Effect of greenhouse gas emissions trading on investment decisions for biomass-to-energy production

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Abstract

Despite the significant boost that some renewable energy sources have undergone lately, partly promoted by the favourable EU legislation, biomass seems to face difficulties in realising its expected share in energy production. Some major reasons for this are the complexity of a bioenergy system and its related fuel supply chain, the wide variety of available technologies and most importantly the low and uncertain financial yield of bioenergy projects. This paper utilizes an innovative generic methodology for performing investment analysis in parallel with optimization of the location and the key characteristics of the biomass-to-energy project. This methodology may serve as a decision support tool for potential investors and may assist in promoting relevant investment decisions. The model developed focuses on the holistic optimization of the design and operational characteristics of a biomass energy conversion facility, including the discrete phases of biomass logistics, energy conversion and final energy products supply. The innovative ideas of using multiple biomass sources as well as employing tri-generation for district energy applications aim at proposing a more cost-effective system layout for biomass energy exploitation. In addition to these ideas, the recent issue of emissions trading and its potential impact on a bioenergy project is investigated in this paper. The analysis performed concludes that emissions trading is of extremely high importance for biomass-to-energy projects, as it may prove to be a major revenue stream.
Keywords: emissions trading, optimization, investment analysis, biomass, biomass supply chain, tri-generation, multi-biomass.

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1 Introduction

Substitution of conventional energy sources with renewable energy presents multifold advantages and is a key priority for the EU. However, renewable energy development is not progressing in the desired pace. Despite the fact that some renewable energy sources, like wind power, have undergone a significant boost lately, others, like biomass, seem to face difficulties in realising their expected share in energy production. One of the major reasons responsible for this is the difficulty in assessing and optimizing an investment decision on biomass energy production. The complexity of a bioenergy system and its related fuel supply chain, the wide variety of available technologies and most importantly the low and uncertain financial yield of bioenergy projects enhance this inherent difficulty.

Concerning the limited financial yield of biomass-to-energy exploitation projects, the main reason identified in the literature has been the narrow operational window of the fuel supply chain, due to the seasonal availability of biomass [1]. Few attempts have been made to investigate the advantages of using multiple biomass sources, such as the one of Nilsson and Hansson [2], reporting a total cost reduction between 15-20% by using two biomass sources. In a similar vein, Rentizelas et al. [3] conclude to a 4-12% cost reduction for a specific case study, depending on the price of the alternative biomass sources. The idea of multiple biomass sources utilization is also present in the work of Papadopoulos and Katsigiannis [4], Voivontas et al. [5] and Freppaz et al. [6], without quantifying the cost reduction that the application of this idea may realize.

The concept of tri-generation, i.e. the simultaneous production of three energy products –electricity, heat and cooling- may be the solution for promoting district energy in relatively warm regions, like Greece and other south-European countries. Medium-to-small scale district heating has been inevitably characterized as an inefficient solution for these countries up to now, as the short heating period did not allow sufficient spreading of the high capital costs. Combining district heating with district cooling may lead to significant improvement of the financial attractiveness of such projects, as the operational time may be more than doubled. District cooling has become a viable option only lately, due to recent technological advances and simultaneous cost reduction of absorption chilling technology. The tri-generation concept has not been evaluated in the biomass-to-energy literature. Therefore, it has been a challenge to include this option in the case study presented in this paper.

A recent development in renewable energy sources is the Kyoto protocol. According to this protocol, all the developed countries that participate and are registered as Anex 1 parties have committed to reduce their greenhouse gas (GHG) emissions to a certain target level. There exist three mechanisms that allow countries or industries to meet this target level, in case their actual emissions exceed it. These are Joint Implementation (JI), Clean Development Mechanism (CDM) and Emissions Trading (ET).

The JI mechanism concerns transfer of emission allowances from one Anex 1 country to another. An entity performing an investment at any Anex 1 country that leads to GHG emissions reduction, including renewable energy projects, may be credited this reduction, which is expressed in Emissions Reduction Units (ERU's), starting from year 2008.

