Ciências ULisboa | Engenharia Geográfica, Geofísica e Energia

Energy Systems

Solid Biomass for Co-generation

Integrated Master in Energy and Environmental Engineering
Academic Year 2020/2021

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1 Introduction

Currently, about 4/5 of the primary energy supply is covered by fossil fuels. In the course of the energy transition, which is becoming increasingly important in the context of climate change to reduce CO2 emissions, these are to be replaced by renewable energy sources. In order to achieve the goal of a clean turnaround as quickly as possible and to prevent global warming, all available resources must be used. Biomass is an emerging resource that has been used for energy generation for centuries. Biomass accounts for between 10-15% of the world's energy supply and in developing countries its share is even higher and lies between 20-30%. Biomass has a very wide range of applications. It can be processed into various solid, liquid and gaseous fuels, or burned directly. The simplest but also the most widespread use of biomass is direct combustion. With a share of 95%-97%, it represents the largest share of current bioenergy production (Abbas, T. et al., 2020). Solid biomass energy crops, garbage and waste from industry, agricultural and forestry operations, urban waste, as well as organic material extracted from forests and uncultivated land can be used for energy purposes. The use of solid biomass for energy production in the EU increased by 134% in 2017 compared to 1990 levels and accounted for 12.5% of total primary energy production. Woody biomass accounts thereby for the largest share of biomass for energy purposes (Malico, I. et al., 2019).

The objective of this work is to evaluate the renewable energy potential of an isolated island, specifically the potential of using direct combustion of biomass for energy production. It provides an overview on today's most relevant technologies and feedstocks. Then an economic analysis is carried out to determine the costs of two different technologies and scales to see which is best suited for the project.

2 Technology

Any biomass with a moisture content lower than 50% can be used for direct combustion. The equipment currently installed ranges from small heating plants to large industrial furnaces with capacities from 10-3000 MW. The most common boilers are grate heaters and fluidized bed combustion chambers. They can be operated either completely with solid biomass or additionally with coal. In industrial combustion plants, mostly woody biomass and urban waste is used. During combustion, heat is generated to supply the surrounding area with direct and industrial heat, or to produce steam for electricity generation. The high-pressure steam is used as a medium to drive a steam turbine and with a generator mechanical work is converted into electricity. The efficiency of biomass combustion plants for electricity generation is 17%-25%, and co-generation can increase the efficiency up to 85%. Co-generation is a widely used method of generating electricity and heat. In this process, a heat exchanger is used to recycle the otherwise wasted heat. The most widespread technologies to produce electricity and heat with biomass are steam cycle and organic Rankine cycle systems (Abbas, T. et al., 2020).

2.1 Steam Cycle

Currently, the most widely used technology for the co-generation of electricity and heat from solid biomass is the steam turbine (Malico, I. et al., 2019). In the steam cycle process, the steam driven by the combustion is fed at high temperature and pressure to a steam turbine, where the thermal energy of the steam is first converted into mechanical work and then into electric power. After the tubing, the expanded steam is liquefied with the release of heat and the heat is transported by means of a heat distribution system and can fulfill various tasks. This process is the most widely used for the production of electricity and heat from biomass and consists of the following main components: a combustion system, a steam boiler and distribution system, a condenser and an electric generator. However, it is not suitable for small scales less than 100 kW (Abbas, T. et al., 2020). Steam turbines can be installed with outputs of up to 50 MWe, but are also economically viable from a value of 1 MWe. Their electrical efficiency is between 15-35% and depends very much on the size of the plant and the efficiency usually increases with the capacity of the plant (Malico, I. et al., 2019). The electrical efficiencies for steam processes with an electrical output of 1-10 MWe are typically between 20-30% and the overall efficiencies are between 80-90% (Marianne, S.P., 2003).

