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FINANCIAL ANALYSIS OF THE CULTIVATION OF SHORT ROTATION WOODY CROPS FOR BIOENERGY IN BELGIUM: BARRIERS AND OPPORTUNITIES

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Abstract

This paper analyses the financial performance of a poplar short rotation woody crop (SRWC) plantation in Belgium, from a farmer's and an investor's viewpoint, based on simulations from the newly developed model POPFINUA. The establishment, production and harvest costs were investigated to calculate the net present value (NPV) and the equivalent annual value (EAV) of the SRWC cultivation when the biomass chips were sold at a price of 40 € Mg^{-1} with a moisture content (m.c.) of 50%. The calculated NPVs were 229 € ha^{-1} and -485 € ha^{-1}, and the EAVs equalled 16.3 € ha^{-1} y^{-1} and -34.6 € ha^{-1} y^{-1} for the farmer's and investor's scenario respectively. The break-even price at which the produced biomass could be sold at the farm gate excluding transport, handling, storage, and profit margins of the involved companies was calculated using the levelized costs method and equalled 78.4 € odt^{-1} (oven-dried ton) and 83.5 € odt^{-1} for the farmer's and investor's viewpoint respectively. Three harvesting strategies, applied on a SRWC plantation of 18.1 ha in Flanders (Belgium), were studied and compared. It became clear that preference should be given to more economic, small-scale harvesters instead of large-scale self-propelled harvesters, given the relatively limited surface available for SRWCs in Belgium. Furthermore, the inclusion of transportation over a distance of 50 km by truck increased the LC by 15.1 € odt^{-1}. Moreover, subsidies such as establishment grants and/or yearly incentives proved indispensable to make this long-term investment profitable. This is particularly true for the scenario where an investor decides to cultivate SRWCs for energy purposes.

1. Introduction

The use of fossil energy is widely considered as being harmful to the global environment by adding greenhouse gases (GHGs) to the atmosphere and by contributing to soil contamination and water pollution [1]. To mitigate these harmful impacts, the transition to renewable energy sources in combination with improved energy use efficiency is indispensable. Biomass has been identified as a renewable energy source which can contribute significantly to the carbon abatement strategy aiming at a 20% reduction and which can increase the share of renewable energy in the total energy consumption to 20% in Europe by 2020 [2]. Therefore the European Commission has developed a Renewable Energy Road map for the deployment of bioenergy as a focal renewable source of energy for the EU within the framework of the Energy Policy for Europe [3,4].

Bioenergy can originate from many sources, from organic waste streams over forest residues to annual and perennial crops, grown specifically for energy production. The latter, in particular short rotation woody crops (SRWCs), such as poplar and willow, are projected to play a major role in the supply of biomass feedstock and are able to deliver 80% to 90% GHG emission reductions compared to the fossil energy baseline [5].

The present analysis fits within this overall framework of bioenergy sources from SRWCs, and their potential for the future energy supply in the EU, in particular from an economic point of view. The study aims at an assessment of the financial feasibility of bioenergy plantations of fast-growing woody crops, in this case poplars, in Belgium. We have opted to focus on the cultivation of poplar for bioenergy because this species is of significant value from an economic point of view in Belgium, covering about 13.8 % of the forest area and accounting for up to 50 % of the hardwood timber production [6]. Moreover, poplar has a number of well know favourable characteristics as compared to other energy crops. Poplars are easy to propagate from cuttings, they show a remarkable early youth growth and a high biomass yield, and they have an intensive gas exchange metabolism. Some drawbacks of this crop, on the other hand, are the considerable water and light demand, and the high susceptibility to diseases [7,8].

Several authors [9-11] have discussed the financial viability of SRWCs for bioenergy in a number of countries, with varying conclusions. Mitchell et al. [9] argued that government incentives and a stable market for wood chips are indispensable for SRWCs to compete with conventional agricultural crops and to become feasible at a commercial scale in the United Kingdom. Styles et al. [10] concluded that the cultivation of energy crops, such as willow and Miscanthus, is highly competitive with conventional agricultural systems in Ireland. Ericsson et al. [11], on the other hand, found that willow is an economically feasible energy crop for relatively large farms in Poland as the production costs are significantly lower compared to Western European countries, because of the lower diesel, labour and fertilizer costs.

Over the past years, a number of financial valuation models have been developed specifically for SRWCs. The budget model, EcoWillow, allows the financial assessment of the entire production chain for willow cultures in the USA [12]. EcoWillow, however, does not allow the modification of a number of parameters, such as the plantation lifetime and the harvesting strategy (only combined harvest and chipping is considered). Moreover, the model assumes coppicing after the first year to produce multiple stems, which is seldom applied when cultivating poplar because of its stronger apical dominance[1] [13]. Rosenqvist [14], on the other hand, developed a model which

[1] Definition: Inhibition of the growth of lateral buds by the terminal bud of a plant shoot, i.e. the main central stem is dominant over the other side stems and as a consequence less shoots per stool are produced and the lower shoots are suppressed

allows the comparison of the financial viability of long-term SRWCs with agricultural annual crops. Unfortunately, the model has been developed for Swedish conditions only and does not allow the modification of the discount rate, neither of the rotation length nor of the lifetime, making a contemporary and detailed financial analysis of the cultivation of SRWCs difficult. The Renewable Energy Crop Analysis Programme (RECAP) developed by the Energy Technology Support Unit (ETSU) on behalf of the UK Department of Trade and Industry (DTI) is another example of a financial feasibility assessment tool dedicated to SRWCs [15]. Despite its apparent usefulness based on the description in the literature [16,17], all the efforts to secure a copy of this model were to no avail. A very useful and detailed, but unfortunately outdated model, is the ECOP model [18]. This model provides a highly detailed financial viability analysis of SRWC production and conversion stages, where electricity is produced in low power gasifiers. Although we were unable to acquire a version of this model, we were able to use several ideas of it [18].

The present study extends previous analysis (i) by discussing the financial viability of the cultivation of poplar SRWCs for bioenergy from both a farmer's and an investor's viewpoint based on data gained from the literature and from an operational plantation in Flanders, Belgium; (ii) by examining the relative impact of key variables (discount rate, biomass yield, subsidies and biomass price) on the financial balance of the cultivation of SRWCs; (iii) by revealing the most important contributors to the final costs together with the (non-)financial barriers to SRWCs in Belgium.

2. Materials and Methods

2.1. Model development

Because the afore-mentioned models did not allow a detailed analysis of the profitability of SRWCs, we developed a new spreadsheet model 'POPFINUA' for poplar in a SRWC culture for bioenergy. The model is designed to analyse the financial feasibility of the cultivation of fast growing woody trees (i.e. poplar and willow) in a short rotation coppice management system for the production of biomass woody chips. The model allows us to alter a number of key variables and simultaneously visualize the impact of the modification on the costs and on the financial viability of a SRWC plantation. Moreover, the user can choose whether the operations are undertaken by farm labour or by contractors and include/exclude the transportation to the power plant (plant gate versus farm gate). The model was developed as a Microsoft® Excel® folder which only contains functions and links between cells (without macros). In this analysis we only focus on the cultivation phase of SRWC plantation with or without including transport to the farm/energy plant. The model exists of four data input sheets, two balance sheets with discounted and non-discounted cash flows and a sheet containing the most relevant graphs. Fig. 1 provides a simplified scheme of the model, including the model input and the output.

2.2. Model input

The model consists of four different data input sheets, of which one is dedicated to the input of general assumptions, such as the land area, land costs, assumed annual biomass increment in the first and subsequent rotations, discount rate, rotation length, number of rotations, plantation lifetime, overhead costs as a percentage of yearly costs, biomass sales price, and government incentives (subdivided in establishment grants and yearly incentives). In addition, a number of options regarding the application of fertilizers and weed control can be modified in this sheet. The other three sheets are dedicated to the input of data regarding the establishment, maintenance, and harvest and transport.

First, the establishment sheet uses input data regarding the site preparation, planting (including planting material) and herbicide application to calculate the establishment cost. For the calculation of the allocated costs of these agricultural operations, machinery costs, labour costs and costs of chemicals and planting material are required. The machinery costs are computed using the purchase price, salvage value, lifetime, fuel costs and transportation costs and are allocated to the agricultural operations based upon the operation rate of the machine for the operation involved. When the work is farmed out, however, data regarding the machinery and labour costs are not required and the user can simply fill in a value per hectare for the considered operation.

Second, three different weed management strategies are distinguished in the maintenance sheet: manual, mechanical and chemical weed control. The model allows the selection of one single or a combination of different weed management strategies, but does not allow the modification of the initial chosen strategy (and the associated costs) over the plantation lifetime. In addition, the maintenance sheet contains cells for the input of data regarding fertilizer application and stump removal at the end of the plantation lifetime.

Lastly, the harvest and the biomass transportation costs are calculated based upon data input in the harvest sheet. The model assumes no storage costs, as the biomass is sold as wet chips at the farm gate and stored at or close to the conversion facility, which implies that on-site storage is not required [12,18].

In accordance with the establishment, the user can either enter detailed data regarding the machinery, labour and material costs or decide to fill in a value per hectare if a contractor performs the maintenance and/or harvest of the SRWC plantation.

2.3. Model output

The model calculates three financial valuation metrics commonly used to calculate and assess the financial feasibility of long-term investments: the net present value (NPV), the equivalent annual value (EAV) and the levelized cost (LC). We did not calculate the internal rate of return, as this metrics can give a biased picture of the profitability of the plantation, certainly if establishment grants are taken into account [19].

2.3.1. Net present value (NPV)

As the costs and benefits of the production of SRWCs are spread over the lifetime of the plantation, it is necessary to discount these items to allow a relevant comparison with competing investment projects. Therefore, the NPV of the SRWC plantation is calculated which brings back the cash flows to a reference time on the basis of a reference discount rate, following Eq. 1.

$$NPV = \sum_{t=0}^{n} (1+r)^{-t} . A_t$$

with t = time (year) at which payment or revenues are made or received, n = lifetime of the plantation or the calculation period, r = discount rate (dimensionless), and A_t= size of the revenues or expenses at time t. A positive NPV means that the plantation is profitable taking into consideration the assumptions about the discount rate, the retail price of the biomass, the yield, and the plantation lifetime (see also Table 1).

