Reclamation of Degraded Landscape due to Open Pit Coal Mining: Biomass for Renewable Power Plants

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Abstract: - Even though it is regarded as a crucial economic activity worldwide, mining has a significant negative impact on environment. Due to its nature, especially opencast mining inevitably leads to serious degradation on ecological and aesthetic values of the landscape. Topography and drainage, air, soil and water quality, vegetation including forest ecosystems, noise levels and ground vibrations, human health and habitation can be listed as the typical parameters that are mainly affected by opencast mining activities. When the extraction of reserve is over, the altered landscape has to be reclaimed in order to relieve the damaging effects of opencast mining and restore the landscape and its immediate surroundings. Biomass as an energy source is an alternative to fossil fuels (coal, petroleum, and natural gas). Burning either fossil fuels or biomass releases carbon dioxide (CO_2), a greenhouse gas. However, the plants that are the source of biomass capture a nearly equivalent amount of CO_2 through photosynthesis while they are growing, which can make biomass a carbon-neutral energy source.

Key-Words: - Open pit mining, degraded mining land, renewable energy, short rotation, energy crops, biofuels.

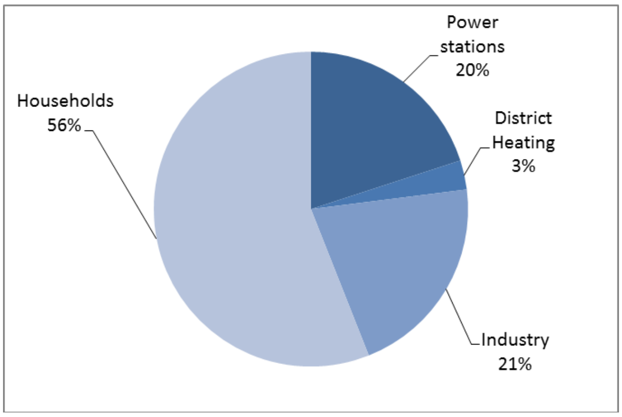
1 Introduction

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 [1]. 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 [2]. 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 [3]. Biomass consumption for electricity generation has been growing sharply in Europe since 1996, with 1.7% of power generation in 1996. The use of wood and wood waste as fuel in 1995 is given in Figure 1.

Figure 1. Use of wood and wood waste as fuel in 1995. (Source: IEA).



Wood biomass combustion generates more particulate matters than natural gas combustion. However, an advanced emission control system could significantly reduce particulate matters emission from wood biomass combustion which would bring the particulate emission to a relatively similar level as for natural gas.

2 Reclamation of degraded mining lands

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 [4]. 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 [5]. 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 [6]. The negative impacts of surface mining on environment can be listed as the following [7]:

- 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 [8].

3 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:

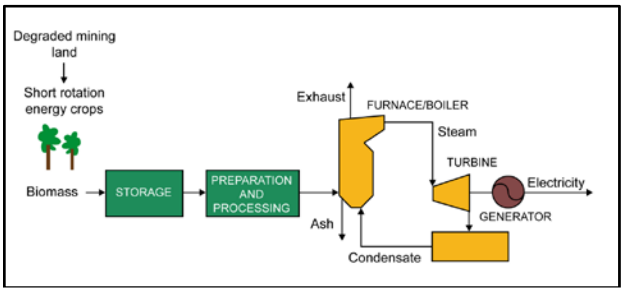
- Fuel storage and handling equipment
- Combustor / furnace
- Boiler

- 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 2), 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 2. Direct combustion. Steam turbine system.



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 reclaimed mining areas.