2.2 Organic Rankine Cycle (ORC)

In Organic Rankine Cylce processes an organic fluid with better thermodynamic properties is used as the heat transport medium instead of water. Due to the lower evaporation temperatures of the medium, higher overall efficiencies of co-generation plants can be achieved. ORC-plants consist of two separate circuits, one using organic liquid and the other using thermal oil. The heat generated from biomass is first absorbed by the oil circuit and then transferred through an exchanger to the organic fluid, which is expanded in the turbine to produce electricity. The main components of this process are a pump, an evaporator, a condenser and a turbine and it is suitable for medium scale plants. After the steam is expanded it changes its phase in the condenser where heat is released for further use. (Abbas, T. et al., 2020). ORC are very similar to steam turbines, but are working with lower temperatures. Systems with volumes of up to 8 MWe are commonly used worldwide, but smaller systems with capacities in the range of 1 MWe are widely used for biomass co-generation. The advantage of ORC over steam turbines is lower investment and maintenance costs. Furthermore, they work better under partial loads and have higher efficiencies at the same production volumes (Malico, I. et al., 2019). One of the first European ORC power plants was installed in 2004 in Scharnhausen near Stuttgart. The nominal power output of the plant is 1 MWe. It can be operated efficiently between 30 and 100 percent of the full load and the excess heat is distributed via a heating network to the neighboring buildings within a distance of 13 km (Strazalka, R. et al., 2010). In the study Techno-economic survey of organic Rankine cycle (ORC) systems of Quoilin et al., they speak of an electrical efficiency of 18% and a thermal efficiency of 70% for modern ORC systems.

3 Usage of heat

In the EU, most of the electricity consumed by industry is used for heating. In 2012, the share of final energy consumption in industry for space heating was 11% and the share for process heating was 60%. More than 80% of the EU's process heat is used in the iron and steel industry, the chemical industry, the paper industry, the tobacco industry, as well as the food and beverage industry. In 2014, the food and beverages industry were the largest sector in the EU in terms of sales, value added and employers (Malico, I. et al., 2019). Since the temperature on our island hardly is below 5 degrees C° there is not that much need for space heating, rather in households or industry. The surplus heat available through co-generation can be used for industrial purposes. Since the goal of our project is to plan a self-sufficient island, it would make sense to use the heat for the food and beverage industry, where heat with temperatures under 200 degrees C° are required. In addition, this sector generates a large amount of organic waste that can be used as feedstock for the CHP plant, thus creating a closed circuit. Another possible way to use the heat could be in the paper industry and it would also make sense in case of the morphological characteristics of our island, since there is a lot of wood. This would again generate biomass waste that could be used for energy purposes.

4 Feedstock

As feedstock, we studied the possibility of using agricultural waste, forest residue, *miscanthus x giganteus* and *panicum virgatum* as energy crops and wood. Agricultural waste is defined as unwanted waste produced as a result of agricultural activities (i.e., manure, oil, silage plastics, fertilizer, pesticides and herbicides) (Ramírez-García, R. et al., 2019). Agricultural residues include stalks, leaves, roots, husks, nuts, and seed shells. The disadvantage of using agricultural residues is crop seasonality that creates an unsteady and unreliable biomass supply. (Gravalos, I. et al., 2016). The study of Singh, J. et al, 2013 showed that 14462.85 thousand tons of crop residues, from various crops, can be used to generate 917.57 MWh of energy. Therefore, we estimated that 1 ton of agricultural waste is produced from 1 hectare in 1 year, that can generate 0.06 kWh ha^{-1} yr^{-1}.

Forest residues include wood chips, bark, sawdust, timber slash, and mill scrap. The energy contained in forest residues due to deforestation, woodland clearing and firebreaks is very high and end up being wasted. These residues can be used as a renewable energy source (Gravalos, I. et al., 2016). Baruya, P., 2015 reported that in terms of forest residue there is about 90 t/ha. And the average calorific value of the residues is 15,78 MJ/kg. (Nurek T. et al, 2019).

In order of studying the possibility of using wood in co-generation systems on our island, it was important to have an estimation of how many trees ha^{-1} we should consider, the average weight of a tree and the energy content of wood. To know how many trees per hectare should be considered, and in order to this value being congruent with the climate data of the island, since the island has similar climate to Portugal, Crowther, T. et al., 2015, suggests, from the histogram of the predicted forest tree density values for Mediterranean locations, that it should be an average 900 trees ha^{-1}. For the estimation of the average weight of a tree, we assume that it was 3.89 tons based on the calculation of the average merchantable weight (tons) of hardwood trees (Cunningham K., 2019). With these values it was estimated that the island has 3501 tons of trees per hectare. In the table X the energy content per hectare per year is presented and the energy density for wood, forest residues and agricultural waste estimated. To estimate the energy density of wood and energy per hectare per year, we started by finding the average value of net-heat combustion for multiple types of wood from (Gunther B. et al., 2012) which was considered to be 4.9 kWh/kg .