2.3.2. Equivalent annual value (EAV)

Despite its undeniable interest from an investor’s point of view, the practical usefulness of the NPV from a farmer’s viewpoint is limited as it does not allow a straightforward comparison with traditional annual agricultural crops. As SRWCs are mostly planted on agricultural land and are therefore often in competition with agricultural crops, it is important to allow a relevant and accurate comparison on a yearly basis. Therefore, the model calculates the EAV, which combines the present value and the annuity method to convert all costs and benefits into constant annual amounts over the considered plantation lifetime, following Eq. 2.

$$EAV = \frac{r}{(1-(1+r)^{-n})}\sum_{t=0}^{n}(1+r)^{-t}.A_t$$

with r = discount rate, n = lifetime of the plantation or calculation period, t = time (year) at which payment or revenues are made or received, and A_t= size of the payment at time *t*. The first right hand fraction of the equation represents the inverse of the annuity factor, whereas the second part is the NPV.

2.3.3. Levelized cost (LC)

A third metric, which is generated by the model is the levelized cost which gives the unique break-even cost price for the woody biomass chips where discounted revenues are equal to discounted expenditures, following Eq. 3:

$$LC = \frac{\sum_{t=0}^{n}(1+r)^{-t}.C_t}{\sum_{t=0}^{n}(1+r)^{-t}.Y_t}$$

with LC = levelized cost in year *t*, C_t= expenses in year *t*; Y_t=biomass yield in year *t*. This metric is used to compare the cultivation cost of SRWCs with other energy crops/feedstock or other (renewable) energy carriers (if converted to a cost per energy unit).

2.4. Data collection

The estimates for SRWC costs and revenues used in this analysis are based on a mixture of observed costs gained from an operational 18.4 ha SRWC site (POPFULL) situated in Lochristi, Belgium (51°06'44" N, 3°51'02" E) and established in April 2010, supplemented with literature data for variables which could not (yet) be collected from the plantation. These included among others lifetime of the plantation, biomass yield in subsequent rotations, etc. For a more detailed description of the operational site and the different genotypes of poplar and willow planted on this site, we refer to Broeckx et al. [20]. Table 2 provides a general overview of the site characteristics.

3. Financial analysis

3.1. Scenario assumptions

This study calculated the average, budgeted costs of production, based on a full economic costs approach, including all variable and the allocated fixed costs, both from an investor's and a farmer's point of view. Therefore, a rental value for land which is owned by the farmer and a charge for the farmer's own labour were included. Moreover, we assumed the same land costs for the farmer and the investor, to eliminate land as a determining variable for the different profitability of the two base case scenarios. These scenarios are based on 2010 prices and a discount rate of 4% y^{-1}. As we are using nominal prices in our analysis, we adopted a nominal discount rate instead of a real discount rate. We calculated the discount rate by adding a risk premium of ± 1% y^{-1} to the nominal discount rate published by the European Commission for risk-free investments (3.07% y^{-1}) [21]. Furthermore, we assume that the overhead cost represent a fixed fraction of 3% of the overall yearly cost (including land rent), these overhead costs include administration costs as well as allocated costs of buildings and infrastructure.

In this study, we assumed the application of a post-emergent herbicide (glyphosate) prior to planting to kill existing vegetation. Next, the soil was (mole) ploughed, harrowed and a pre-emergent herbicide was applied. After soil tillage and the application of herbicides, 25 cm long dormant and unrooted stem cuttings were planted in a double-row planting scheme, which implies an alternating distance of 75 cm and 150 cm between the rows and a varying distance between trees within the rows depending on the desired planting density. This double-row spacing facilitates the use of existing agricultural machinery for any necessary management operation. Regarding the cultivation, we assumed no fertilization during the lifetime of the plantation, as previous research on a 16-year-old SRWC plantation showed no decline of productivity after 4 rotations without fertilization [22,23]. Most of the nutrients in a poplar SRWC plantation are in the leaves and these are annually being returned and recycled to the soil [24-26]. Moreover, we assumed weed control to take place only in the establishment phase. We are aware that these optimistic assumptions had an impact on the costs and have therefore also calculated the cultivation costs when weed management is required in subsequent rotations (see Section "Management options"). An overview of the cost categories included and the management scheme assumed in this analysis are shown in Table 3.

Table 1 provides an overview of the general assumptions which were equal for both scenarios. Unlike a number of studies [11,27] we did not assume that the production of SRWCs has moved beyond the 'pioneering' stage, as this is not the case in Belgium yet. As a consequence, Belgian farmers and investors interested in cultivating these energy crops are penalized by the unavailability of the appropriate machinery for planting and/or harvesting.

3.2. Scenario 1 - Mechanization by the farmer

In this scenario a farmer produces SRWCs for bioenergy among other crops using his own equipment for agricultural operations, such as (mole) ploughing, harrowing, planting, spraying and collection of the chips during harvest. The harvest is subcontracted, as the costs of purchasing and owning a SRWC harvester are too high to be justified. The farmer remunerates himself for the hours he works on the plantation using the average hourly labour cost of 35 € h^{-1} in Belgium for the cost analysis [28]. The actual hours of labour generally exceed the field machine time because of maintenance and travel time. Therefore, we calculated the labour costs by multiplying the number of hours that the machine is used to perform a certain agricultural operation by 1.1, as suggested by Edwards [29] and as applied in earlier studies assessing the economic performance of bioenergy crops [30].

For the analysis from the farmer's viewpoint, we also took into account the farm machinery costs allocated to the different agricultural operations based upon the operation rate, which we measured at the POPFULL plantation (Table 4). We assumed the use of modern agricultural machinery for the cultivation of poplar SRWCs. Although there are several differences in agricultural practices between the USA and Europe, we have used the recommendation of the American Agricultural Economics Association (AAEA) for the calculation of the maintenance costs of the agriculture equipment, as there were no reliable European data and recommendations available. We used the following formula for these calculations Eq. 4 [31]:

$$\mathrm{R} = \mathrm{RF}_1 * \mathrm{PP} * \left(\frac{\mathrm{h}}{1000}\right)^{\mathrm{RF}_2}$$

with R = accumulated repair and maintenance costs (€); $RF1$ = repair factor 1; $RF2$ = repair factor 2; PP = purchase price (€); h = accumulated machine use at the end of the lifetime (h).

For the calculation of the diesel consumption, however, we have not used the standardized methodology suggested by the AAEA, where the fuel use is calculated as a fixed fraction of the maximum power of the considered tractor. Alternatively, we have used the real fuel consumption rates (see Table 4), which differed depending on the operation performed, gained from the operational POPFULL plantation. Table 4 provides an overview of the costs of the agricultural machinery used for the cultivation of SRWCs.

3.3. Scenario 2 - Investor in SRWCs

In this scenario a company or an investor interested in cultivating energy crops to produce biomass chips rents land and appoints one or several contractors to carry out all the work at the plantation. This includes soil tillage, weed control, harvest and fertilizer application (if any). As a consequence, we did not estimate the operation cost of the machinery (as we did in the farmers scenario), but we based our analysis on prices provided by Belgian contractors that submitted a tender for a contract in the framework of the POPFULL plantation for which we invited tenders. Table 5 provides an overview of the range of rates that Belgian contractors charged for the different operations required for a SRWC plantation, showing considerable differences in charged rates among contractors.

4. Results and discussion

4.1. Base case scenario 1 - Mechanization by the farmer

Under the base case conditions the investment in the plantation was profitable for a farmer after 21 years (Fig. 2). This profit, however, was rather limited and amounted to 229 € ha^{-1} or 16.3 € ha^{-1} y^{-1}. The break-even dry matter price for biomass chips at the farm gate was 78.4 € Mg^{-1}. The harvesting costs made up 45% of the total discounted cultivation costs, while the general costs including land rent and overhead costs accounted for 37% of these costs. Establishment costs only contributed to the total costs for 16%, whereas maintenance costs barely made up 2% of the total discounted costs. This low share of the maintenance costs resulted logically from the assumption of little maintenance and no fertilization.

4.2. Base case scenario 2 - Investor in SRWCs

As opposed to the farmer's viewpoint, the cultivation of SRWCs was not profitable from an investor's viewpoint considering the base case assumptions. The NPV equalled -485€ ha^{-1} over the lifetime of 21 years and the EAV was -34.6 € ha^{-1} y^{-1}, while the required dry matter price for the woody biomass chips to reach a break-even amounted to 83.5 € Mg^{-1} (Fig. 2). The contributions of the harvesting (42%) and general costs (35%) to the total discounted costs were lower than in the farmer's scenario, while the shares of the establishment costs (20%) and the maintenance costs (3%) were slightly higher. This is due to the higher costs for agricultural operations if the establishment and maintenance are subcontracted as compared to the farmer's own mechanization and labour.

4.3. Scenario analyses

A number of assumptions were made to calculate the financial balance of SRWCs in Belgium. To assess the impact of the most uncertain assumptions on the profitability of these energy crops, we carried out a number of sensitivity and scenario analyses. The results of these analyses are summarized below.

4.3.1. Biomass yield

The biomass yield is a crucial parameter in the financial performance of the SRWC plantation. In the base case scenario we assumed a dry matter yield of 12 Mg ha^{-1} y^{-1}, which corresponds to the average values for poplar trees in a coppice culture under temperate European conditions, ranging from 10 Mg ha^{-1} y^{-1} to 15 Mg ha^{-1} y^{-1} [32-35]. Given the assumption that the SRWCs are planted on fertile agricultural land in Belgium (Stijn Overloop, Flemish Environment Agency; personal communication) and since breeding and selection programs to improve the yield and to decrease the susceptibility to rust and diseases are ongoing, there is a significant potential for yield improvements. Dry matter yields between 20 Mg ha^{-1} y^{-1} and 25 Mg ha^{-1} y^{-1} have been reported under optimal conditions [36,37]. These yield potentials are also backed by process-based models, accounting for the climatic conditions of Belgium, under the assumption that water and nutrients are not limiting and given that the SRWCs are established on soils with high agronomic potentials [38]. Biomass yields during the first rotation period, however, are significantly lower due to the plant's investment in root growth during early development [11,39]. For our calculations, we assumed a dry matter yield of 4 Mg ha^{-1} y^{-1}, which is the first rotation yield we measured on our POPFULL plantation.

