Biomass Production in Surface Mines: Renewable Energy Source for Power Plants

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Abstract: - The use of renewable energy sources is becoming increasingly necessary, if we are to achieve the changes required to address the impacts of global warming. Biomass is the most common form of renewable energy, widely used in the third world but until recently, less so in the Western world. Latterly much attention has been focused on identifying suitable biomass species, which can provide high-energy outputs, to replace conventional fossil fuel energy sources. The type of biomass required is largely determined by the energy conversion process and the form in which the energy is required. The potential of reclaimed land of mines to act as a biofuel source, providing fuel to supplement conventional power stations, is examined, together with the replacement of fuels in gas or diesel boilers for the production of thermal energy.

Key-Words: - Energy crops, renewable power, poplar clones, biomass, bioenergy, degraded mining land.

1 Introduction

Solid and gaseous biomass –particularly wood and wood waste1– used for electricity, heating and cooling production is the biggest source of renewable energy in the EU and is expected to make a key contribution to the 20% EU renewable energy target by 2020. Sustainable biomass can play an important role in helping to address concerns about climate change and security of energy supply, while contributing to economic growth and employment, particularly in rural areas.

Over 81% of the total energy consumed in the world, of which 58% is represented by electricity generation in the countries members of the Organisation for Economic Co-operation and Development (OECD), is obtained from fossil fuels This dependence is not sustainable because fossil fuels are limited and impact the environment (e.g., the greenhouse effect). It is therefore necessary to develop renewable sources of energy to replace the electricity obtained from fossil fuels in the near future.

Biomass is an important contributor to the world economy. Biomass, mainly now represent only 3% of primary energy consumption in industrialized countries. However, much of the rural population in developing countries, which represents about 50% of the world's population, is reliant on biomass, mainly in the form of wood, for fuel [1]. Biomass energy currently represents approximately 14% of world final energy consumption, a higher share than that of coal (12%) and comparable to those of gas (15%) and electricity (14%). Biomass is the main source of energy for many developing countries and most of it is noncommercial. Hence, there is enormous difficulty in collecting reliable biomass energy data. Yet good data are essential for analyzing tendencies and consumption patterns, for modeling future trends and for designing coherent strategies. The energy dimension of biomass use is importantly related to the possible increased use of this source as a critical option to address the global warming issue. Biomass is generally considered as an energy source completely CO_2-neutral. The underlying assumption is that the CO_2 released in the atmosphere is matched by the amount used in its production. This is true only if biomass energy is sustainably consumed, i.e. the stock of biomass does not diminish in time. This may not be the case in many developing countries.

Biomass is burned by direct combustion to produce steam, the steam turns a turbine and the turbine drives a generator, producing electricity. Gasifier is used to convert biomass into a combustible gas (biogas). The biogas is then used to drive a high efficiency, combined cycle gas turbine. Biomass consumption for electricity generation has been growing sharply in Europe since 1996, with 1.7% of power generation in 1996.

2 Energy crops

Dedicated SRC energy crops, such as poplar (Populus spp.) and willow (Salix spp.), are grown commercially for heat and power generation as a consequence of their rapid growth rate and favourable energy ratio. Provided local markets exist, SRC offers growers the chance to diversify into nonfood crops and, when planted in place of conventional arable agriculture, has secondary benefits including enhanced biological diversity. However, the main importance of such crops is their intrinsic value as a renewable energy resource. Greenhouse gas emissions are abated as a consequence of reduced fossil fuel inputs and increased carbon sequestration, when compared with traditional crop systems. Whilst species vary, each oven-dry tonne (odt) of energy crop converted to electricity displaces approx. 0.44 toe (tonnes of oil equivalent).

Poplars (Populus spp.) grown under a short-rotation coppice (SRC) regime have been extensively studied in function of bioenergy production [2-7]. Decades-long research has led to a solid expertise in many countries and practical experience on growing poplar at high densities (i.e. _5000 cuttings per hectare) has been translated in best practice guidelines. Yet, the environmental impacts and economic feasibility of SRC as an alternative energy source to fossil fuels are still under debate [8-11]. The environmental impacts and energy balance of dense poplar plantations are evaluated through life cycle assessment (LCA), although a widely accepted and uniform methodological approach is lacking thus far [12]. The economic viability is assessed by means of life cycle cost and by financial models considering the costs and benefits over the entire lifetime of the plantation.