The CDM mechanism allows private entities or governments of Anex 1 countries to invest in emission reduction projects in developing countries. The emission reduction is expressed in Certified Emission Reductions (CER's) and the investor may be credited for those.

Finally, the third mechanism concerns a world-wide emissions trading market, where the owner of emission reduction allowances may trade them at the current price that is settled by the laws of demand and supply, like other commodities. The trading unit is the allowance of a ton CO_2 equivalent. This mechanism is of high importance for renewable energy projects, as it may constitute a new income stream that will improve their financial yield and, therefore, attractiveness. The potential effect of this mechanism at the investment analysis results of a biomass-to-energy project is investigated thoroughly in this paper.

2 Methodology

2.1 Simulation and optimization model description

The effect of including income from GHG emissions reduction trading to the economics of a bioenergy exploitation system is investigated using a model built by SIMOR. This model is a tool with the ability to simulate a biomass-to-energy supply chain, taking into consideration not only the upstream biomass supply chain up to the biomass energy conversion facility, as most of the researchers do, but also the downstream supply chain of the energy products produced, such as electricity, heat and cooling. One of the important innovations of this model is its ability to include the case of using multiple biomass sources, an issue that is very rarely tackled in the relevant literature. The energy conversion facility may be a Combined Heat and Power (CHP) or a tri-generation plant, and provision is made to incorporate the investment and operational costs of a district heating or/and district cooling network. The energy conversion unit consists of a base-load biomass co-generation unit that provides base-load heat and cooling, and a peak-load biomass heat boiler that covers the peak heat and cooling loads.

The simulation model has been coupled to an optimization module, which optimizes the major design and operational characteristics of the whole system, by determining the optimal values of a set of variables. The optimization variables in the case examined are the geographical coordinates of the plant position, the rated capacity of the base-load and peak-load technological devices of the bioenergy exploitation plant, the quantity to be procured from each biomass source for year-round operation and the biomass inventory at the end of each year. A holistic optimization approach has been adopted, in the sense that all the stages of the biomass-to-energy supply chain have been incorporated, extending from biomass collection and transportation, to energy delivery to the final customers. Energy delivery in this case requires construction of electricity grid and district energy pipeline for supplying heat and cooling to the consumers. The optimization is performed on the basis of the Net Present Value (NPV) investment analysis criterion.

2.2 Optimization method

Several optimization methods have been applied in the bioenergy supply chain literature. Linear Programming, a method that has the advantage of simplicity and assurance of identifying the global optimum has been used [8,9]. MILP was used in [10] to include binary operators for investment decisions in the variables. Papadopoulos and Katsigiannis [4] have used dynamic programming to identify the optimum fuel mix for a biomass CHP unit. However, most of the models found in the bioenergy literature employ simulation techniques and not optimization.

The optimization method applied in this model is a hybrid one, in order to overcome the limitations of using a specific non-linear optimization method. This means that firstly, one optimization method is employed to define a good solution to the problem. This solution is used as the starting point of the second optimization method that bears the task to enhance further the solution found at the first step.

The first step optimization method is a Genetic Algorithm (GA). GAs have been applied for a great variety of optimization problems and are based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the selected criteria [11]. Some of the advantages of a GA include that it optimizes even non-linear, non-continuous and non-differentiable functions with continuous or discrete variables, it doesn't require derivative information, it simultaneously searches from a wide sampling of the cost surface and it deals with a large number of variables. Moreover, a GA may succeed in finding the global optimum due to the fact that the method evaluates simultaneously a large population instead of a single point for most non-heuristic optimization methods. These advantages are intriguing and produce stunning results when traditional optimization approaches fall miserably [11].

A disadvantage of a GA is that, despite the good chance of finding a solution close to the global optimum, the method advances very slowly after a certain point, especially for complex problems. For this reason, a Sequential Quadratic Programming (SQP) optimization method is applied at the second step to define the optimum. This type of continuous optimization methods presents the advantage of very fast convergence. Its disadvantage is mainly the fact that it may identify a local optimum instead of the global, and that the results may be disappointing if one does not use a good starting point. However, having defined a very good solution in the vicinity of the global optimum using the GA, the application of the SQP method with the GA optimum as its starting point may lead to identification of the global optimum with high accuracy.

