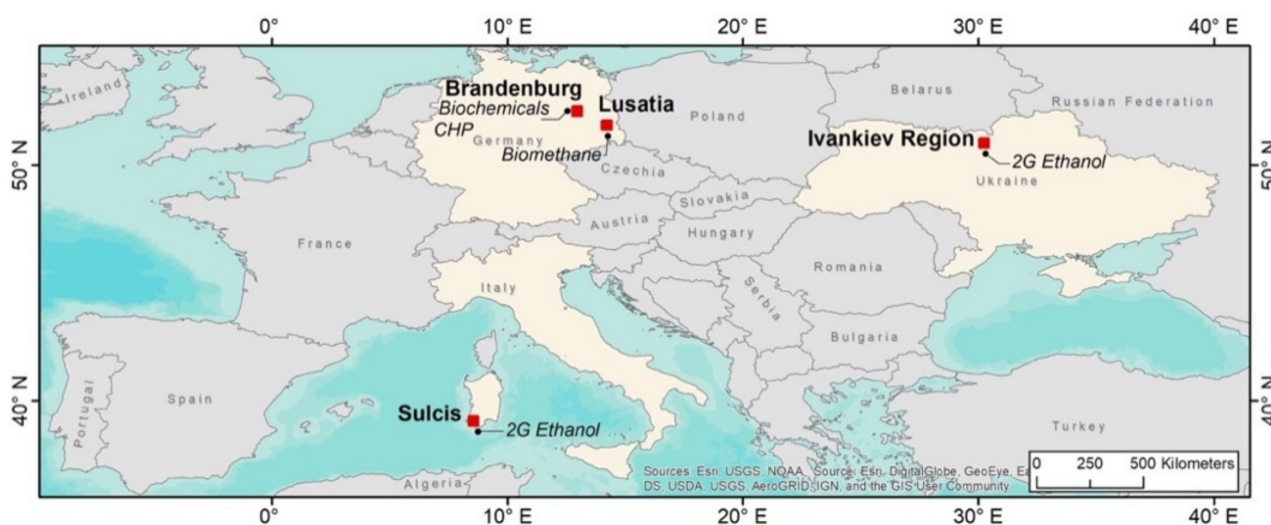
| CS        | Crop Name                               | Management | Site            | Site Features                                  | Bioenergy Pathway | WoP * Scenario |
|-----------|-----------------------------------------|------------|-----------------|------------------------------------------------|-------------------|----------------|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

\* Without Project.

**Table 2.** Feedstock production and relative cost for the selected investments.

| CS        | Biomass Yield<br>(Tonnes of DM<br>ha <sup>-1</sup> Yr <sup>-1</sup> ) | FSTK<br>Production Cost<br>(€ Tonne <sup>-1</sup> ) | Potential FSTK<br>Production<br>(Tonnes yr <sup>-1</sup> ) | Feedstock Price<br>(€ Tonne <sup>-1</sup> ) | Potential Annual Net<br>Benefits of FSTK<br>Production (€ ha <sup>-1</sup> ) 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 1.** Potential bioenergy sites identified for the analysis.**Table 3.** Total hectares and Capital (CAPEX) and operation (OPEX) expenditures of the selected investment.

| Pathway              | Total Hectares<br>Considered | CAPEX (Thousand of €)<br>2018 | OPEX (Thousand of €)<br>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 1, in Italy, the case study (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) [17,18]. Irrigated Giant reed was considered for the production of 2G ethanol and electricity as co-product with an average yield of 25 tons ha<sup>-1</sup> yr<sup>-1</sup> 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 [19,20]. According to Mergner et al. [20], 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. [21], miscanthus grown on contaminated soils can accumulate up to 5 mg Cd kg<sup>-1</sup>, 150 mg Pb kg<sup>-1</sup> in its biomass, as well as 700 mg Zn kg<sup>-1</sup>, making it a promising crop for phytoremediation. The considered yield for miscanthus production was 15 tons ha<sup>-1</sup> yr<sup>-1</sup> of DM. Miscanthus production was considered for combined heat and power (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 [20]. According to Thumm et al. [22], there are new options to use grassland biomass for energy purposes as well as for biobased products. Based on Knoche et al. [19], the identified potential for the cultivation of grasslands was approximately 1140 ha, while 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. [20], the identified potential for the cultivation of Lucerne and Sorghum was approximately 7295 ha. The considered yields for Sorghum and Lucerne selected for the production of biomethane would be 5 and 10 tonnes DM ha<sup>-1</sup> yr<sup>-1</sup>, 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<sup>-1</sup> yr<sup>-1</sup> [23]. As for the Italian case study site, in Ukraine, Salix biomass was considered for 2G ethanol production.