4.1 Possible biomass crops

In theory, any crop could be used as an energy crop. In practice, however, issues relating to the availability of feedstock and the efficiency, cost effectiveness and sustainability of the whole chain, from field to fuel restrict the choice. The term ‘‘dedicated biomass crops’’ refers to nonfood crops that are solely grown for biomass production. These comprise mostly perennial grasses and fast-growing trees. Dedicated biomass crops were first developed for combustion and thermal conversion technologies. (Karp, A. et al., 2010). This type of crops can be profitable while generating renewable energy, especially in tropical and sub-tropical regions, which is our case, considering the great availability of solar energy, as well as fertile and wet land.

In this chapter we explore *miscanthus x giganteus* and *panicum x virgatum* crops as feedstock. These crops were chosen considering their capabilities of surviving the climate of the island and for their promising characteristics.

4.1.1 Miscanthus

Miscanthus x giganteus is a large perennial rhizomatous grass, which is originally from East Asia. (Sa, M. et al., 2020). In this paper it is referred to as *Miscanthus*.
The key advantages of Miscanthus are:

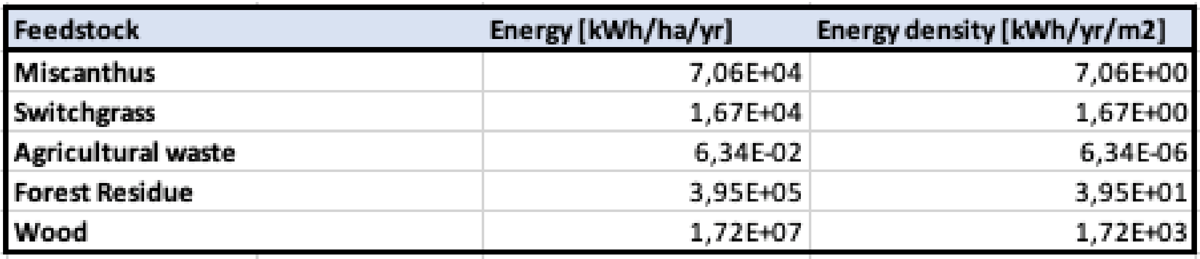
1. High biomass yield and land use efficiency. It is reported that its average annual biomass yield can reach 30 t/ha (dry matter) with minimal agricultural inputs. This is much higher than other energy crops, such as switchgrass and reeds. This means that planting *Miscanthus* has higher land use efficiency by using less land to match more energy demand.
2. Remarkable environmental adaptability and strong stress-tolerance ability. *Miscanthus* can grow under a wide range of climatic conditions. This assures that it can be planted at a large scale and that it can maintain a steady supply for energy use. Moreover, it can be planted on non-agricultural lands. This allows more arable land to be used for food production.
3. Low fertilizer and pesticide inputs and high water use efficiency, compared to other energy crops, which lowers the maintenance cost.
4. Low labor and management costs compared to other crops. This type of grass can be harvested for 15 to 20 years after its establishment.
5. Low ash content and high calorific value. In contrast with agricultural wastes and other herbaceous energy crops. Which makes it an ideal option to the production of heat and electricity, from direct combustion (Sa, M. et al., 2020).

In terms of energy, *Miscanthus* biomass produces more net energy per hectare than other bioenergy crops. Felten et al. (2013) reported 254 GJ/ha/yr (McCalmont J. et al., 2017). Present-day clones and varieties yield over 55 tons of raw biomass per hectare per year in favorable conditions. (Weger, J. et al., 2020).