Shorter rotation cycles allow higher planting densities and thus, higher biomass yields per unit land area. Coppicing usually stimulates spring re-growth and apparently avoids replanting costs. When rotation lengths are too short for a given species or genotype, re-growth may be hindered by depletion of the carbohydrate reserves primarily stored in the root system [6]. A recent study covering 12 years of poplar SRC in North Italy investigated the effect of 1-, 2- and 3-year harvest cycles on biomass potential of the commonly used Populus deltoides Bartr. clone Lux. Under the annual harvesting scheme, most poplar stools were soon exhausted and did not survive the seventh year. On the other hand, highest survival rates and maximum productivity were ascertained in plots with a 3-year harvest cycle. For many years, poplars have been in the first place selected for single-stem growth and straight stem form in traditional breeding and selection programmes. As a result, several commercially available poplar clones may not withstand frequent harvesting or short-rotation cycles without a decrease in productivity or in resprout capacity.

3 Surface coal mining restoration

Most surface mining methods are large scale, involving removal of massive volumes of material, including overburden, to extract the mineral deposit. Large amounts of waste can be produced in the process. Surface mining also can cause noise and disturbance, leave scars on the landscape and may pollute the air with dust [5]. Therefore, it is not only crucial to have a detailed understanding of the pre-mining environment, but also important to apprehend the utilized mining method in order to plan a meaningful surface rehabilitation, wherever possible [6]. The process of removing, storing and subsequently replacing the soil during the mining activity lead to potential problems in relation to subsequent restoration. In this respect, a major distinction should be drawn between those sites where, for operational reasons, soil has to be stored for a period of years while the mining progresses, and those, usually larger, sites where a progressive system of restoration can be practiced [7]. The negative impacts of surface mining on environment can be listed as the following [8]:

- Occupation of large farming areas needed for excavation and dumping operations,
- Alteration of land morphology,
- Disturbance of native fauna and flora,
- Modification of surface and ground water balance,
- Resettlement of residential areas, roads and railways,

- Release of air, liquid and solid pollutants and noise pollution.

It's crucial to make a mine disturbed land environmentally stable in order to transfer an unpolluted environment and natural resources to the next generations. However, when a demolished land is left with its own, it may take years and years to recover and reach an ecological balance. During this period, these types of lands need human hand for reclamation and recovery. Therefore, post-mining reclamation works are those aiming to regain landscape's fertility, its ecologic, economic and esthetic values [9].

Figure 1. Open pit coal mine. Exploitation phase.

Figure 2. Restoration phase

On the other hand, through productive restoration, short-term restored land is valued by planting fast-growing energy crops. With this type of crops, much higher growth is achieved and by applying shorter cutting shifts, economic benefits are obtained from the first years using the biofuels obtained for the production of energy. Although the initial investment is higher in the case of productive restoration, the profitability is much higher than in the case of environmental restoration.

4 Material and Methods

In 2008 research began on a restored surface of old mining operations with an extension of 7.5 ha that were planted with forest energy crops using different clones of poplar, willow and birch. In total, 3 trials were carried out in different recovery areas.

Figure 3. Plantations in restored mining areas. Poplar Trial

Figure 4. Measurement of the height of the trees.

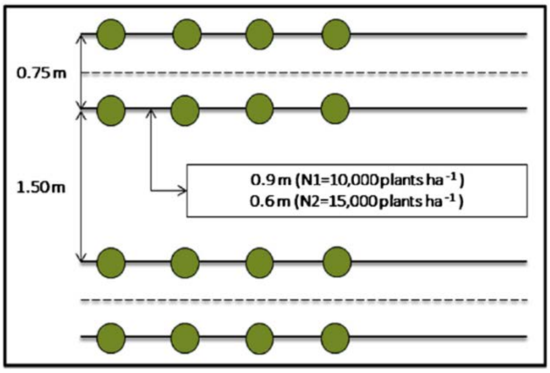
4.1 Location of the study area

The study area is characterized by an average annual temperature of 13°C and an average annual precipitation of 1,115 mm, of which 345 mm falls during the growing season (May– September). The climate is oceanic with high annual precipitation and, although summer precipitation is relatively low in some areas, physiological drought does not occur in any part of the region, which is located entirely within the European Biogeographic Atlantic Region [13].

