Estimating greenhouse gas emissions reduction and allowances' trading revenue for biomass tri-generation applications

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Abstract
Biomass tri-generation constitutes an innovative renewable energy application. An approved UNFCCC baseline methodology has been extended in this paper to examine a biomass tri-generation application. Some environmental and financial aspects of this type of applications were investigated through a case study. It has been shown that tri-generation may result in significant emissions reduction, compared to using conventional energy sources or even biomass co-generation. The emissions reduction achieved may be materialized into a considerable revenue stream for the project, if traded through EU ETS. However, the high volatility of the tCO2e value and the EU Trading Scheme being still in its infancy prevent a reliable estimation of the related revenue. For this reason, a sensitivity analysis has been performed. The work concludes that greenhouse gas emissions trading may develop into one of the major revenue streams of biomass tri-generation projects, significantly increasing their financial yield and attractiveness.
Keywords: Tri-generation; environmental effects; emissions trading; greenhouse gases; biomass.

1. INTRODUCTION

Scientists have been very concerned about the effects of climate change, which is mainly attributed to the increased global Greenhouse Gas (GHG) emissions [1,2]. Significant effort has been placed on various scientific fields, in order to determine ways of mitigating the climate change phenomenon. One of the major fields of interest in this framework is renewable energy generation.

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 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, starting from year 2008. The CDM mechanism allows private entities or governments of Anex 1 countries to invest in emissions reduction projects in developing countries. Finally, the third mechanism concerns an emissions trading market (European Union Greenhouse Gas Emission Trading Scheme - EU ETS), 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 CO2 equivalent (tCO2e). This mechanism is of high importance for renewable energy projects, as it may constitute a new revenue stream that will improve their financial yield and, therefore, attractiveness.

This work focuses on a particular innovative type of renewable energy application, namely tri-generation based on biomass. Tri-generation concerns the simultaneous production of three energy products –electricity, heat and cooling– from one installation. More particularly, the potential environmental and economical effects of adopting this concept in order to substitute conventional energy sources are examined. A tri-generation plant powered by renewable energy sources may contribute to reduced GHG emissions, as it could serve electrical, thermal and cooling energy needs currently satisfied by fossil fuel sources. This contribution can be quantified and materialized into an extra revenue stream for the tri-generation project, through trading of the resulting emission allowances. Potential buyers of the allowances could be polluting industries or even governments that exceed their emission allowances. This project could be included in the framework of JI or CDM projects, depending on the host country. The concept of tri-generation 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. However, combined district heating & cooling applications 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 recently, due to recent technological advances and simultaneous cost reduction of absorption chilling technology. The biomass tri-generation concept has not been evaluated in the relative literature up to now.

The case study used in this work concerns a biomass tri-generation project situated at a rural area of Greece, generating electricity to be fed at the national grid, as well as heat and cooling to be used for domestic and commercial space heating and cooling applications, through a district energy network. In this paper, the methodology of calculating the GHG emissions reduction as well as the potential revenue from allowances trading is presented. This methodology is applied to the case study, in order to come up with some tangible results that allow interesting conclusions to be drawn.

2. METHODOLOGY

2.1 GHG emissions reduction calculation

The methodology adopted for calculating the reduction of GHG emissions is based on the relevant approved methodology of UNFCCC-ACM0006 [3], which has been extended to allow examination of biomass tri-generation cases. According to this methodology, the researcher has to take into account several factors that lead to GHG emissions reduction, as well as others that produce extra GHG, all of which are related to the specific project under investigation. In order for this methodology to be appropriately applied, one has first to define the baseline scenario, which concerns the most realistic alternative solution to the project examined, in order to satisfy the same energy needs. Defining the baseline scenario has a major impact on the way the effective GHG emissions reduction is calculated, as it is the measure with which the proposed project is compared. The case examined in this work assumes the following choices as the most probable baseline scenario solutions to the project examined:

1. Electricity is supplied by the national grid; therefore it is assumed to be provided by the current generating mix of the country's electricity generation system.
2. Heat is produced in boilers using fossil fuels. In particular, the use of diesel oil has been assumed, as it is the most frequently used fuel for domestic, commercial and industrial space heating applications in Greece.
3. Cooling is produced using electric heat pumps. This is the usual case in Greece.
4. The alternative use for biomass would be dumping, leaving it to decay or burning it in an uncontrolled manner without any kind of energy exploitation.