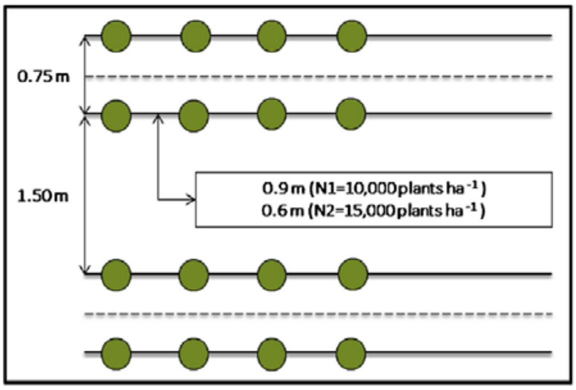
4.1 Location of the study area

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 [9].

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) [10] and because they display good structural attributes and yield capacities for biomass production in SRC [11]. The cuttings were planted according to a double row planting design, leaving a distance of 0.75 m between each set of double rows, a distance of 1.5m 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 4).

Figure 4. 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 [12] 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 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. Table 1 shows the results obtained, with maximum productions reached of 95 t/ha of wet biomass for poplar clones AF2 (populous 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 $^{-1}$.

Table 1. Biofuels production from poplar clones

Poplar Clone	Fertilization Level	Humidity (%)	Wet Production (t/ha)
AF2	F0	46	25
	F1	50	75
	F2	43	95
Beaupré	F0	51	27
	F1	49	50
	F2	55	90
Monviso	F0	45	15
	F1	44	62
	F2	53	87

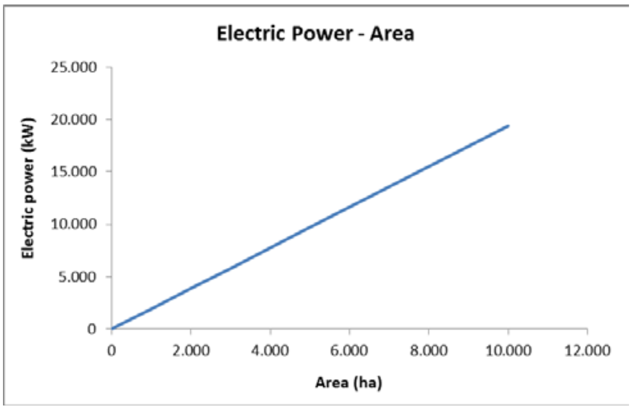
After five years of growth, the plantation was harvested for the first time. Depending on the slope of the land in which the plantation is located, this cut could be mechanized, assuming a reduction in costs. The processed material is extracted from the forest and transported to a stock for a while, 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 fuel. Table 2 summarizes the production of electricity 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 kWh^{t} ha^{-1} year^{-1}. The production of electrical energy is 14.574,24 kWh^{e} ha^{-1} year^{-1}. The electric power would be 1.94 kW per hectare of land.

Table 2. Electrical power per hectare

Electrical Power	
Biomass production (t ha^{-1})	95
Rotation cycle (years)	5
LCV (kcal kg^{-1})	2,200.00
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
Power (kWe ha^{-1})	1.94

Figure 5 shows the installed electrical power as a function of the surface repopulated with short rotation energy crops, with the biomass productions that have been previously indicated.

Figure 5. Electric power



6 Conclusions

The use of biomass energy has many unique qualities that provide environmental benefits. It can help mitigate climate change, reduce acid rain, soil erosion, water pollution and pressure on landfills, provide wildlife habitat, and help maintain forest health through better management.

The application of such fuels in industry offers a wide range of ecological and, in many cases, economical advantages like: conservation of fossil fuel resources, reduction of the dependence on fuel imports, utilization of agricultural and forest residues, reduction of emission of harmful species from fossil fuel combustion, recultivation of non-utilized exploitation areas, and minimization of waste disposal.

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 restored lands can be used for the production of biofuels through repopulation with fast-growing energy crops and high planting densities. 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.

By growing poplar SRC on degraded lands and with a minimum of energy input (e.g. use of chemicals, irrigation and fertilization), environmental challenges and competition with food crops can be minimized. From this study, we learnt that the SRC systems on degraded lands can payback the energy invested in their production. Carefully selected plant material and adjusted plantation maintenance may even further increase the energy ratio of poplar SRC on degraded lands.

Acknowledgements

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