The yield of SRWCs depends on both environmental variables (soil fertility, climate conditions, pathogen infections, etc.), and plantation management (weed control, fertilization scheme, etc.). Therefore, we performed a sensitivity analysis to assess the impact of a wide range of possible yield figures on the profitability of the plantation. We found that for both the farmer's and the investor's scenario, a dry matter yield of 11-13 Mg ha^{-1} y^{-1} is required to reach the break-even point (Fig. 3). An increase in the biomass yield by only 25% (from 12 Mg ha^{-1} y^{-1} to 15 Mg ha^{-1} y^{-1}) would trigger a more than fivefold increase in the NPV over the lifetime, while decreasing the LC by 22%. The major impact on the NPV is explained by the twofold impact of the yield on both the costs and benefits. All the agricultural operations were charged per hectare, as a result of which the increased yield decreased the costs per unit of biomass while increasing sales revenues. The only costs of agricultural operations which could possibly increase with increasing biomass yield are the harvest costs. However, in our base case scenario, this is not the case as the harvesting was put out to subcontractors who charged a cost per hectare (see Section 'Harvesting options'). As the LC only took into account the costs of the plantation, the yield impact on this metric was moderate.

4.3.2. Land costs

In Belgium farmers can lease land at reasonable rates for a minimum period of nine years, whereas non-farmers rent land at higher prices. The rental prices for farmers are limited by law and are calculated by multiplying the (non-indexed) cadastral income of the plot with a 'tenancy coefficient'. This coefficient is determined per agricultural region by the provincial rental price commission every three years [40]. There is, however, no correlation between the soil type and the rent, as the region and the scarcity of (agricultural) land are the major variables determining the rental price. Due to the more limited availability of suitable agricultural land in Flanders, land rent is higher in the Flemish (Northern) region as compared to the Walloon (Southern) region, averaging 273 € ha^{-1} y^{-1} and 202 € ha^{-1} y^{-1} respectively [41].

The land rent has a major impact on the profitability of the project. In our base case scenario we assumed a land cost of 250 € ha^{-1} y^{-1} which is approximately the average long-term rental price for agricultural land in Belgium. An increase in this land rent by only 15 € ha^{-1} y^{-1} would render the production of SRWCs unprofitable under the base case conditions for the farmer, whereas a decrease in the base case land rent by at least 31 € ha^{-1} y^{-1} is required to make the investment in SRWCs profitable from the investor's viewpoint (Fig. 4).

An investor, however, is not able to rent land at this low rate and is obliged to enter into a contract for a short-term rental, with much higher prices. Short-term rental prices for fertile agricultural land in Flanders start at 750 € ha^{-1} y^{-1} up to 1300 € ha^{-1} y^{-1}, which are roughly the annual revenues when the farmer decides to grow corn or wheat instead of renting his land [42,43]. With such high land costs, it is clear that the cultivation of SRWCs for energy purposes cannot be profitable without considerable government incentives and/or considerable increases in the biomass sales price in Belgium from an investor's point of view. Although this is a firm conclusion of our analysis for Belgium, it cannot be extrapolated to all European countries. Recent studies [11,44] have shown that in other countries such as Poland and Spain it is economically feasible to establish and manage SRWC plantations to produce bioenergy. Furthermore, Sweden has many district heating facilities that (partly) rely on biomass from willow SRWCs of which the Enköping combined heat and power plant is a world-famous model for a successful enterprise using SRWCs [45].

4.3.3. Discount rate

As can be seen from Fig. 5, the NPV varied inversely with the discount rate, showing a decreasing sensitivity of the NPV to the discount rate with increasing discount rates. The LC, however, was more or less linearly correlated with the discount rate and showed a lower sensitivity than the NPV. An increase in the discount rate by 1% y^{-1} increased the LC by 2.75% on average (Fig. 5). The discount rate reflects the risk an investor or a farmer attributes to the cultivation of SRWCs, and the minimum required return on investment given this risk. This risk assessment is subjective, making the estimation of the appropriate discount rate not straightforward.

4.3.4. Harvesting options

Three harvesting alternatives were considered in this study, which were demonstrated at our operational POPFULL site. These harvesting machines are different in terms of the economics, the form of the harvested biomass delivered and the impact of the machines on the soil:

1) A self-propelled combined harvest-chipping machine of New Holland was used which produces chips while harvesting, decreasing the number of operations needed to produce the desired energy carrier. The major disadvantages of this machine are its weight – 13.5 Mg – and the fact that the machine is operated on tires instead of on tracks. This is not a problem as such on dry or frozen soil. The latter, however, is very unlikely to happen in the normal harvesting period, under Belgian climatic conditions. On wet soil, however, this heavy equipment causes a major compaction of the soil and forms deep ruts in the field, with a pernicious influence on the resprouting of the poplar trees.
2) A pull-type combined harvest-chipping machine from the Danish company Ny Vraa, combined with a tractor on tracks and an attached trailer specially designed for the efficient collection and unloading of biomass chips was used to harvest the willows at the POPFULL site. The advantage of this machine is its relatively low weight, both the harvester and the trailer weigh approximately 2 Mg each, in combination with tracks on both the tractor and the trailer, protecting the soil against compaction and rutting. The harvester, however, is not able to harvest trees with a diameter of more than 6 cm, which

makes its usability in a poplar SRWC plantation rather limited (Henrik Bach, Ny Vraa Bioenergy I/S; personal communication).

3) A pull-type stem harvester from the Danish company Nordic Biomass, combined with a tractor on tracks was used to harvest the poplar trees at the POPFULL site. This harvester cuts the entire trees and puts the stems on the trailer with a built-in offloading system. Thanks to the tracks of both the tractor and the trailer, the impact on the soil is limited. One disadvantage of this harvesting system, however, is the necessary post-harvest chipping. When biomass chips are to be delivered, this requires additional processing of the stems to biomass chips and consequently additional costs.

An additional disadvantage of the two last mentioned Danish harvesters, as compared to the New Holland machine, is their unavailability in Belgium and its neighbouring countries. This means that the transportation costs for these Danish-based harvesters were much higher than for the New Holland harvester, which is available in Belgium (Table 6).

Although common sense suggests that the operation rate (measured in h ha^{-1}) of the harvesting machines is dependent on the biomass yield as a higher yield would necessitate additional and more frequent offloading, we assumed a constant operation rate for the different machines irrespective of the assumed yield. This simplified assumption is due to the lack of reliable data concerning the correlation between yield and operation rate of the harvesting systems. The only data on the relation between the performance of the SRWC harvesting machines and the biomass yield date from 1998 and are not applicable to the newly developed and contemporary harvesters discussed in this paper [46]. Furthermore, in our analysis the harvest was subcontracted based on a rate per ha justifying a constant harvesting cost per ha, both in the farmer's and investor's scenario. This assumption implies that the harvesting cost per unit of biomass is inversely correlated with the yield, which is in line with the earlier findings of the study of Mitchell et al. [46].

Table 6 provides an overview of the harvest costs for the different harvesters, while Fig. 6 depicts the NPV and the LC of the different harvesting options. The lower operation costs of the Danish companies outweighed the high transportation costs if an area of 18 ha was considered (Fig. 6). A site of at least 10 ha is required to balance the harvesting costs of the Ny Vraa harvester with the New Holland harvester. If the land area is smaller than 10 ha, however, the Danish Ny Vraa harvester becomes more expensive than the Belgian based harvester. The Nordic Biomass stem harvester seemed the most favourable harvesting option (Fig. 6), but could not be compared straightforwardly with the other harvesters, as post-harvest chipping operations were required to deliver the same final product (i.e. woody biomass chips). The costs of this chipping operation were 552 € ha^{-1} per harvest assuming a dry matter yield of 12 Mg ha^{-1} y^{-1} and a 50% moisture content (m.c.). If we add up this value to the harvesting costs of the stem harvester (Table 6), this yields 952 € ha^{-1}, which is slightly higher than the costs of Belgian based cut-and-chipper, making the stem harvester the least interesting harvesting option taking into account the higher transportation costs for this machine.

4.3.5. Transportation costs

To analyse the impact of the transportation of biomass chips on the profitability of SRWCs, we also performed a cradle to plant gate assessment, where the transportation to the power plant is included. In this scenario, we assumed that both the farmer and investor outsource the transportation to the power plant, as a truck and trailer are excessively expensive to be owned and used by a single farmer. Table 7 summarizes the assumptions and the input data for the calculation of the transportation costs of the woody biomass chips. We assume an hourly cost of 55 € h^{-1} for the transportation of the woody chips including diesel consumption and labour, in line with our experience at the POPFULL plantation and also in line with a study of NEA reporting costs of 55.66 € h^{-1} for the transportation of bulk goods [47]. Furthermore, we assume that the truck returns to the farm unloaded, incurring an extra hourly cost for the return trip. Based on the assumption in Table 7, we calculated that the transportation to the power plant increased the levelized cost by 15.1 € odt^{-1}, from both the investor's and the farmer's point of view. This reflects an increase in the levelized costs by 18-19% as compared to the cradle to farm gate assessments depicted in the base case scenario. If a cradle to plant gate assessment was considered, harvest and transportation costs made up almost 51% of the total discounted costs investor's scenario and more than 54% in the farmer's scenario.