Table 2 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 case study 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.

## 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 [24] 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);
- Outline the cash flows which support the calculation of the socio-economic costs and benefits.

Following the CBA framework defined by the European Commission [22], impact categories were identified and associated with the alternative scenario (with project 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 A1–A4. Particularly, prices for the financial analysis are presented in Table A4.

Annual financial net benefits of producing biofuels are given by:

$$\pi_b(Qb) = Pb(Qb) - (wLb + fFb + nNb + eUb - mMb) \quad (1)$$

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)

$\pi_b(Qi)$ : annual net benefits of the biofuel pathway *i*

*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 [15,16]. 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 modern or 2G biofuels and biochemicals biorefineries (e.g., 2G ethanol or lactic acid plants). Furthermore, for consistency, the same aggregation was applied to the analysis of non-modern bioenergy such as CHP.

Following the method described by the Guide to cost-benefit analysis of investment project of the European Commission [24] and [25], 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% financial discount rate was considered as per EC (2015) Commission Implementing Regulation (EU) 2015/207 of 20 January 2015 and 8% for Ukraine as a neighbouring country, as suggested by [26]. 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 ( $S_n$ ).

The FNPV is given by the following equation:

$$\text{FNPV} = \sum_{t=0}^n a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \dots + \frac{S_n}{(1+i)^n} \quad (2)$$

While the FIRR is given by the following equation:

$$0 = \sum \frac{S_t}{(1 + \text{FIRR})^t} \quad (3)$$

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 3, 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 150 and 125 million euros, respectively [16]. In Germany, 18 million euros were considered for building a new CHP biomass power plant (3.6 MW) for the combustion of miscanthus chips for heat and electricity production [20]. The total investment cost considered for a modern green biorefinery for the production of biochemicals was 800,000 euros. As green biorefinery concepts are rather new, no exact data on full investment costs is available; 800,000 euros is a realistic indication, but more information needs to be collected in the future [20]. Finally, for the biomethane investment a CAPEX of 7 million euros plus 2 million for the upgrading of biogas to biomethane was considered for a total initial investment of 9.7 million euros [20]. The operation costs (OPEX), as presented in Equation (1), 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 3. The average lifetime of the investment is assumed equal to 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 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 A3).

Table 4 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 With Project (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 4.** Reference scenarios (WoP) considered for the analysis.

| Reference Pathway    | WoP Production | Yield (Tonnes ha <sup>-1</sup> ) | Production Cost (€) | Market price (€/Tonne <sup>-1</sup> ) | CAP Incentives € ha <sup>-1</sup> | Annual Revenue € ha <sup>-1</sup> | Annual Net Benefit € ha <sup>-1</sup> |
|----------------------|----------------|----------------------------------|---------------------|---------------------------------------|-----------------------------------|-----------------------------------|---------------------------------------|
| 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                                   |

### 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 [24,25,27], 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 A2 of Appendix A presents the direct benefits and externalities that were considered for the proposed investments.

Following the standard approach suggested by [24,25], 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 [24]. The calculation of shadow prices is carried out through the use of National Input-Output matrices retrieved from the OECD database [28,29]. Table A1 of Appendix A shows the conversion factors calculated for the analyses.