The unit established for measuring emissions worldwide is the ton CO2 equivalent. This unit is common for all the greenhouse gases and is also used at the emissions trading mechanism. There exist various gases that contribute to the greenhouse effect, the main ones being CO2, CH4, NOx, CO and others (HFCs, PFCs & SF6). These gases can be expressed – depending on the impact they have on the greenhouse effect – in tCO2e.

According to the UNFCCC methodology, the GHG emission sources that the researcher has to take into account for the baseline scenario are the CO2 emissions for electricity production by the power plants connected to the electricity grid and the CO2 emissions for heat production by fossil fuel boilers. Cooling is produced using electric heat pumps and therefore the emissions assigned to cooling can be determined by calculating the amount of electricity needed for this purpose. On the other hand, one has also to take into account the negative effect of CO2 emissions caused by using fossil fuels in the biomass supply chain as well as CO2 emissions due to fossil fuel use for any other reason within the biomass power plant. In the application examined here, biomass supply chain entails transportation using conventional diesel-powered trucks, and it is assumed that the only factor creating emissions within the power plant is the diesel-powered handling and loading/unloading equipment. Any electricity required for the operation of the tri-generation plant is subtracted from the gross electricity generated. This methodology offers the researcher the option to include in the baseline scenario the GHG emissions caused by the uncontrolled burning or decaying of biomass. However, in this case, he should also include in the calculations the methane emissions from the proposed biomass energy plant operation. In this work it has been chosen to mutually ignore these emission sources, due to limited data availability for biomass plant methane emissions.

In order to calculate the emissions reduction obtained by biomass electricity generation, one has to calculate the amount of GHG emissions that would be produced if the same amount of electricity was generated by grid-connected power plants. It is therefore necessary to define the average CO2 emission factor of the electricity system, according to the UNFCCC methodology. The average CO2 emission factor of the Greek electricity system g_E has been found to be equal to 876 kg CO2/MWh$_{el}$ [4]. The total net electricity generated by the biomass power plant multiplied by g_E provides the total GHG emissions reduction G_E due to renewable electricity production. The net electricity generated is calculated by subtracting the electricity required for district energy pumping E_P, absorption chillers and cooling towers E_{DC} from the gross electricity generated E_{ME}.

$$G_E = g_E(E_{ME} - E_{DC} - E_P) \quad (1)$$

It should be mentioned that the grid losses for transferring electricity from the biomass power plants to the final consumers have not been included in the calculations. This assumption has been performed because fossil fuel electricity generation faces also the same problem. As a matter of fact, the grid losses of the biomass power plant would probably be significantly lower than fossil fuel plants, as the electricity would be consumed locally, thus avoiding long-distance transportation. However, the fossil fuel electricity generation-related grid losses should be accounted for, if the biomass power plant would be used for autoproduction, which means that electricity would be consumed on the spot, without being fed to the grid. The assumption made leads to probable underestimation and not overestimation of the GHG emissions reduction.

The GHG emissions reduction obtained by using biomass-produced heat G_T equals the product of the total amount of heat required E_{HD} and the fossil fuel heat production CO2 emission factor g_T. In this work, the heat production CO2 emission factor has been calculated for diesel oil (g_T = 270 kg CO2/MWh$_{th}$) [5], as it is the most commonly used fuel for space heating applications in Greece.

$$G_T = g_T E_{HD} \quad (2)$$

Likewise, the GHG emissions reduction due to renewable cooling generation G_C, by converting co-generation heat to cooling using absorption chillers, is equal to the product of cooling demand E_{CD} and the cooling production CO2 emission factor. In this work, it has been assumed that the baseline scenario concerns electric heat pumps for cooling generation. Therefore, the GHG emissions reduction from renewable cooling generation can be calculated via the electricity savings by avoiding using electric heat pumps with Coefficient of Performance COP (the value used in this work is 3,2, an optimistic one for domestic cooling heat-pumps available in the market).