4.3.6. Management activities

As there is still a lot of discussion with regard to the optimal management of a SRWC plantation [48,49], the POPFINUA model allows the adjustment of several management parameters, i.e. rotation length, number of rotations, plantation lifetime, application of fertilizers at the establishment and/or after each harvest, number and method of herbicide treatment. For the sake of simplification, we assumed that a given operation is carried out in the same way and with the same equipment throughout the entire lifetime of the plantation. In the base case scenario, we assumed that no management (i.e. weed control or fertilization) was necessary except for initial weed control at the establishment. Obviously this is the best-case scenario, as in reality weeding and/or fertilizing after coppicing (on nutrient-poor soils) are often required to guarantee a satisfying productivity of the SRWC plantation [7]. Since SRWCs in general and poplars in particular are light-demanding crops, weed management in a SRWC plantation is especially crucial during the establishment period, and –in a lesser extent– after every harvest [7,50]. On the POPFULL plantation, intensive weed control –mechanical, chemical, and manual– was applied during the first two year after planting to decrease competition for light and nutrients. A more detailed overview of all the weed treatments that have taken place in the first two years after the establishment of the plantation was provided earlier by Broeckx et al. [20].

If we only assumed the necessity of additional mechanical weed control after each harvest, the levelized cost would increase by more than 2 € Mg^{-1} to 80.6 € Mg^{-1} in the farmer's scenario and the NPV would become negative, switching the investment from profitable to loss-making under the base case conditions. This analysis clearly demonstrates the financial risk involved in the cultivation of SRWCs for bioenergy, as the application of an additional mechanical weed treatment after each harvest would render the plantation loss-making under the base case conditions.

4.3.7. Establishment grants and annual incentives

As expected, the NPV was linearly correlated with the level of establishment grant and the level of annual incentives, but with a different sensitivity level. The NPV was 15.6 times more sensitive to an increase in the establishment grants as compared to a nominally equal increase in annual incentives, considering a plantation lifetime of 21 years. This is due to the fact that an establishment grant is only granted once, at the establishment of the plantation, whereas an annual incentive was defined as an annual subsidy per land area. An establishment grant of at least 500 € ha^{-1} or an annual area subsidy of at least 32 € ha^{-1} y^{-1} was required to render the investor's scenario profitable under the base case assumptions (Figs. 7-8). Although subsidies have a major impact on the profitability of a SRWC plantation and consequently on the adoption of these energy crops by farmers (and investors), they are only justified if the life-cycle environmental performance of SRWCs for bioenergy is better than the alternatives [5,51]. As a consequence, an accurate quantification of the ecological benefits of SRWCs as compared to fossil fuels is required to work out a clear incentive program.

4.3.8. Biomass price

A farm gate price for the harvested biomass chips (50% m.c.) of at least 39.2 € Mg^{-1} and 41.7 € Mg^{-1} for the farmer and the investor respectively, was required to reach the break-even point using the base case scenario inputs (Fig. 9). An increase in the biomass price by only 1 € Mg^{-1} would increase the NPV by 280 € ha^{-1} and the EAV by 20 € ha^{-1} y^{-1} (Fig. 9). This illustrates that both the NPV and the EAV were highly sensitive to changing biomass prices. Throughout the POPFULL project, in which we have established an operational SRWC plantation, we have discovered that there is no stable national market for biomass (chips) in Belgium yet. As a consequence, wet biomass prices offered by local individual buyers fluctuated between 20 € Mg^{-1} and 30 € Mg^{-1} turning the cultivation of SRWCs into a loss-making investment (Kristof Mouton, Wood Energy bvba; personal communication). This shows that it is essential to establish a long-term stable market for biomass (chips), as a well-functioning and sufficiently valuable market is a pre-requisite for a widespread deployment of SRWCs for bioenergy [9,52,53].

5. Conclusions

This study described the influence of a number of key variables on the profitability of SRWCs in Belgium, making use of a newly developed model POPFINUA, and highlighted a number of barriers to the widespread adoption of SRWCs by Belgian farmers. In order to convince farmers to establish SRWC plantations, several conditions should be fulfilled. First of all, SRWCs should be at least as profitable (with or without government incentives) as traditional agricultural crops, such as corn [18]. Secondly, there should be a well-performing market for the produced woody biomass chips [52,53]. Thirdly, the farmer should be confident that the equipment to plant, cultivate (e.g. specially designed line cultivators for energy crops) and harvest the energy crops is available within a reasonable distance. This study shows that none of these conditions are met in Belgium at present. The cultivation of SRWCs is only financially feasible if a number of strict conditions regarding the biomass yield, biomass sales price and management activities are met and only when a farmer uses his own agricultural machines to plant and maintain the plantation. Moreover, this profit is very limited as the NPV equals 232 € ha^{-1} over the entire lifetime of 21 years for the farmer's best-case scenario, whereas a farmer can earn up to 1300 € ha^{-1} y^{-1} by planting an annual crop, such as corn. Our calculations showed that the farmer faces a very high financial risk if the crop is infested with diseases or insects or becomes overgrown with weeds, as this would require additional herbicide and/or pesticide applications switching the SRWC culture from profitable to loss-making. The inclusion of transportation by truck over a distance of 50 km increased the LC by 18-19% increasing the share of harvest and transportation costs in the total discounted costs by 9% from 45% to 54% (farmer's viewpoint) and from 42% to 51% (investor's viewpoint). Establishment grants could decrease the (initial) investment risk associated with the cultivation of SRWCs, but are only advisable if steps are taken to establish a market for the produced woody biomass chips and if the environmental benefits of SRWCs as compared to alternatives justify these subsidies. By inciting power plants to enter into long-term contracts with SRWC farmers for the delivery of woody biomass chips, the establishment of a market for biomass chips can be accelerated, as suggested by Helby et al. [52]. With regard to the life-cycle environmental impact of SRWCs, however, a thorough analysis is required as a recent study of

Njakou Djomo et al. [5] has shown that there is still a lot of uncertainty regarding the environmental costs and benefits of SRWCs. This study revealed a wide variation in the GHG emission of SRWCs found in literature, reporting values from 9 to 161 times lower than the GHG emissions of coal. To reduce this variability in numerical results, the authors emphasize the need for a standardized and widely accepted framework for a reliable assessment of the environmental impact of SRWCs.

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Table captions

Table 1 Summary of the general and the base case scenario assumptions of the POPFINUA model simulations of this study

Table 2 Site characteristics and climate conditions of the operational short rotation woody crop plantation in Lochristi, BE, this plantation provides input data for the POPFINUA model

Table 3 Overview of cost items for the cultivation of short rotation woody crops for bioenergy during an assumed lifetime of 21 years with 3-year rotations [7,12,54]

Table 4 Overview of the costs and characteristics of agricultural equipment used for the cultivation of short rotation woody crops [30,31,55] (Kristof Mouton, Groep Mouton bvba; personal communication); (Marc Verhoest, Verhoest Marc bvba; personal communication)

Table 5 Overview of the costs for different agricultural operations for the cultivation of short rotation woody crops carried out by a Belgian contractor

Table 6 Summary of the costs and working capacity of three different harvesting options applied on the POPFULL site

Table 7 Summary of input data for the calculation of the transportation costs of woody biomass chips with a truck over a distance of 50 km [47,56]

Figure captions

Fig. 1 Schematic flow-chart of the POPFINUA model for the simulation/calculation of the financial balance of a short rotation woody crop plantation for bioenergy, the dotted lines with an arrow show which cost factors are required to calculate the full economic cost of the various agricultural operations

Fig. 2 Simulated discounted yearly cash flows and accumulated discounted cash flow for farmer's (top panel) and investor's (bottom panel) base scenarios for a short rotation woody crop plantation with a three-year rotation and a total lifetime of 21 years

Fig. 3 Results of the sensitivity analysis showing the impact of biomass yield on the net present value (NPV) and the levelized cost (LC) per oven-dried ton (odt) of a short rotation coppice culture from the POPFINUA model runs, the two viewpoints, farmer (top panel) and investor (bottom panel) are shown

Fig. 4 Results of the sensitivity analysis showing the impact of land costs on the net present value (NPV) and the levelized cost (LC) per oven-dried ton (odt) of a short rotation coppice culture from the POPFINUA model runs, the two viewpoints, farmer (top panel) and investor (bottom panel) are shown

Fig. 5 Results of the sensitivity analysis showing the impact of the discount rate on the net present value (NPV) and the levelized cost (LC) of a short rotation coppice culture from the POPFINUA model runs, the two viewpoints, farmer (top panel) and investor (bottom panel) are shown

Fig. 6 Results of the simulation runs of the POPFINUA model with different harvesting options, the diagram illustrates the impact of the harvesting strategy on the net present value (NPV) and the levelized cost (LC) per oven-dried ton (odt) from a farmer's viewpoint, the three studied harvesters include one self-propelled cut-and-chipper (New Holland), one tractor-pulled cut-and-chipper (Ny Vraa) and one tractor-pulled whole-stem harvester (Nordic biomass)

Fig. 7 Results of the sensitivity analysis showing the impact of the establishment grant on the net present value (NPV) and the levelized cost (LC) per oven-dried ton (odt) of a short rotation coppice culture from the POPFINUA model runs, the two viewpoints, farmer (top panel) and investor (bottom panel) are shown

Fig. 8 Results of the sensitivity analysis showing the impact of the annual incentives on the net present value (NPV) and the levelized cost (LC) per oven-dried ton (odt) of a short rotation coppice culture from the POPFINUA model runs, the two viewpoints, farmer (top panel) and investor (bottom panel) are shown

Fig. 9 Results of the sensitivity analysis showing the impact of the biomass price on the net present value (NPV) of a short rotation coppice culture from the POPFINUA model runs, the two viewpoints (farmer and investor) are shown