2.3 Objective function

The objective function of the optimization problem is the NPV of the investment, for its economical lifetime. All the elements of the system are included for the investment analysis, i.e. the power plant, the supply chain of the biomass, the district heating and cooling network and connection to the customers, as well as the electricity transmission line and connection to the grid. All operational costs are also taken into account. NPV was chosen for numerous reasons. Firstly, Ryan et al. state that it is the most commonly used project appraisal method in business practice [12]. More specifically, NPV appears to be the dominant investment appraisal method for cogeneration plants, according to Biezma and San Cristóbal [13]. In addition, textbooks consider the NPV criterion as theoretically superior to others [14].

2.4 Constraints

Several constraints have been introduced in the optimization model. Energy constraints ensure that heat and cooling demand of the district energy customers are always satisfied. Furthermore, biomass safety stock is required to allow increased reliability of the district energy system towards its final customers. Additional logical and legislative constraints are also taken into account. Finally, social constraints concerning mainly the proximity of the power plant to sensitive locations have been included.

3 Case study

The simulation and optimization model has been implemented for a case study that concerns the investment analysis of a tri-generation power plant, given the demand of a specific customer for heat and cooling. The district energy customer is a local community in Greece of about 500 houses, for which the heat and cooling demand profiles are available. The main revenue sources of the power plant under consideration are electricity sales to the national grid, heat and cooling to the customers via a district heating network as well as emissions reduction units' (ERU's) trading. The price of heat is assumed to be a fixed percentage of the cost of heat obtained by using oil whereas the price of cooling is a fixed percentage of the cost of cooling obtained by electrical compression chillers. Due to the novelty of the emission trading mechanisms, it is extremely interesting to investigate the effect that it may have on the economics of a biomass-to-energy system.

A base-load co-generation module and a biomass boiler for peak-load heat production comprise the energy exploitation module. Heat produced from the abovementioned devices will be transferred by the main district heating pipeline to a position near the final consumers. A terminal point follows, containing heat exchangers and absorption chillers to produce cooling using heat as primary energy source. The same distribution network is used for district heating and cooling. The plant will operate in heat-match mode, to serve the heating and cooling needs of the customers. The electricity produced will be sold directly to the grid, at prices determined by the Greek energy authority. Five biomass types have been characterized as dominant in the region, using Pareto analysis, and all of them are considered as potential fuel sources for the power plant. The basic characteristics of the biomass sources considered in the analysis are presented in Table 1.

The abovementioned tri-generation plant results in GHG emissions reduction that can be quantified using an appropriate baseline methodology, for this case the UNFCCC-ACM0006 [7]. The baseline case for heat production is assumed to be heating oil, for cooling is electricity used at compression chillers and the baseline case for electricity is production by the current generating mix of the country in question. From the emissions reduction calculated one has to subtract additional emissions of the proposed system, mainly originating from fossil fuel use in biomass logistics (transportation and handling).

The price of biomass appearing in Table 1 is assumed to incorporate the cost of loading the biomass from the field to the transportation vehicles. All biomass types are agricultural residues, and therefore are characterized by high seasonality. Biomass types 2 to 5 are assumed to be agricultural residues with no current commercial use, whereas biomass type 1 has a competitive use and therefore limited amounts are available for energy recovery and at a higher price, equal to its commercial price. The main financial data used for the NPV calculation are presented in Table 2.

Table 1: Biomass characteristics.

Biomass type	Type 1	Type 2	Type 3	Type 4	Type 5
Price (€/ton)	50	20	20	30	30
Biomass availability (months)	Jul-Aug	Nov-Dec	Oct-Nov	Nov-Feb	Dec-Feb
Heating Value (KJ/kg wet)	14900	12300	15100	13400	13100
Density (kg/m3)	140	200	200	250	300
Moisture (%)	20	50	30	35	40
Yield (tons/hectare)	0,45	2,15	3,83	2,54	5,59

Table 2: Main financial data.