4.1.2 Switchgrass

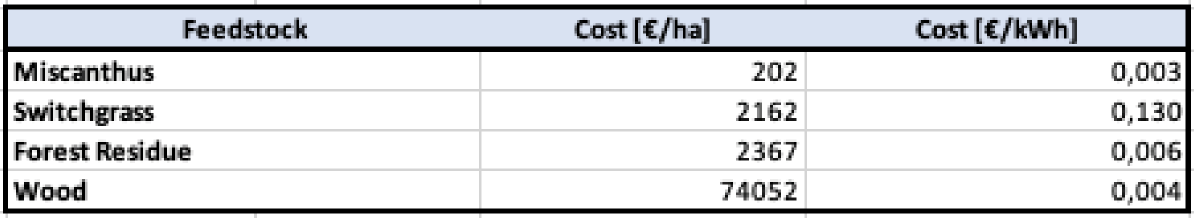
Panicum virgatum, is commonly known as switchgrass. As a cultivated crop, switchgrass has gained a great deal of attention as a biomass feedstock for renewable energy. In addition to biofuel feedstock and forage, other major uses for switchgrass include conservation plantings to control erosion, sedimentation, and nutrient runoff. Switchgrass in general is efficient utilized as resource and is well adapted to sites with limited to moderate fertility. In terms of energy, switchgrass yields equated to an average net energy yield of 60 GJ ha^{-1} yr^{-1} (Keene, T. et al.,2010). According to McLauglin S. et al., 2005, a summary of switchgrass yields across 13 research trials sites in the United States found that the top two cultivars in each trial to yield 9.4 to 22.9 t/ha.
The table X also gives us the estimations of the energy per hectare per year it can be produced from *Miscanthus* and switchgrass, with their respective energy density [kWh/yr/m^2] of these perennial grasses.

Analyzing this table, it’s observed that agricultural waste would have a residual value in our feasibility study and therefore it was not considered. In the table below we have the price per hectare and kWh for the rest of the feedstocks.



Feedstock	Energy [kWh/ha/yr]	Energy density [kWh/yr/m2]
Miscanthus	7,06E+04	7,06E+00
Switchgrass	1,67E+04	1,67E+00
Agricultural waste	6,34E-02	6,34E-06
Forest Residue	3,95E+05	3,95E+01
Wood	1,72E+07	1,72E+03

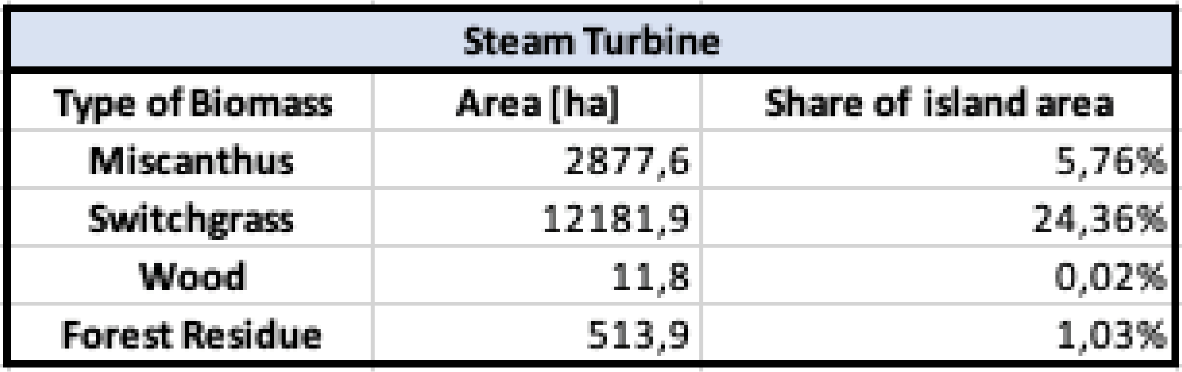
Table 1: Energy content of feedstocks



Feedstock	Cost [€/ha]	Cost [€/kWh]
Miscanthus	202	0,003
Switchgrass	2162	0,130
Forest Residue	2367	0,006
Wood	74052	0,004