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Table 1

General assumptions	Unit	Value
Land area	ha	18
Percentage of headland	%	20
Planted area	ha	14.5
Assumed biomass increment - 1st harvest (dry matter)	Mg ha^{-1} y^{-1}	4
Assumed biomass increment (dry matter)	Mg ha^{-1} y^{-1}	12
Land rental, lease or opportunity costs	€ ha^{-1} y^{-1}	250
Discount rate	% y^{-1}	4
Rotation length	y	3
Number of rotations		7
Plantation lifetime	y	21
Fuel price	€ l^{-1}	0.9
Biomass sales price at 50% m.c. (farm gate)	€ Mg^{-1}	40

m.c. = moisture content

Table 2

Site characteristics		
	Latitude	51°06’44” N
	Longitude	3°51’02” E
	Elevation (above sea level)	6.25 m
	Topography	Flat
	Vegetation	*Populus* Spp. & *Salix* Spp.
	Soil type	Sandy with poor natural drainage
Climate conditions	Average annual temp.	9.5°C
	Average annual precipitation	726 mm

Table 3

Cost item/ plantation year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Post-emergent herbicide	Y																					
Soil preparation	Y																					
Pre-emergent herbicide	Y																					
Planting	Y																					
Weed control		Y		(Y)			(Y)			(Y)			(Y)			(Y)			(Y)			(Y)
Harvest				Y			Y			Y			Y			Y			Y			Y
Fertilization	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Stump removal																						Y
Land rent	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
General and overhead costs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Y: included in the base case scenario; (Y): included in the scenario analysis; n.a.: not assessed

Table 4

Machine	Purchase price (k€)	Use (h y^{-1})	Lifetime (y)	RF1	RF2	Maintenance costs (€ h^{-1})	Lubricant use (€ h^{-1})	Salvage value (k€)	Fuel use (l h^{-1})	Operation rate (h ha^{-1})	Combined tractor
Tractor - 160 HP	135	800	12	0.007	2.0	9.1	0.307	36.45	n/a	n/a	
Tractor - 360 HP	200	800	12	0.007	2.0	13.4	0.603	54.0	n/a	n/a	
Subsoiler	7.5	125	20	0.28	1.4	3.0	n/a	1.95	19.0	1.0	160 HP
Plough	12	75	20	0.29	1.8	4.8	n/a	3.12	16.7	0.3	160 HP
Harrow	9.5	100	20	0.27	1.4	3.4	n/a	1.52	18.3	0.2	160 HP
Line cultivator	25	100	10	0.23	1.4	5.8	n/a	7.50	16.0	1.0	160 HP
Leek planting machine	12	150	10	0.32	2.1	6.0	n/a	4.80	6.1	0.9	160 HP
Rotary cultivator	66	150	10	0.36	2.0	35.6	n/a	19.8	25.0	2.0	360 HP
Spraying equipment	20	200	10	0.41	1.3	10.1	n/a	16.0	16.7	0.3	160 HP
Fertilizing equipment	8	100	10	0.63	1.3	5.0	n/a	3.2	17.0	n.a	160 HP
Trailer - 40m³	44	800	10	0.19	1.3	15.6	n/a	11.4	20.0	n/a	160 HP

HP: horse power; RF1: Repair factor 1; RF2: Repair factor 2; n/a: not applicable; n.a.: not assessed

Table 5

Operation	Price range (€ ha^{-1})
Post-emergent herbicide	140-220
Pre-emergent herbicide	260-280
Mole ploughing	120-180
Ploughing	120-250
Harrowing	110-240
Planting	500-1000
Mechanical weeding	120-300
Fertilizing (300 kg N ha^{-1})	200-250
Stump removal	550-1700

Table 6

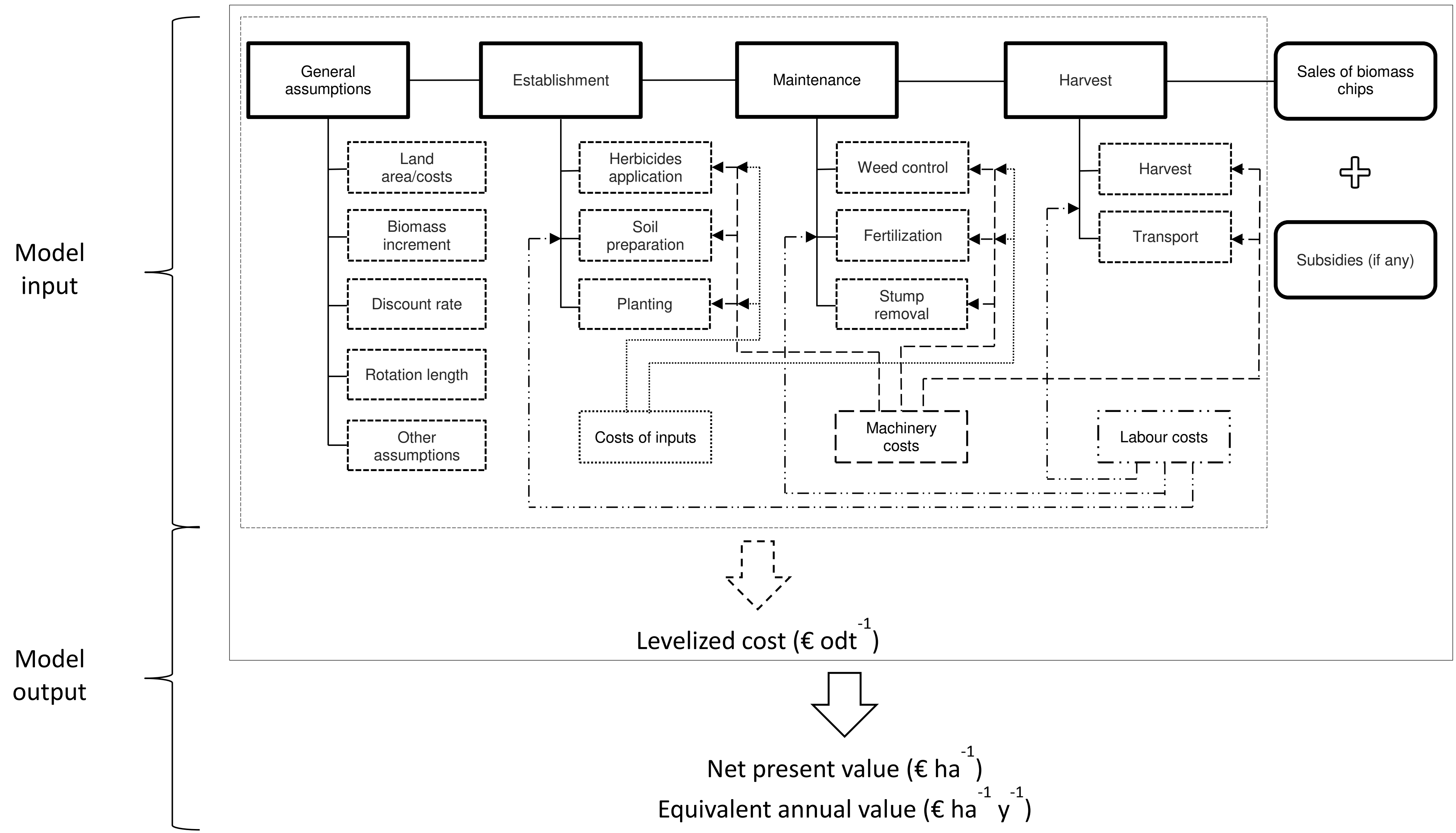
Harvester	Operation rate (h ha^{-1})	Operation costs (€ ha^{-1})	Transportation costs (€)	Costs * (€ odt^{-1})
Self-propelled cut-and-chipper	1.3	950	400	30.9
Tractor pulled cut-and-chipper	1.7	600	3950	23.6
Tractor pulled stem harvester	2.0	400	3950	18.0

* The costs per oven-dried ton include the harvest operation costs and the harvester's transportation costs and consider the base case scenario, based upon a planted area of 14.5 ha, a dry matter biomass yield of 12 Mg ha^{-1} y^{-1}, and a rotation length of three years.

Table 7

	Unit	Value
Average speed	km h^{-1}	48
Hourly cost	€ h^{-1}	55
Distance	km	50
Woody chips density	kg m^{-3}	0.38
Woody chips moisture content	%	50
Maximum load capacity	Mg	27
Maximum load volume	m^3	80
Loading time	h	0.25
Unloading time	h	0.16