Discount rate	8%	Electricity price (€/kWh)	0,0684
Inflation rate	3%	Heating oil price (€/kg)	0,5
Investment lifetime	20 years	Cooling price (€/kWh)	0,036
Public Subsidy	40%	CO_2 price (€/ton equiv.)	20

4 Results

The results concern two scenarios, the base case, which includes revenue from GHG emissions trading and the alternative scenario, which does not include it. The application of optimization on both scenarios leads to the optimum system design and operational characteristics definition. The main investment appraisal criteria for the optimized system are presented in Table 3.

Table 3: Investment appraisal.

	Base case	No GHG trading
NPV (mill. €)	11,51	6,69
IRR	0,292	0,227
Pay-Back-Period (years)	4,4	6

It is more than obvious that the additional income stream due to emissions trading may significantly improve the financial yield of the project. The increased yield can prove to be a strong incentive for more investments in biomass-to-energy projects. The contribution of emissions trading to the income cash flows can be seen in Fig. 1. Emission trading offers 18% of the total income present value (PV) for the base case scenario, significantly more than the 14% of cooling sales.

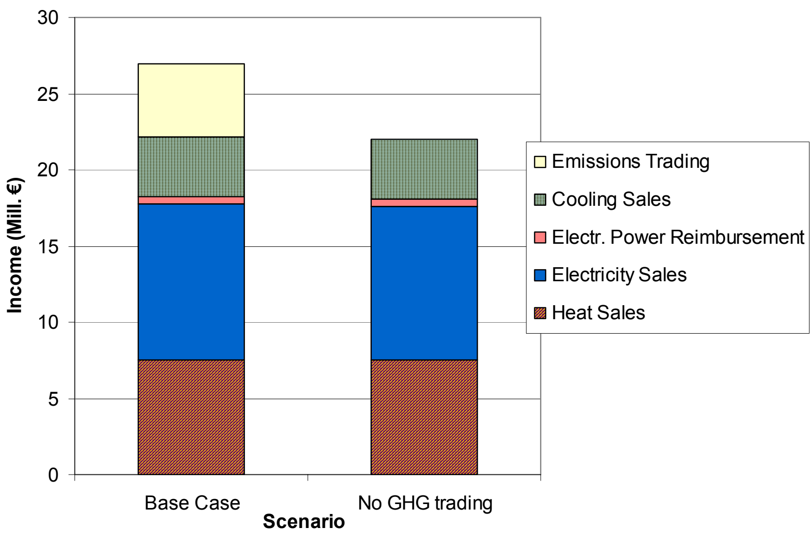

Figure 1: Income breakdown.

The most critical income source is electricity, which contributes about 40% of the total revenue. A small fraction of this amount is the reimbursement fee for electric power availability, which runs into 1,7% of the total revenues. Finally, heat sales is the second income source in order of significance, as it provides about 28% of the project's revenues.

One should also notice that the project constitutes an attractive investment option even without GHG trading. The main reason for this result is the innovative tri-generation option that was assumed. This option extends considerably the yearly operational time of the plant, thus resulting in wider spreading of capital costs, better utilization of resources and reduced biomass supply chain costs. The multi-biomass approach amplifies further the positive effect of tri-generation at the biomass supply chain, by reducing the fuel purchasing cost -as it provides access to cheaper biomass sources-, and by increasing efficiency, spreading of capital costs and reducing warehousing requirements.

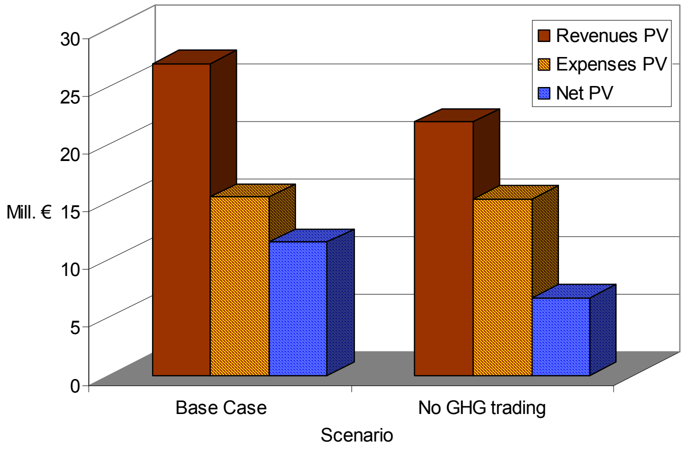

Figure 2: Present value of cash flows.