$$G_C = g_E E_{CD}/COP \quad (3)$$

On the other hand, the GHG emissions caused by fossil fuel use in the biomass supply chain have to be calculated. It has been assumed that heavy duty diesel-powered vehicles and equipment will be used for biomass transportation, handling and loading/unloading, and that they all use the same engine technology. The CO2 emission factor for this type of vehicles and equipment g_D has been found to be 3172,3 gr CO2/kg fuel [6]. As a result, the biomass logistics-related CO2 emissions G_L due to total use of diesel fuel M_T for transportation and M_L for handling and loading/unloading is:

$$G_L = g_D (M_T + M_L) \quad (4)$$

2.2 Emissions trading-related revenue calculation

The value of the ton CO2 equivalent has been the subject of the EU ETS exchange market. The price of tCO2e has been fluctuating significantly in the range of 1€ to 31,5€ since the establishment of this market. In order to calculate the potential income that a renewable energy project might have from trading its emissions reduction allowances one has first to determine the amount of tCO2e that is avoided by the project, by using an appropriate approved baseline methodology. Then the revenue expected by trading the emissions reduction (R_G) can be calculated by the expected value of tCO2e (C_{CO2}) and the amount of GHG that is avoided by the project implementation:

$$R_G = C_{CO2} (G_E + G_T + G_C – G_L) \quad (5)$$

3. RESULTS AND DISCUSSION

3.1 Environmental effect

The tri-generation project examined reduces GHG emissions by substituting fossil fuel use with renewable energy. The amount of GHG emissions savings by renewable electricity, heat and cooling generation (positive values), as well as the extra GHG emissions caused by parasitic electricity and fossil fuel required at the district energy network and biomass logistics respectively (negative values), are presented in Table 1. The same methodology has also been applied for the case of co-generation, where cooling is not generated by biomass, to perform a comparison between tri- and co-generation GHG reduction potential. Co-generation is a typical biomass application for north Europe.

Table 1. Biomass tri-generation and co-generation GHG emissions compared to baseline scenario

	Amount of energy (Tri-generation)	**Tri-generation GHG reduction** *(tCO2e)*	**Co-generation GHG reduction** *(tCO2e)*
Electricity	12311 MWh_{el}	10785	5874
Heat	12816 MWh	3460	3460
Cooling	8856 MWh	2424	-
Parasitic electricity	-32,6 MWh_{el}	-28	-11
Biomass Logistics	-18587 kg diesel	-59	-31
Sum		16582	9292

It is apparent that the major emissions savings can be attributed to renewable electricity generation, due to the very emissions-intensive current electricity generation mix of Greece. Therefore, a biomass tri-generation project would result in increased emission allowances compared to another

EU country with less emissions-intensive electricity system. Furthermore, one can conclude that significant emissions reduction can be obtained by applying the tri-generation concept. The extra emissions due to parasitic electricity in district energy pumping and biomass logistics can be considered negligible, as they constitute only 0,5% of the emissions reduction achieved. At total, 16582 tCO2e can be saved yearly, or else 331640 tCO2e during a hypothetical 20-year lifetime of the project. It is very interesting to note that a typical co-generation project applied for the same case would result in only 9292 tCO2e reduction per year (Table 1), which means that tri-generation can achieve 78,5% more GHG emissions reduction.

3.2 Financial effect

The potential of trading the emissions reduction achieved by the biomass tri-generation project may constitute an extra revenue stream for the project. The historical prices of tCO2e have been highly volatile, since the trading system is still in its infancy. Therefore, one cannot safely forecast the future value of tCO2e. However, a sensitivity analysis has been performed in order to investigate the effects that this new revenue stream might have. Sensitivity analysis has been performed for prices between the two theoretical extreme values: zero and 40€/tCO2e. Zero value is only theoretical, but very low values equal to 1€ have been observed recently. On the other hand, the value of 40€ is currently the upper limit, since this is the amount of the penalty an installation has to pay if it exceeds its emissions allowance. It is obvious that any installation would prefer to pay the penalty instead of buying allowances from the ETS if the allowances were traded over the margin of 40€. This margin is expected to change in 2008, when the penalty will arise to 100€/tCO2e.