Fig 1

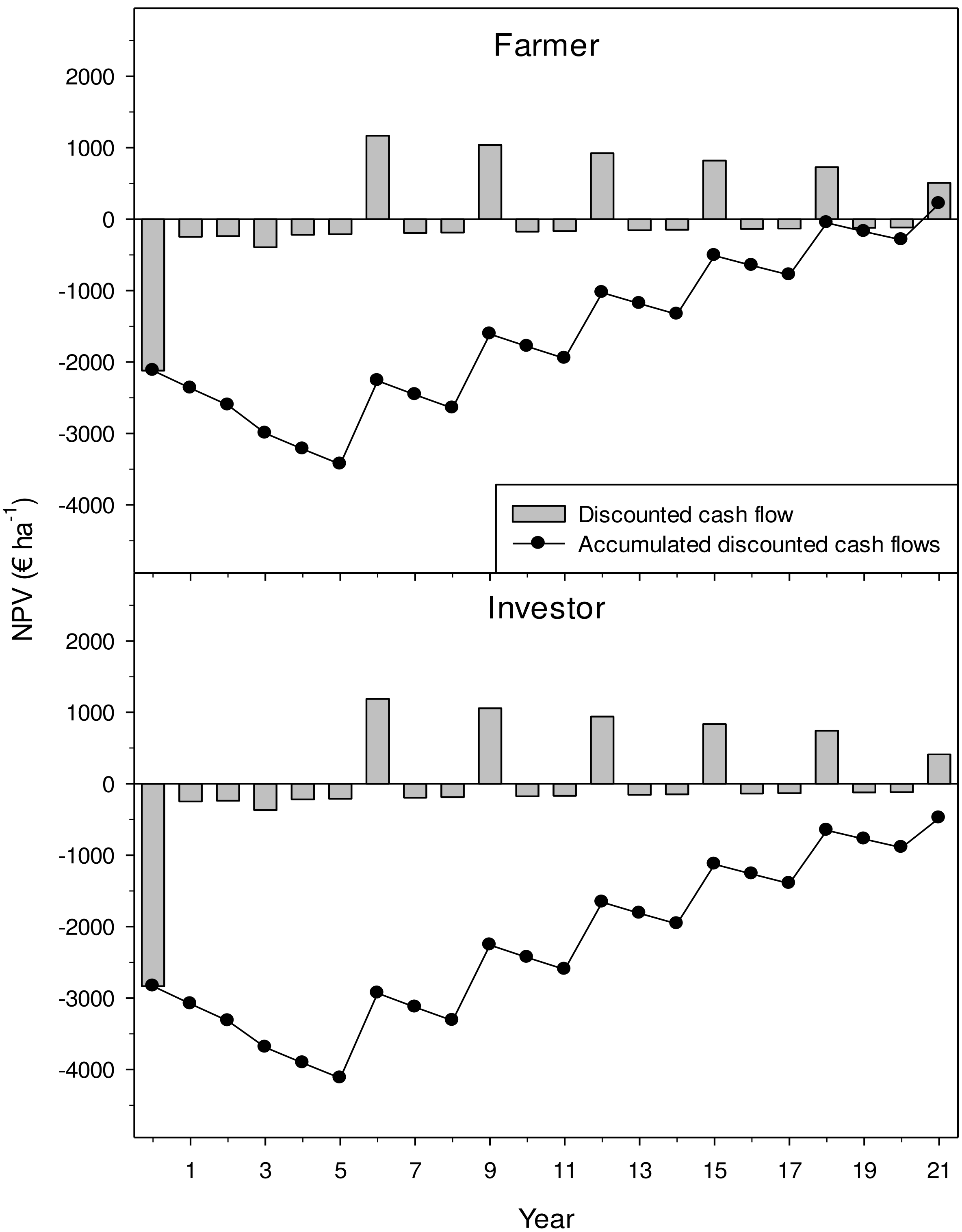


= data input sheets

= general assumptions or cost categories in the data input sheets necessary to calculate the levelized cost (odt = oven-dried ton)

= revenues from biomass sales or subsidies necessary to calculate the net present value and equivalent annual value

Fig 2



Farmer
Investor
Discounted cash flow
Accumulated discounted cash flows
NPV (€ ha^{-1})
Year
2000
1000
0
-1000
-2000
-3000
-4000
1
3
5
7
9
11
13
15
17
19
21

Fig 3

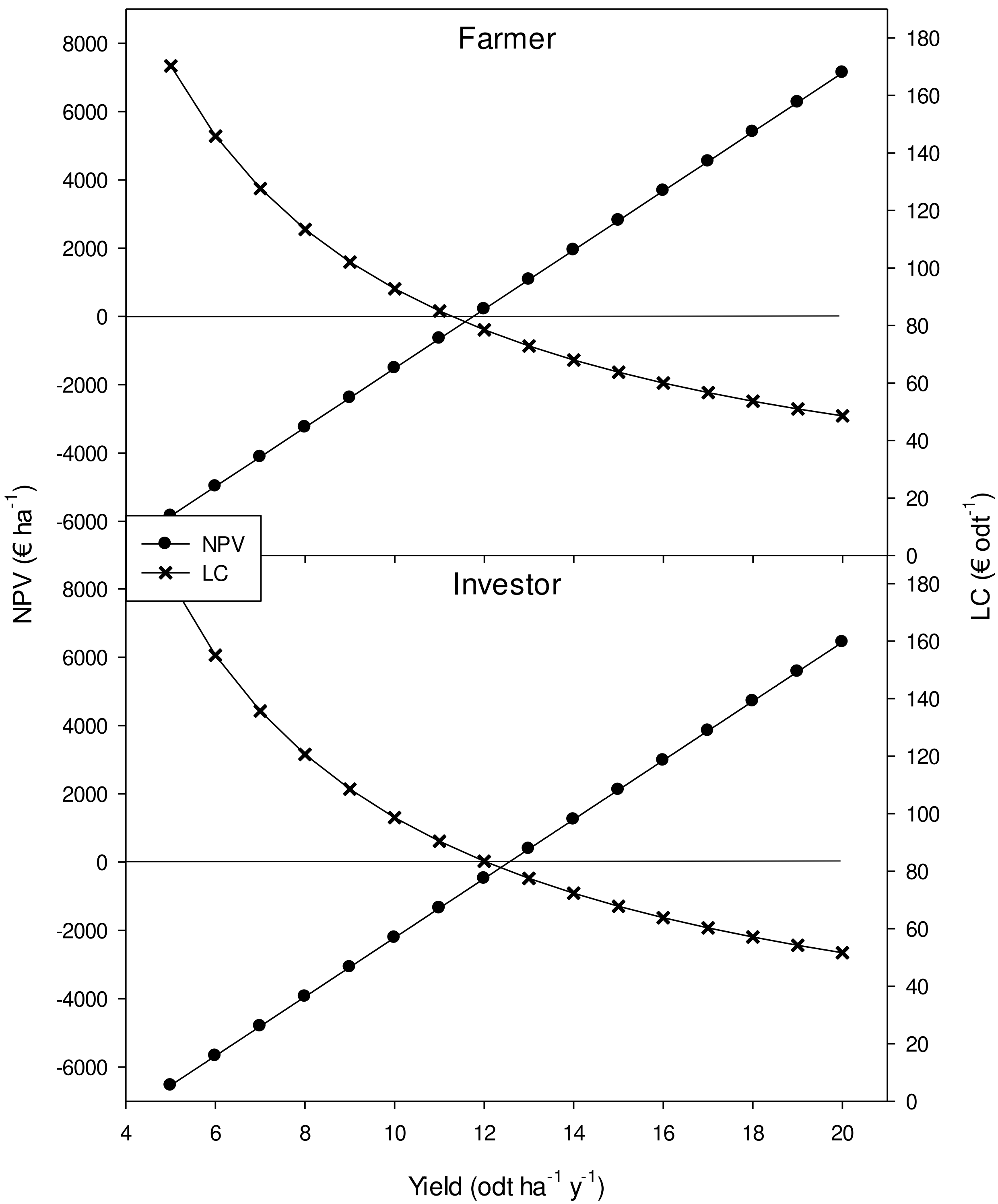
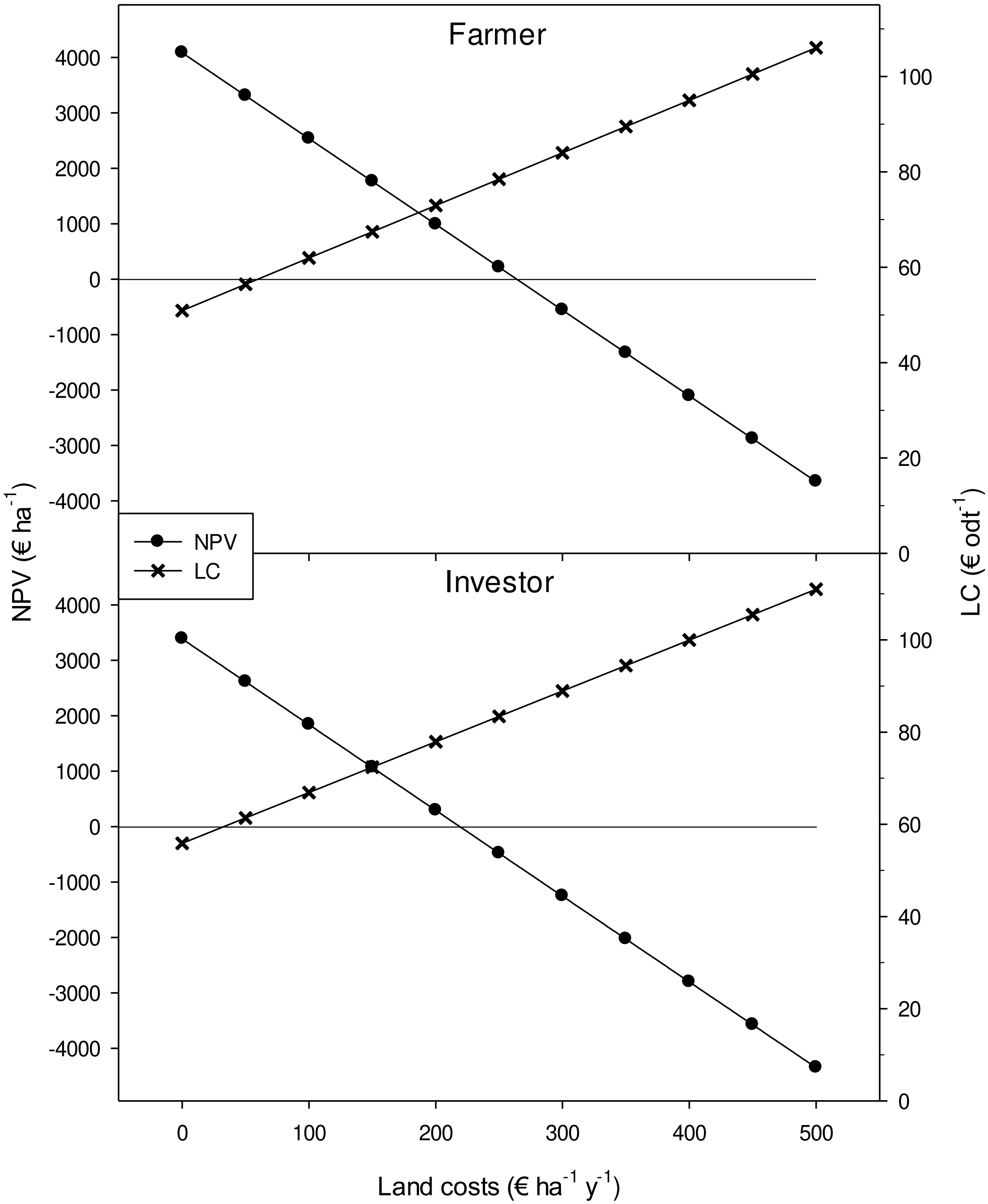
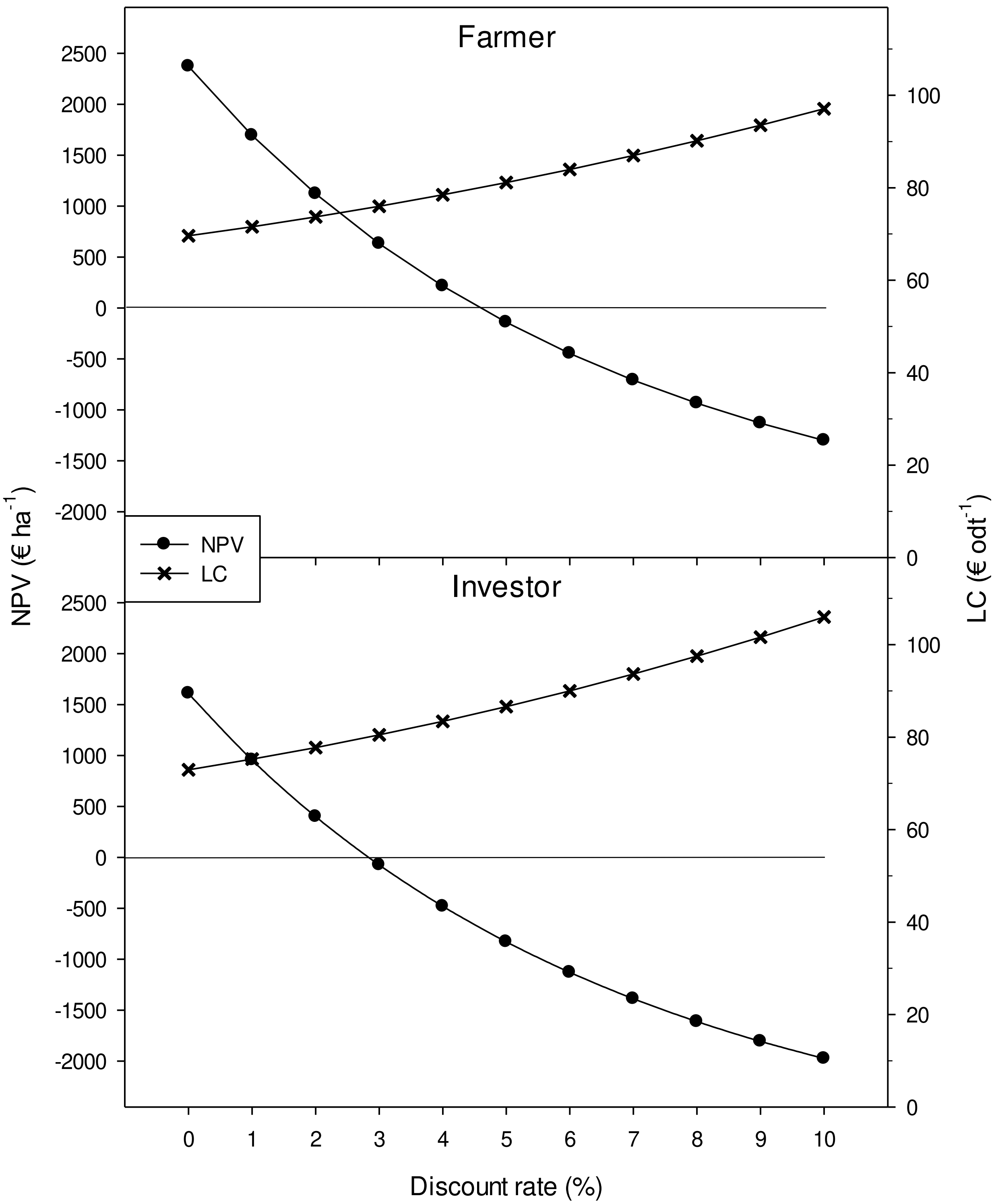