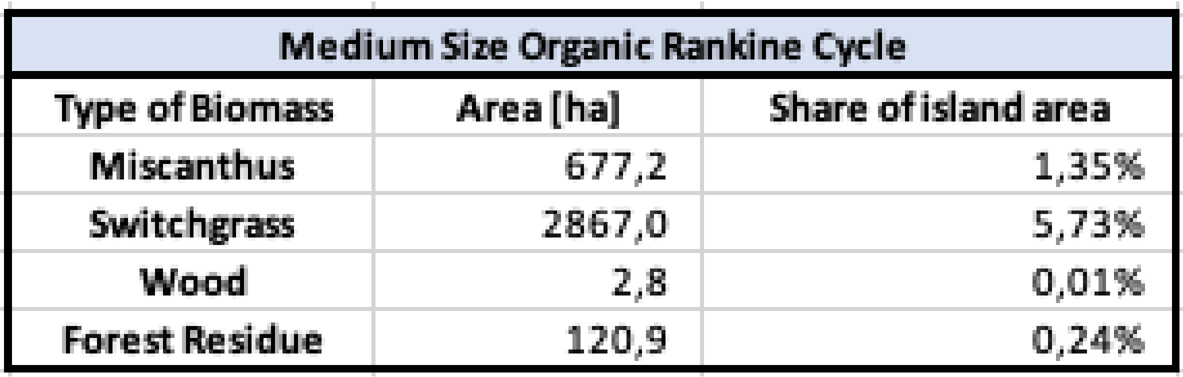
Table 2: Costs of Feedstocks

In order for a biomass power plant be efficient, it should have a fuel gathering radius, to help keep transportation costs low. According to Liu, Z., 2017 from a fuel gathering radius of 30 km, wheat can sufficiently supply a plant with a nominal capacity of 31 MWe. This means that for a steam turbine with the characteristics referred on this paper it would be a radius of 4,84 km (which is equivalent to 7355 ha and for the Medium Size Organic Rankine Cycle a radius of 0,97 km (which is equivalent to 294 ha). The average total output energy of wheat production was 38 GJ ha^{-1} (Khoshnevisan B. et al., 2013). So, in this case, wheat energy density would be of 1,06 kWh yr^{-1} m^{-2} which is lower than any of the feedstocks considered in our case of study. This means that with the same number of hectares, using our feedstock, we can produce more energy. So, in this case we need to know how many hectares of each feedstock would be necessary to supply the powerplant. The next table shows how many hectares would be necessary to supply the whole power plant considering the use of only that feedstock.



Steam Turbine		
Type of Biomass	Area [ha]	Share of island area
Miscanthus	2877,6	5,76%
Switchgrass	12181,9	24,36%
Wood	11,8	0,02%
Forest Residue	513,9	1,03%

Table 3: Area of feedstocks covering primary energy demand for Steam Cycle



Medium Size Organic Rankine Cycle		
Type of Biomass	Area [ha]	Share of island area
Miscanthus	677,2	1,35%
Switchgrass	2867,0	5,73%
Wood	2,8	0,01%
Forest Residue	120,9	0,24%

Table 4: Area of feedstocks covering primary energy demand for ORC

Analyzing the table X,Y,Z, it is observed that switchgrass is the most expensive one, it doesn´t have the most energy density and it would require more of the area inside of the fuel gathering radius to produce enough power to supply the systems alone. So, it should also not be considered in our feasibility study. We can also conclude that the cheapest ones to use would be miscanthus and wood, and that for the steam turbine system their production, considering they have to supply the power plant alone, is inside of the fuel gathering radius for the steam turbine system. But to prevent excessive costs of production for the steam turbine we considered a usage of 50% of the total area of *miscanthus* necessary to supply the whole power plant alone and 50% of total area of wood. For the ORC, we considered 20% of miscanthus and 80% of wood.

5 Socioeconomic perspectives

With the increase in the use of biomass as an energy source, there is constant talk of rapid land use change and threats to food security. In 2007, when food prices peaked, the production of biomass for energy purposes was believed to be responsible. However, the assumptions were not reasonable, and as new data were collected, it became clear that food prices could not be explained so simply. For example, it was observed that food prices dropped dramatically when biomass production peaked. A study from the USA also showed that the environmental impact of using biomass for energy is less than initially assumed. For example, no direct relation was found between the cultivation of corn as an energy crop and deforestation in other parts of the world. However, it is clear that with an increased use of biomass, the demand for land in the agricultural sector will also grow. However, it is difficult to verify whether this will affect the production of food. Increasing the productivity of energy crops, reducing the amount of wasted food and developing the technologies used in this context play a major role (Rosillo-Calle, F., 2016).