One can easily understand the effect that emissions trading has on the projects' cash flows from Fig. 2. It should be noted here that the expenses PV should not be affected by including or omitting emissions trading revenue. In Fig. 2 a slight decrease in the expenses PV can be observed. This difference is due to the application of optimization, which leads to a slightly different system setup for the two scenarios. However, this expense decrease is counterbalanced by an equal decrease of the electricity revenues, therefore not affecting the NPV.

The abovementioned results have been obtained by assuming a certain trading price for the ton CO_2 equivalent. However, its price is highly volatile, since the respective market is still in its infancy and requires some time to mature and stabilize. Since June 2003, when emission allowances were traded for the first time, the price has fluctuated between 5 and 30 €. Therefore it is essential that a sensitivity analysis is performed, concerning the effect on the NPV of the project that CO_2 price fluctuation may have.

Figure 3 reveals the degree of sensitivity of the financial yield of the project on CO_2 allowances trading prices fluctuation. It is apparent that increasing the price of CO_2 from 5€ to 35€ almost doubles the NPV of the project. This value range may seem extreme for a sensitivity analysis; however, the innovative character of the emissions trading market and the uncertainty concerning the future emissions reduction obligations of developed countries leave all options open. A different expression of the sensitivity analysis result may be that a 10% change of the CO2 allowances prices from the base case value of 20€ leads to a 4,2% change of the NPV of the project. The conclusion from the sensitivity analysis is that CO_2 allowances' prices have a major influence on the project yield, and thus great effort should be made by the investor when determining this price for performing the project investment analysis.

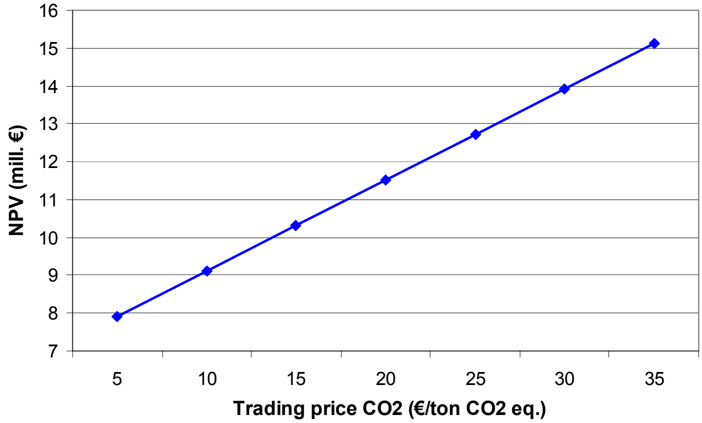

Figure 3: Sensitivity analysis for CO_2 trading price.

5 Conclusions

In this paper, the effect of emissions trading on the yield of a biomass-to-energy project has been investigated. The analysis has been performed using a multi-biomass tri-generation model applied in a case study region of Greece.

The conclusions that may be drawn from the analysis are numerous. First of all, it has been shown that emission allowances trading may become a significant revenue stream for similar renewable energy projects, thus greatly enhancing their yield and attractiveness. Nonetheless, revenue from emission allowances trading cannot be reliably determined at the current period, due to the 'experimental' nature of the relative market. Investors should also be aware that the sensitivity of the yield of the project on emission allowances prices is relatively high and attention should be paid when determining a suitable value for this parameter in investment analysis.

Last but not least, the use of multiple biomass sources and the district energy with tri-generation may lead to considerable economies, in the form of capital cost spreading, improved resource utilization and higher efficiency of the biomass supply chain. As a result, a district energy system using biomass may prove to be financially viable even without including potential revenues from GHG emission allowances trading, when tri-generation applications and multi-biomass sourcing are considered.

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