For the positive externalities, as shown in Table A2, five additional benefits were monetized for the analyses. The calculations were done using data collected from FAO specific literature [16,30]. Particularly, the reduction of CO<sub>2</sub>eq 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 alternative fuel scenario (petrol or diesel) and the results of the LCA. The tonnes of CO<sub>2</sub>eq were associated to the EU market price for carbon dioxide. The Total Organic Carbon (TOC) stored into soil was also obtained from [16]. The total TOC was then converted to CO<sub>2</sub>eq following the methodology provided by [31], and the CO<sub>2</sub>eq was monetized as for the benefits from the emission reduction.

For the land restoration component, phytoremediation capability was considered for *Arundo donax* and *Miscanthus*. The amounts of lead and zinc were obtained from [16,19,32,33] and monetized following the method provided by [34,35] 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 [26], the considered social discount rate (SDR) was 3% for Italy and Germany (as defined by EU for major projects in Cohesion countries) and 5% 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 represent the difference between the project scenario and the WoP scenario.

The ENPV is given by the following equation:

$$\text{ENPV} = \sum_{t=0}^n k_t S_t = \frac{V_0}{(1+r)^0} + \frac{V_1}{(1+r)^1} + \dots + \frac{V_n}{(1+r)^n} \quad (4)$$

While the FIRR is given by the following equation:

$$0 = \sum \frac{V_t}{(1 + \text{EIRR})^t} \quad (5)$$

where:

$V$ : annual economic net benefit

$t$ : time

$k_t$ : economic discount factor

$r$ : economic discount rate

#### 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 [24].

Following the methodology described by [24,25], 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, negative) on the project. A variable is defined as critical when a variation of  $\pm 1\%$  in its initial value gives rise to a variation of more than  $\pm 1\%$  in the value of the Net Present Value (NPV) [24]. 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 interpreted. For the probabilistic risk analysis, a Monte Carlo simulation was developed following the method applied by Rayner et al. [36], 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. [36], the application of the Monte Carlo simulation provides a 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 A4 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.

### 3. Results

In this section, we present the results of the data analysis in accordance with the theoretical framework described in Section 2. The results are presented in suitable tables and charts to compare different scenarios of CBAs and risk analysis.

#### 3.1. Financial Analysis

Table 5 shows the results of the financial CBA, including WP annual net benefits, FNPV and FIRR for all case study investments. The WP incremental scenario is compared with the WoP scenario to calculate the incremental NPV and IRR.

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 taken into account.

**Table 5.** 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%     |

### 3.2. Economic Analysis

Table 6 presents the economic analysis of the five case study 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 6.** 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 case study sites. In Italy, the results show that, although the introduction of economic benefits (derived from the CO<sub>2</sub>eq emission 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).

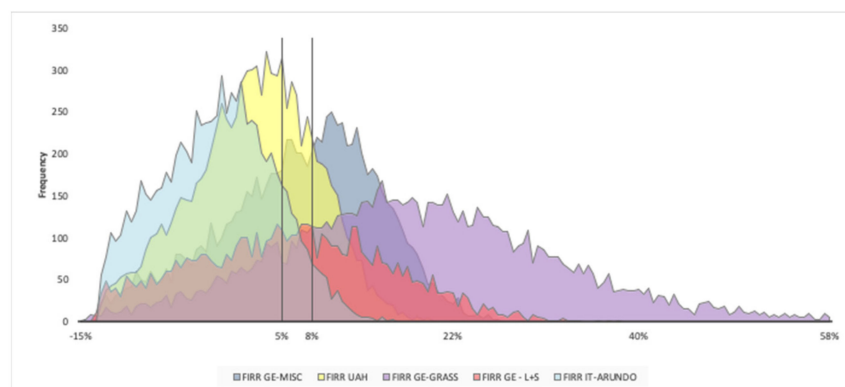
### 3.3. Risk Analysis

Figure 2 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.