Farmer
Investor
NPV
LC
NPV (€ ha-1)
LC (€ odt-1)
Yield (odt ha-1 y-1)
8000
6000
4000
2000
0
-2000
-4000
-6000
180
160
140
120
100
80
60
40
20
0
4
6
8
10
12
14
16
18
20

Fig 4



Farmer
Investor
NPV
LC
NPV (€ ha⁻¹)
LC (€ odt⁻¹)
Land costs (€ ha⁻¹ y⁻¹)
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
100
80
60
40
20
0
0
100
200
300
400
500

Fig 5



Farmer
Investor
NPV (€ ha^{-1})
LC (€ odt^{-1})
NPV
LC
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
Discount rate (%)

Fig 6

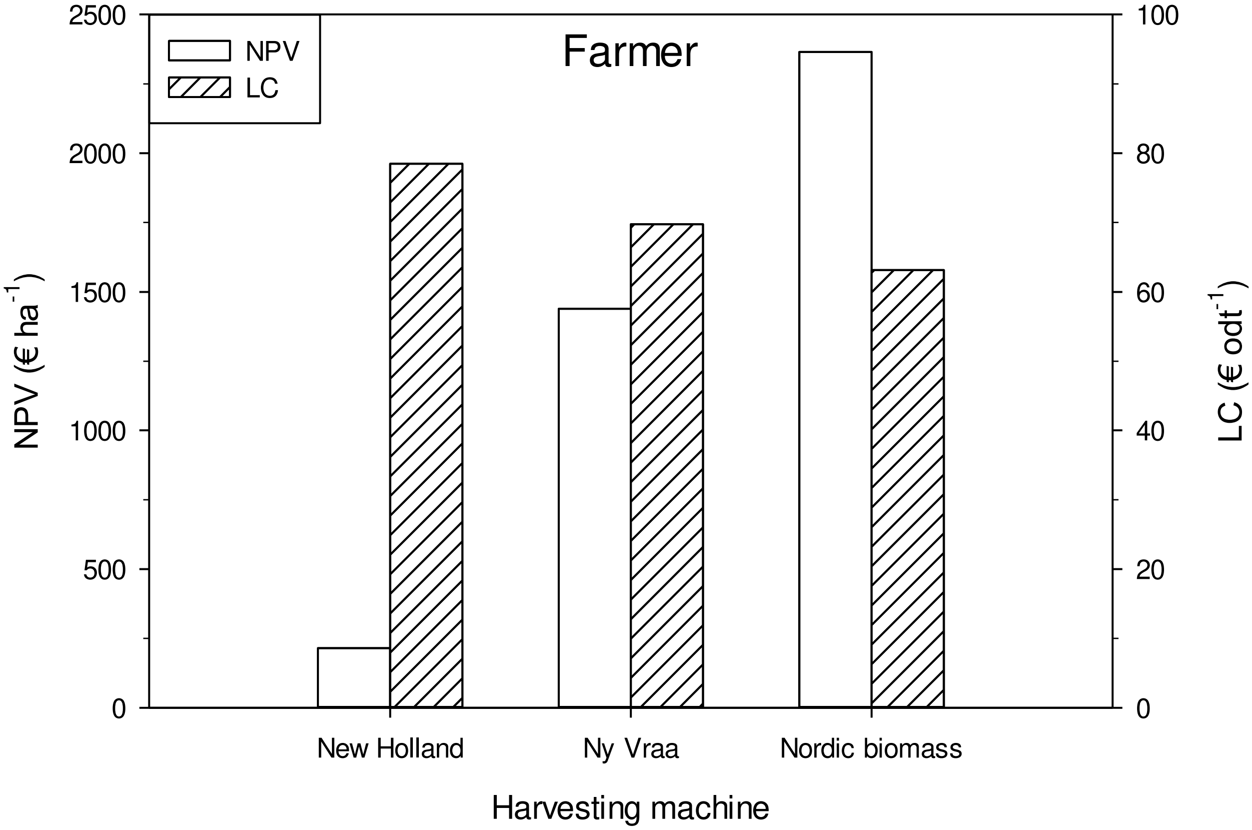
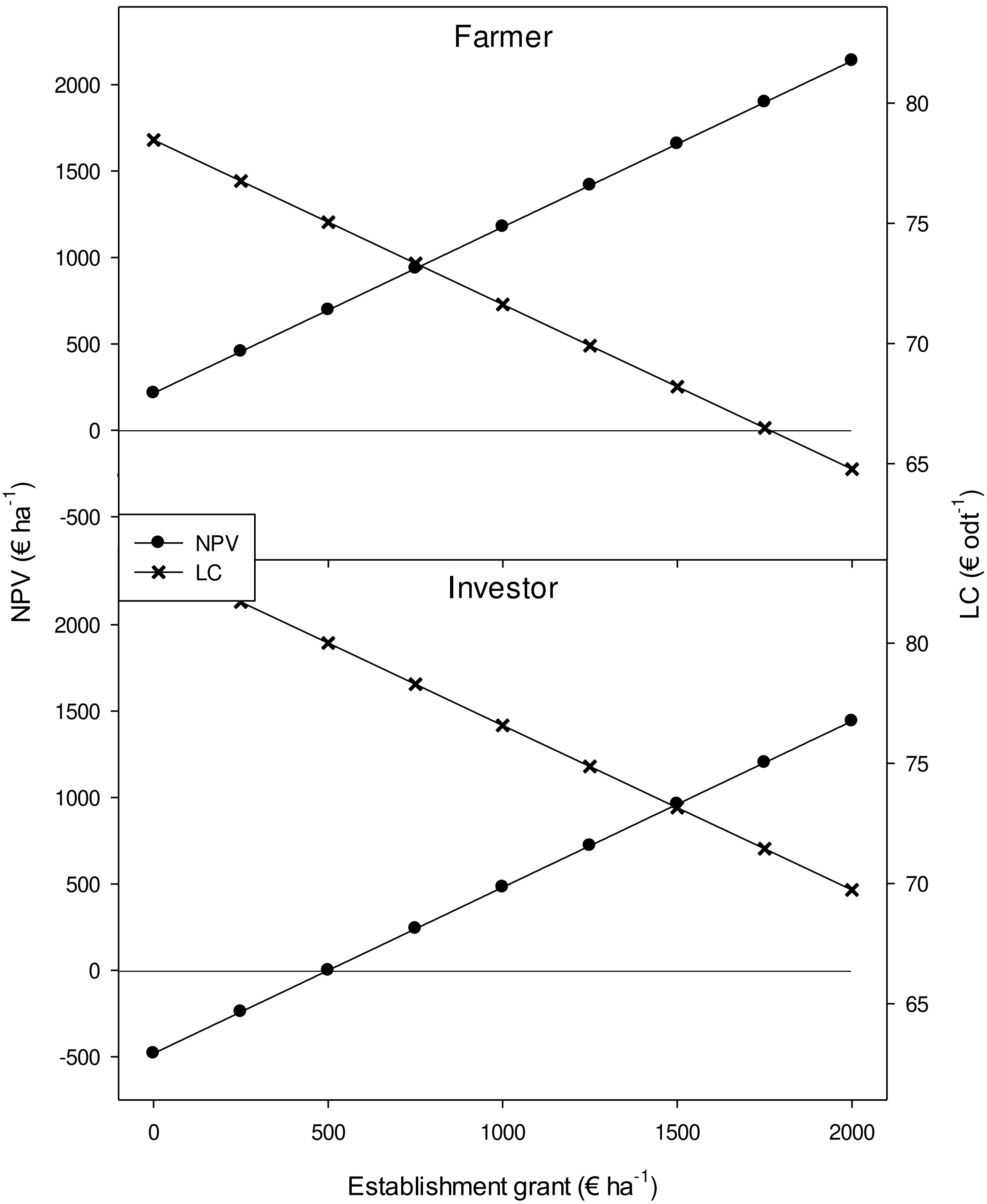
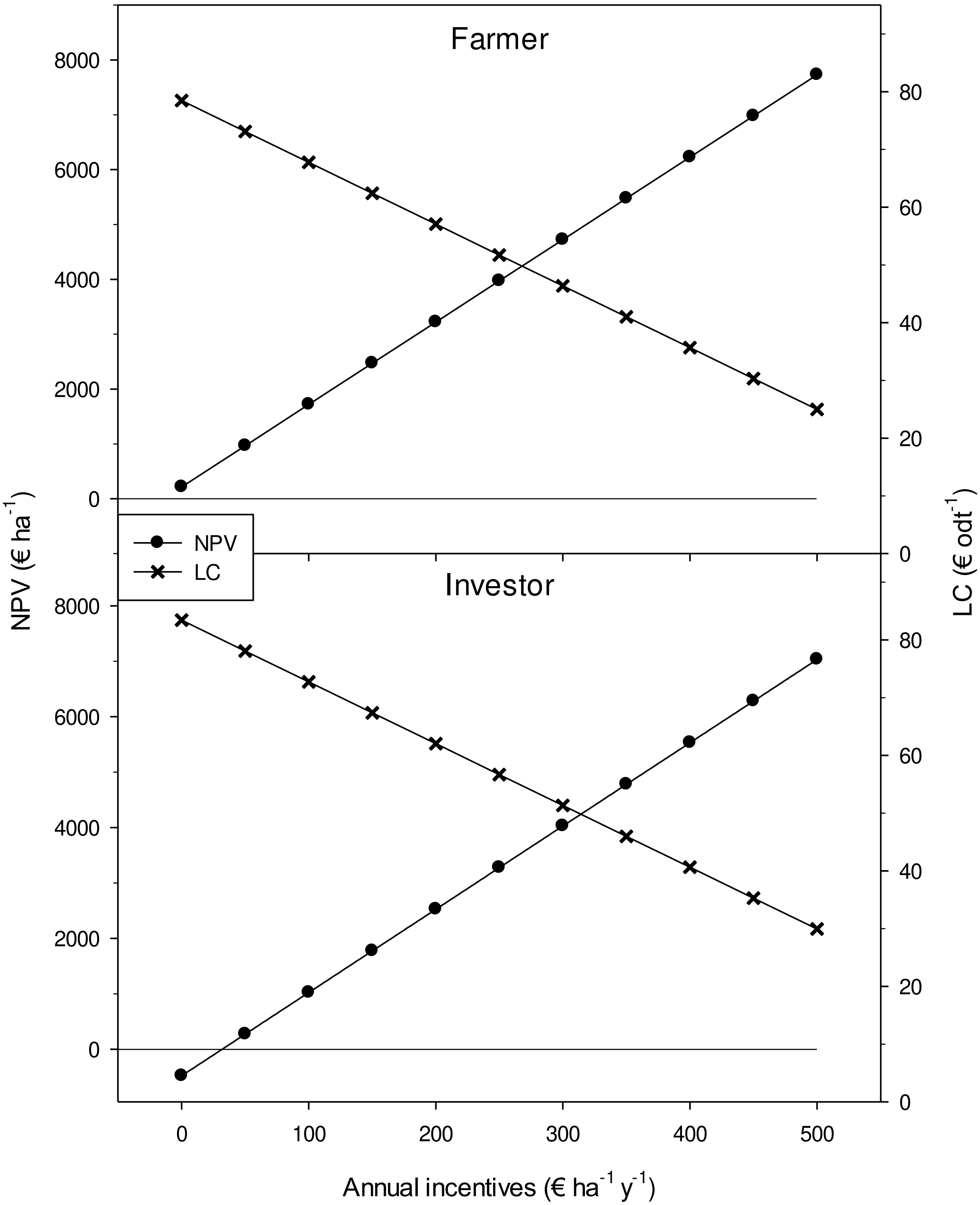