Even though the EU 28 is still almost self-sufficient in biomass supply, there was an increase in import dependency over the last years. In addition, an increase in the use of biomass for energy and material use is also predicted. Since the sustainable production possibilities are limited experts have concerns about the future sustainable supply of biomass for EU 28. Much of the forest biomass used in energy production is sourced from unverified forests. The farming of forests in the EU is mainly regulated by the reliable forest management rules and additional sustainability criteria for receiving subsidies. However, further binding regulations on the aspect of sustainability for the use of solid biomass for energy usage have already been considered by the European Commission. A consequence of this could be a reduced availability of biomass. Furthermore, biomass can be used as a substitute for fossil resources in the chemical industry as feedstock for the production of bulk chemicals (Malico, I. et al., 2019).

Thus, in addition to the competition from the food and energy industries, there would be another competitor and it might result in a further shortage of biomass availability.

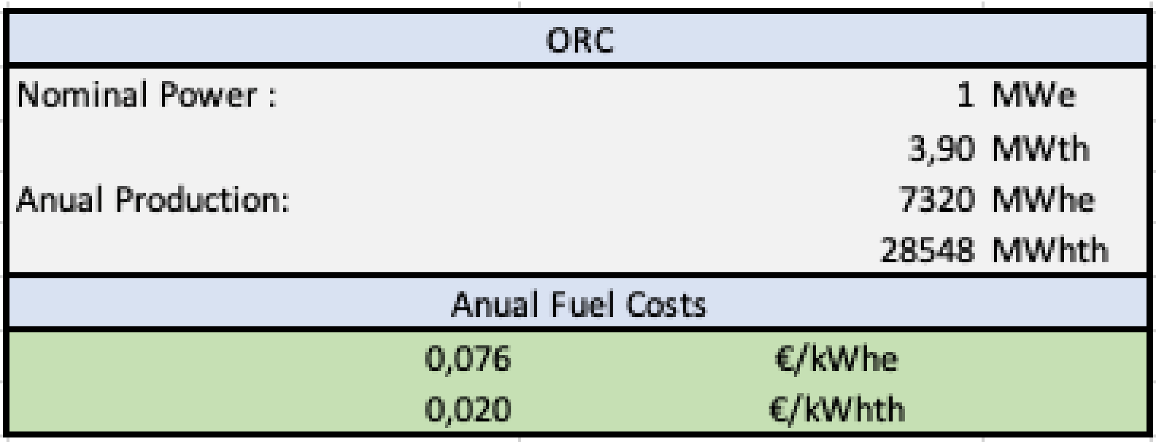
The use of biomass, such as woody biomass, to generate energy is generally suitable for a more sustainable and environmentally friendly energy supply. However, it is important that the resource is assessed over its entire lifetime and that regional impacts are also taken into account. All in all, the use of biomass for energy production can reduce CO2, NOx, CH4 and CO emissions. In addition, the processing of woody biomass can create rural jobs and new business opportunities for the forestry industry. Through increased job opportunities, a greater output can be generated, and therefore it can be seen as a optimal way to push the regional economy.

6 Feasibility study

After we had done our research and found suitable technologies and fuels, we carried out an economic analysis. We decided to investigate two different systems with different capacities. From the literature we used, we found that ORC is better suited for smaller capacities, so we chose a system with a nominal electrical output of 1 MW. On the other hand, it is evident that the efficiency of steam cycle systems is very dependent on their size. Here we chose a system with a nominal electrical output of 5 MW. For our calculations we assumed a discount rate of 5% and a lifetime of 25 years, which is usual for these kinds of investments. The feed-in tariff for electricity from woody biomass is 119€/MWhe according to the renewable energy policy database of the European Union and for the generated heat we assumed that the price is about one third of the electricity price and amounts 39,97 €/MWh. The operating time of the power plants is 305 days per year, because we took into account 2 months for maintenance and cleaning and for the fuel prices, we used the values from the feedstock chapter.