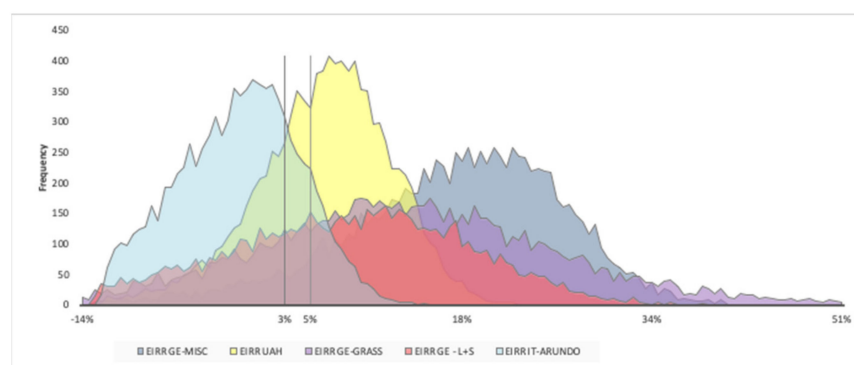
In the overlay chart of Figure 3, the economic results present a similar positioning to that noted in Figure 2, although volatility across results appears to be slightly reduced. Furthermore, while results for the Italian case study have not improved, the Ukraine and Germany (CHP) probability distribution functions have transitioned to the right-hand side of the chart, denoting an improvement in the economic profitability indicators.

For each profitability indicator, we identified the entire range of uncertainty as well as certainty levels linked to positive results. Figure A1 provides 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 7 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 A2–A4 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 2.** Overlay chart of financial internal rate of return (FIRR) of the selected investments.



**Figure 3.** Overlay chart of Economic Internal Rate of Return (EIRR) of the selected investments.

**Table 7.** Certainty levels by profitability indicator and investment.

| CS        | 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. 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; we also compared the obtained results to the work done by Traverso et al. [7]. The reason for this is clearer when the sensitivity analysis is taken into account; 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 [37]. 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 certainty level, far beyond its Italian cousin with a certainty level of 19%). The Ukrainian case study 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 in order 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.

The current study has a number of limitations that could be considered as a point of departure by future studies. The first of these limitations relates to the data. Given that the project from which the 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., CO<sub>2</sub>eq air emissions; CO<sub>2</sub> 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.

## 5. Conclusions

Based on the result of the CBA, several conclusions can be drawn about the performances of the selected bioenergy investments on MUC lands and the impact of the different variables to the models.

For 2G ethanol, the financial cost benefit analysis was negative in both Italy and Ukraine; this was due mainly to the low international market price of ethanol. When environmental benefits are taken into account in the economic analysis, the result for the 2G ethanol in Ukraine is positive. Therefore, stable incentive systems that internalise the positive externalities to society in the energy prices are required to improve the competitiveness of low iLUC 2G ethanol produced on MUC lands compared with fossil fuels and 1G ethanol alternatives.

In Germany, there is a good environment for the development of low iLUC bioenergy on MUC lands. However, it will be essential that policies provide support to reduce the risk of these investments and that economic instruments are introduced that consider the positive environmental externalities to social welfare.

This study has shown how low iLUC biomass and bioenergy produced on MUC lands may bring positive results in terms of both financial and economic cost benefit analysis. However, the profitability is strongly correlated and dependent on the specific context and circumstances where such investments are placed.

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**Data Availability Statement:** All data related to the bioenergy investments analysed are available from the official and public deliverables available in the FORBIO's project (see footnote above).

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** 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 <sub>2</sub> 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 A2.** Positive externalities considered by the study per each of the selected investment.

| Pathway | ha     | Air Emission                             | CO <sub>2</sub> from Carbon Stored in Soil |                              | Pb, Zn Removals from Soil |                 | Heat Production |
|---------|--------|------------------------------------------|--------------------------------------------|------------------------------|---------------------------|-----------------|-----------------|
|         |        | Tonnes of CO <sub>2</sub> e Reduction/yr | Tonnes of C/yr                             | Tonnes CO <sub>2</sub> 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 A3.** 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 A4.** 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 CO <sub>2</sub> e 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        |                                |       |       |                          |