Farmer
NPV
LC
2500
2000
1500
1000
500
0
100
80
60
40
20
0
NPV (€ ha-1)
LC (€ odt-1)
New Holland
Ny Vraa
Nordic biomass
Harvesting machine

Fig 7



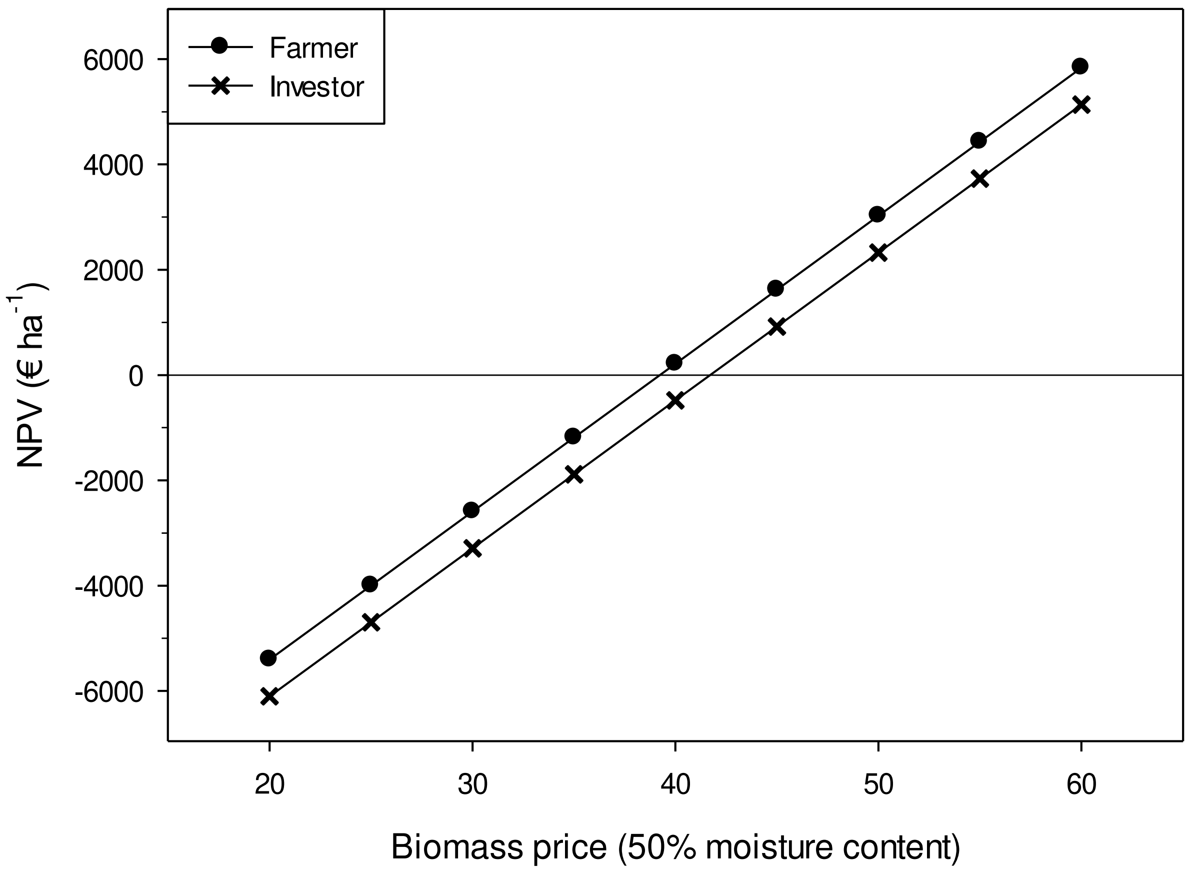
Farmer
Investor
NPV
LC
NPV (€ ha^{-1})
LC (€ odt^{-1})
Establishment grant (€ ha^{-1})
2000
1500
1000
500
0
-500
80
75
70
65
0
500
1000
1500
2000

Fig 8



Farmer
Investor
NPV
LC
NPV (€ ha^{-1})
LC (€ odt^{-1})
Annual incentives (€ ha^{-1} y^{-1})
8000
6000
4000
2000
0
80
60
40
20
0
100
200
300
400
500

Fig 9



Farmer
Investor
6000
4000
2000
0
-2000
-4000
-6000
NPV (€ ha^{-1})
20
30
40
50
60
Biomass price (50% moisture content)