4.2 Experimental design

In the winter of 2008, the surface was subsoiled, plowed to a depth of 30–40 cm, and harrowed before the poplar cuttings were planted. Three commercially available poplar clones were chosen for the study because of their adaptability to extreme soil conditions (e.g., nutrient poor and polluted soils) and because they display good structural attributes and yield capacities for biomass production in SRC [14]. The cuttings were planted according to a double row planting design, leaving a distance of 0.75mbetween each set of double rows, a distance of 1.5 m to the next set of double rows, and a distance between plants of 0.9 m (10,000 plants ha−1) or 0.6 m (15,000 plants ha−1) to provide two stocking levels (Figure 5).

Figure 5. Diagram of the planting designs used in the trial



Soil formation is at an early stage and the soil structure is still unstable. The steep slopes of the terrain minimize groundwater effects. The physiography of the plots was characterized by a mean slope of 19% and an elevation ranging from 508 to 597 m above sea level.

The first of the plantations was carried out in 2008, the factors to be studied in this first trial were: the type of clone, the density of plantation and the treatment (F0=Control F1=300 kg ha^{-1} NPK 6:20:12 and 4 l ha^{-1} glyphosate, F2 = 600 kg ha^{-1} NPK 6:20:12 and 4 l ha^{-1} glyphosate).

The amounts of fertilizer to be used were chosen in view of the results obtained in the soil analysis prior to planting, taking into account the maximum amount of nitrogen allowed to be applied in vulnerable areas, which is 170 Mg ha^{-1}.

The information regarding the growth was obtained following the protocol described by the *Forestry Commission* [15] for the data collection in willow and poplar plantations in short rotations. According to their indications, the number of shoots per strain, the height of each one of the shoots (m) and the basal diameters (at 0.25 m from the ground) and normal (at 1.30 m) of all of them were measured.

5 Biomass power plants

Biomass is used for facility heating, electric power generation, and combined heat and power. Compared to many other renewable energy options, biomass has the advantage of dispatchability, meaning it is controllable and available when needed, similar to fossil fuel electric generation systems. The disadvantage of biomass for electricity generation, however, is that the fuel needs to be procured, delivered, stored, and paid for. Also, biomass combustion produces emissions, which must be carefully monitored and controlled to comply with regulations.

Most biopower plants use direct-fired combustion systems. They burn biomass directly to produce high-pressure steam that drives a turbine generator to make electricity. In some biomass industries, the extracted or spent steam from the power plant is also used for manufacturing processes or to heat buildings. These combined heat and power (CHP) systems greatly increase overall energy efficiency to approximately 80%, from the standard biomass electricity-only systems with efficiencies of approximately 20%. Seasonal heating requirements will impact the CHP system efficiency.

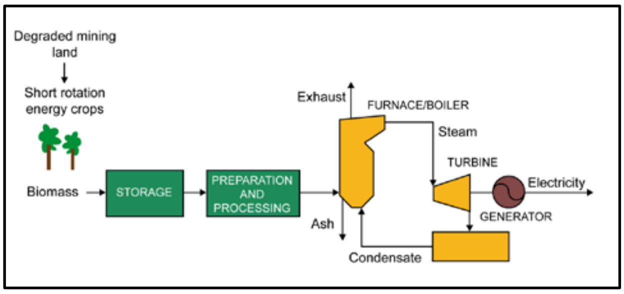
A simple biomass electric generation system is made up of several key components. For a steam cycle, this includes some combination of the following items:

- Fuel storage and handling equipment
- Combustor / furnace
- Boiler
- Pumps
- Fans
- Steam turbine
- Generator
- Condenser
- Cooling tower
- Exhaust / emissions controls
- System controls (automated).