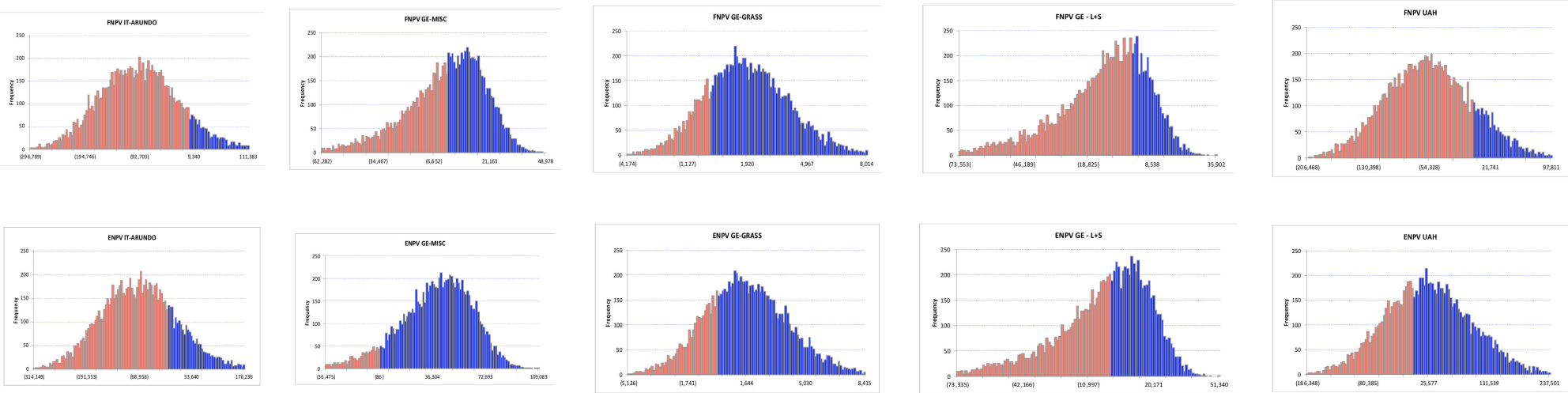


Figure A1. Probability distribution of FNPV (upper) and ENPV (lower) resulting from Monte Carlo simulation.

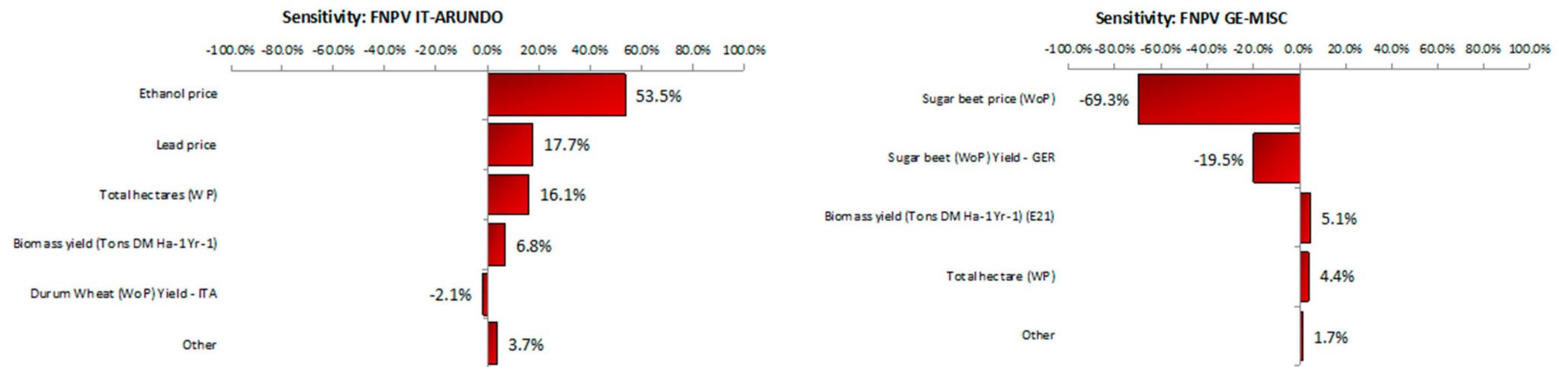


Figure A2. Tornado plot sensitivity analysis of selected investments.