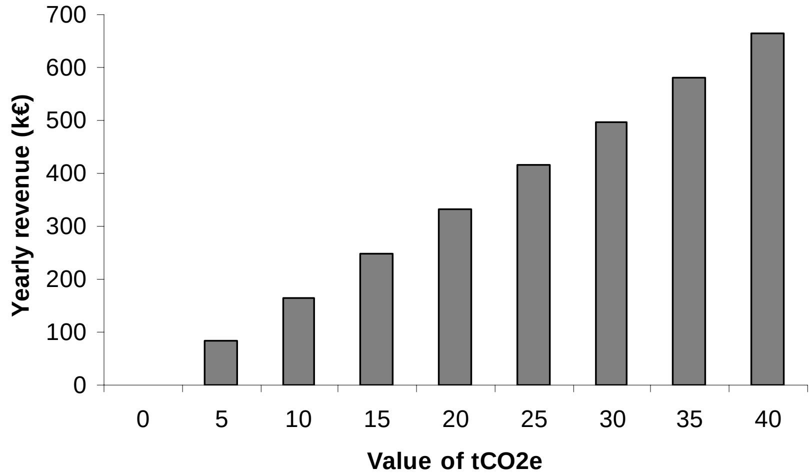

Figure 1. Yearly revenue from emissions trading.

One can see in Figure 1 that the expected revenue from emission allowances trading is linearly dependent to the value of tCO2e. This is natural, since the amount of GHG allowances produced by the project examined is considered independent of the value of tCO2e. For values near the lower end, the revenue is actually negligible, whereas for the upper end, revenue is surprisingly high, and could theoretically reach 663 k€ per year for a value of 40€/tCO2e. The importance of this revenue can be better understood from Figure 2, where the relative contribution of the emissions trading revenue to the total project revenues is presented. It is shown that this revenue stream is of high importance even from the value of 5€/tCO2e, since it contributes 4,4% of the project’s revenue. The extra cash flow generated from GHG emissions trading may be critical for the viability of a biomass tri-generation project [7]. The contribution of emissions trading revenue does not follow a linear pattern, and ends up to contributing 26,8% of the total revenue for the marginal price of 40€/tCO2e. Despite the fact that this is a purely theoretical case for the time being, it is not unlikely that such high or even higher values can be observed when the Kyoto protocol mechanisms are fully functional. Therefore, one can observe that emissions trading may represent one of the major revenue streams for biomass tri-generation projects in the near future.

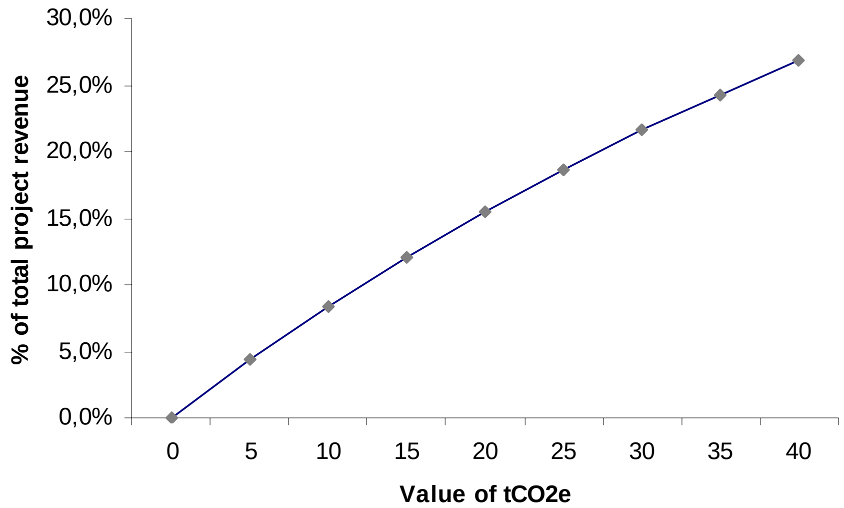

Figure 2. Proportion of total project revenue coming from emission allowances trading.

4. CONCLUSIONS

A methodology for assessing the GHG emissions reduction from biomass tri-generation projects, based on the UNFCCC guidelines, has been presented. The methodology has been applied on a case study to evaluate the potential environmental benefits as well as the financial incentive from the prospective emission allowances trading. The case study results indicate that emissions trading could constitute a very significant revenue stream, being able to contribute up to 26,8% of total project revenue. The GHG emissions reduction is further enhanced, due to the currently very emissions-intensive electricity generation mix. Furthermore, the tri-generation concept leads to extended operational time of the power plant, thus resulting in significantly increased renewable energy generation and, consequently, GHG emissions reduction. As a conclusion, biomass tri-generation projects appear to be a great opportunity for GHG emissions reduction, and the higher the prices of emission allowances get, the greater will the incentive for investing in such projects be.

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