Direct combustion systems feed a biomass feedstock into a combustor or furnace, where the biomass is burned with excess air to heat water in a boiler to create steam. Instead of direct combustion, some developing technologies gasify the biomass to produce a combustible gas, and others produce pyrolysis oils that can be used to replace liquid fuels. Boiler fuel can include wood chips, pellets, sawdust, or bio-oil. Steam from the boiler is then expanded through a steam turbine, which spins to run a generator and produce electricity.

In a direct combustion system (Figure 6), biomass is burned in a combustor or furnace to generate hot gas, which is fed into a boiler to generate steam, which is expanded through a steam turbine or steam engine to produce mechanical or electrical energy.

Figure 6. Direct combustion. Steam turbine system.

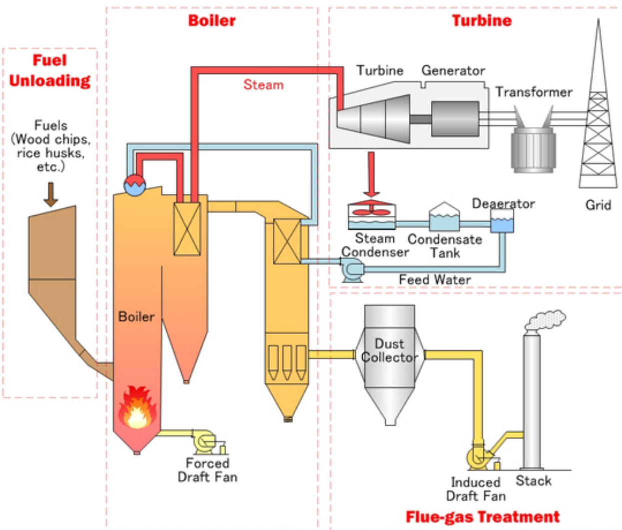


The fuel that is normally used is wood chips, according to the ÖNORM M 7133 standard. Depending on the moisture content, the density can vary between 165-330 kg m^{-3}, and the energy density between 3.14 and 2.74 MJ m^{-3}. In Figure 7 a sample of wood chips is indicated. The Net Calorific Value is between 19.06 MJ kg^{-1} for 0% humidity and 8.31 MJ kg^{-1} for 50% humidity.

Figure 7. Wood chips sample

Figure 8 shows the diagram of a power plant for the production of electricity from forest biomass. The generator transforms mechanical energy into electrical energy, which after passing through the transformer is delivered to the power grid.

Figure 8. Biomass power plant. (Yokogawa Industries)

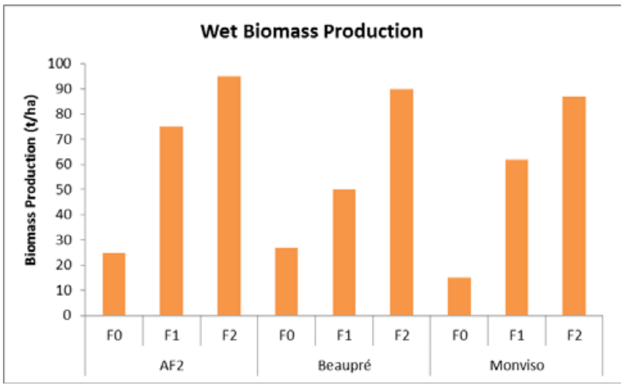


6 Results and discussion

The results of biofuel production reflect encouraging figures for some of the crops that have been tested, reaching productions even higher than those obtained by native species in natural soils in the vicinity of the restored lands.

Figure 9 shows the results obtained, with maximum productions reached of 95 t/ha of wet biomass for poplar clones AF2 (populus x canadensis), with a level of fertilization F2, of 600 kg ha^{-1} NPK. After five years of growth, the annual productions are of 19 t ha^{-1} year $^{-1}$.

Figure 9. Biofuels production from poplar clones



In addition to the annual productions, samples have also been analyzed to know their properties. Table 1 shows the laboratory results, including the calorific value of the biofuel obtained on dry basis.