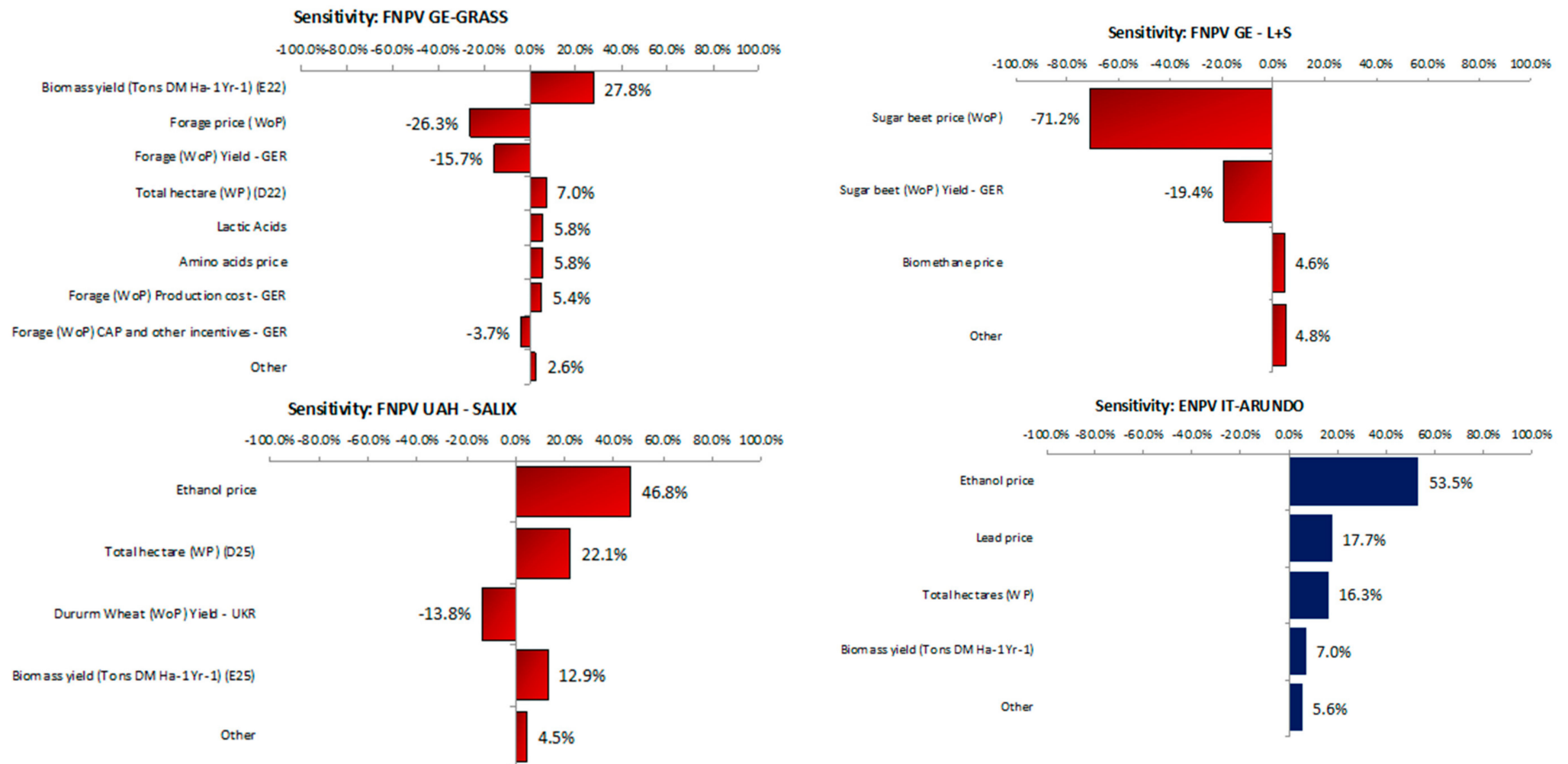


Figure A3. Cont.

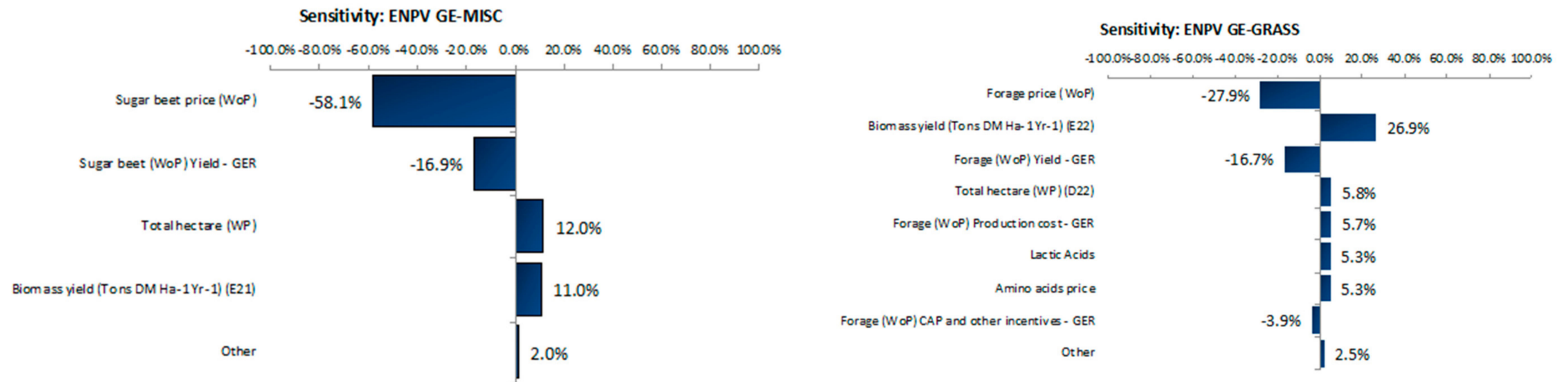


Figure A3. Tornado plot sensitivity analysis of selected investments.

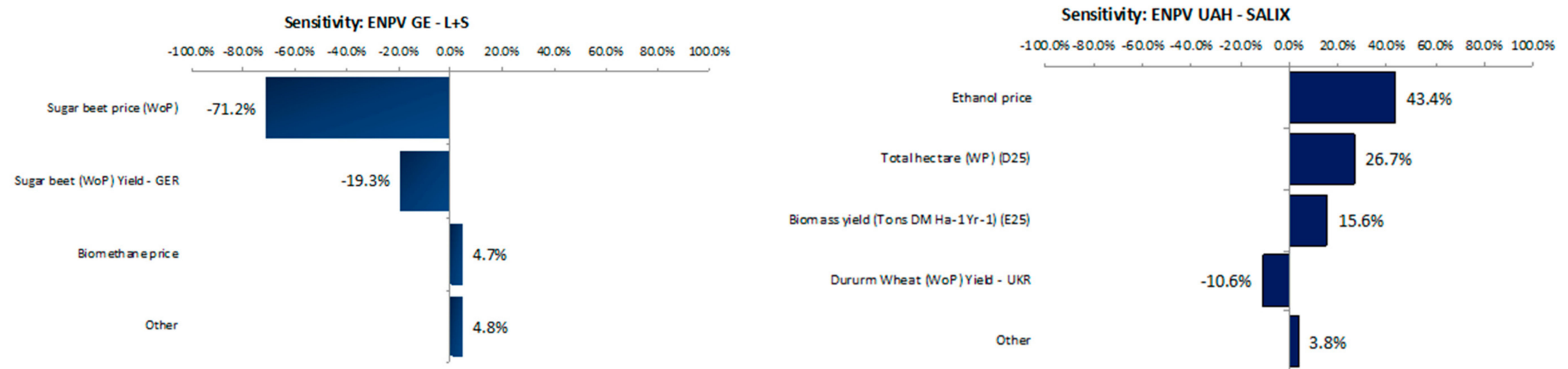


Figure A4. Tornado plot sensitivity analysis of selected investments.

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