Table 1. Biofuels analysis

Parameter	Biofuel
Immediate analysis (% d.b.)	
Humidity	11.25
Ash	1.3
Volatile matter	82.82
CF	15.98
Elemental analysis (% d.b.)	
C	49.76
Humidity	5.99
N	0.58
S	0.03
O	42.34
HCV (kcal/kg, dry basis)	4,673
LCV (kcal/kg, dry basis)	4,379

The use of the biofuels produced will be destined to the production of energy. After five years of growth, the plantation was harvested for the first time. Depending on the slope of the land in which the plantation is located, this cut could be mechanized, assuming a reduction in costs. The processed material is extracted from the forest and transported to a stock for a while, producing the natural drying of the biomass.

According to the tests that have been carried out, in the North of Spain humidity drops up to 35%. When the required percentage of humidity has been reached, the forest biomass will be chipped, which would be ready for use as a biofuel. Table 2 summarizes the production of thermal and electrical energy from the fuels that have been obtained.

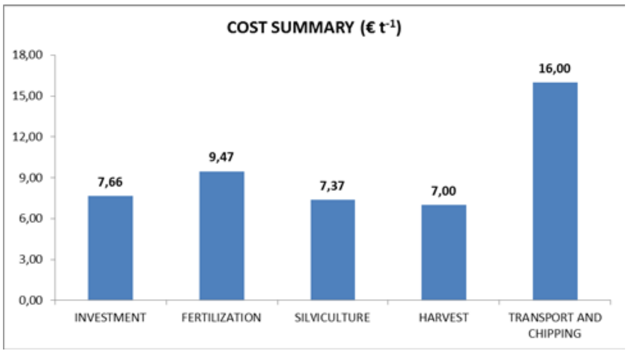
With the amounts of forestry biomass that have been obtained, the production of thermal energy is 242,903.98 kWht ha^{-1}, which if we convert it into annual production, after five years of growth, the energy production would be 48,580.80 kWht ha^{-1} $year^{-1}$. The production of electrical energy is 14.574,24 kWhe ha^{-1} $year^{-1}$. The electric power would be 1.94 kW per hectare of land.

Table 2. Heat and power production per hectare

Heat and power production	
Biomass production (t ha^{-1})	95
Humidity (%)	43.00
Humidity dry (%)	35
LCV (kcal/kg)	2,200.00
Energy production (Wht kg^{-1})	2,556.88
Energy production (kWht ha^{-1})	242,903.98
Heat production (kWht ha^{-1} $year^{-1}$)	48,580.80
Electric Efficiency (%)	30
Power production (kWhe ha^{-1} $year^{-1}$)	14,574.24
Availability (h $year^{-1}$)	7,500
Electrical Power (kWe ha^{-1})	1.94

Due to the resprouting capacity of the poplar species with which we have worked, the initial investment of the plantation would only need to be carried out at the beginning of the project. Short rotation energy crops on degraded soils costs around 3.640 €/ha, and the main costs are shown in the Figure 10.

Figure 10. Cost summary



7 Conclusions

The restored lands can be used for the production of biofuels through repopulation with fast-growing energy crops and high planting densities. With the biofuels obtained, electrical energy can be produced. For the construction of a 15MW power plant, 150,000 tons of wet biomass would be necessary.

The exploitation of coal in open pit mines in the North of Spain has occupied large areas of land. The restoration of mining operations is an obligatory activity for mining companies according to current legislation. The impacts derived from the mining activity must be corrected in the final phase of restoration, returning the landscape to an aspect similar to the original one, prior to the mining exploitation.

The soils generated in the restoration present extreme conditions (e.g., nutrient poor and polluted soils) for their use for the production of forest biomass, so it is essential to search for new species that adapt to the conditions of the environment.

The productions obtained for some poplar clones, such as AF2 (populus x canadensis), exceed in most cases the productions that are being achieved by native species in natural soils in the areas close to the plots that have been studied.

In addition to the production of renewable energy and capture of CO_2 emissions, this activity involves the generation of a new economic activity in abandoned land and the creation of jobs in depressed areas due to the closure of mining operations.

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