6.1 ORC

According to the study by Malico, I. et al., the price of an ORC system with an electrical output of 1 MW is around € 3.6 million. For the maintenance costs we calculated 200,000 € per year and for the administration we assumed a value of 60,000 € per year. We took these figures from an economic analysis already carried out for a system of the same scale in the study by Uris, M. et al. In order to stay within the fuel radius already described and to achieve the best economic result, 20% of the primary energy demand is covered with miscanthus and 80% with wood. In Table 5 the annual produced Energy and the annual fuel costs are reported. To see when our power plant starts to make a profit, we applied the discounted payback method and came to the conclusion that profits are generated from the third year onwards. In addition, we used the net present value method to determine the discounted value of the investment after 25 years. This is € 18,790,000. The above calculations can be found in the appendix.

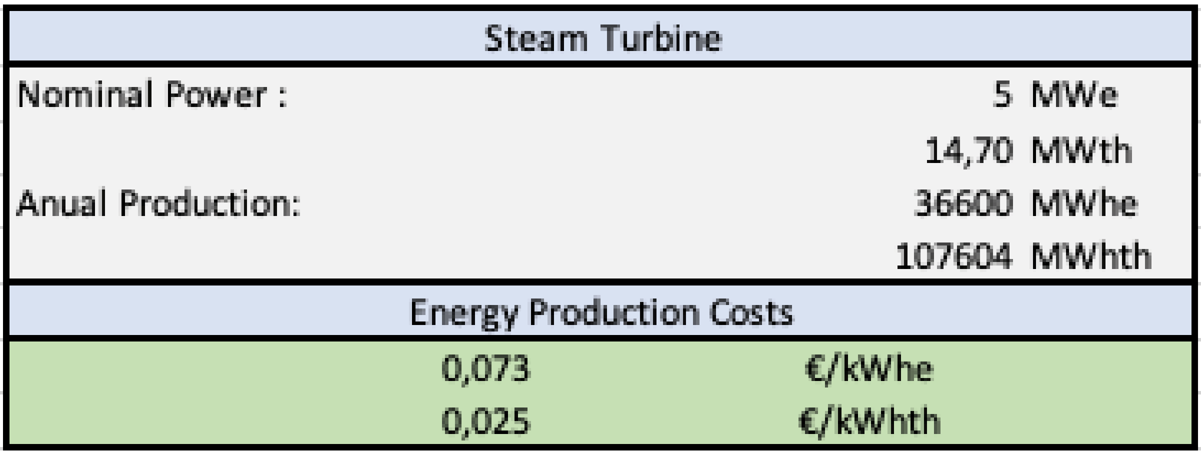


ORC		
Nominal Power :	1	MWe
	3,90	MWth
Anual Production:	7320	MWhe
	28548	MWhth
Anual Fuel Costs		
	0,076	€/kWhe
	0,020	€/kWhth

Table 5: ORC Data

6.2 Steam Cycle

The costs for a steam cycle plant with 5 MW of electrical output were taken from the same study, but according to this study the maintenance costs for ORC are lower, so we calculated 7% instead of 5.5% for maintenance. The investment costs are € 18.5 million, the annual maintenance costs are € 1.295 million, and the administration costs are € 60,000. However, since the fuel radius is much larger and miscanthus is cheaper than wood, 50% of each was used to cover the primary energy demand. The cost per kWh is almost identical to the cost of the ORC. They can be found together with the figures for annual energy production in Table 6. The discounted payback time for this investment is 4 years and the NPV is €75,575,800. The calculations can be found in the appendix.



Steam Turbine		
Nominal Power :	5	MWe
	14,70	MWth
Anual Production:	36600	MWhe
	107604	MWhth
Energy Production Costs		
	0,073	€/kWhe
	0,025	€/kWhth

Table 6: Steam Cycle Data

7 Conclusion

Finishing the analyze for the energy potential of the island using direct combustion of biomass for energy production and by observing the data we can settle that the price of producing energy using the steam cycle plant or the ORC system are similar. So, if the construction of a biomass power plant was to be considered, the choice of which one of these cycles to use should be about the scale of the power plant needed and not about the energy production costs. If what fits best the requirements of island is a bigger biomass power plant, it should be considered the use of a steam cycle plant but if what fits best those necessities is a smaller one, the structure should be built using an ORC system.

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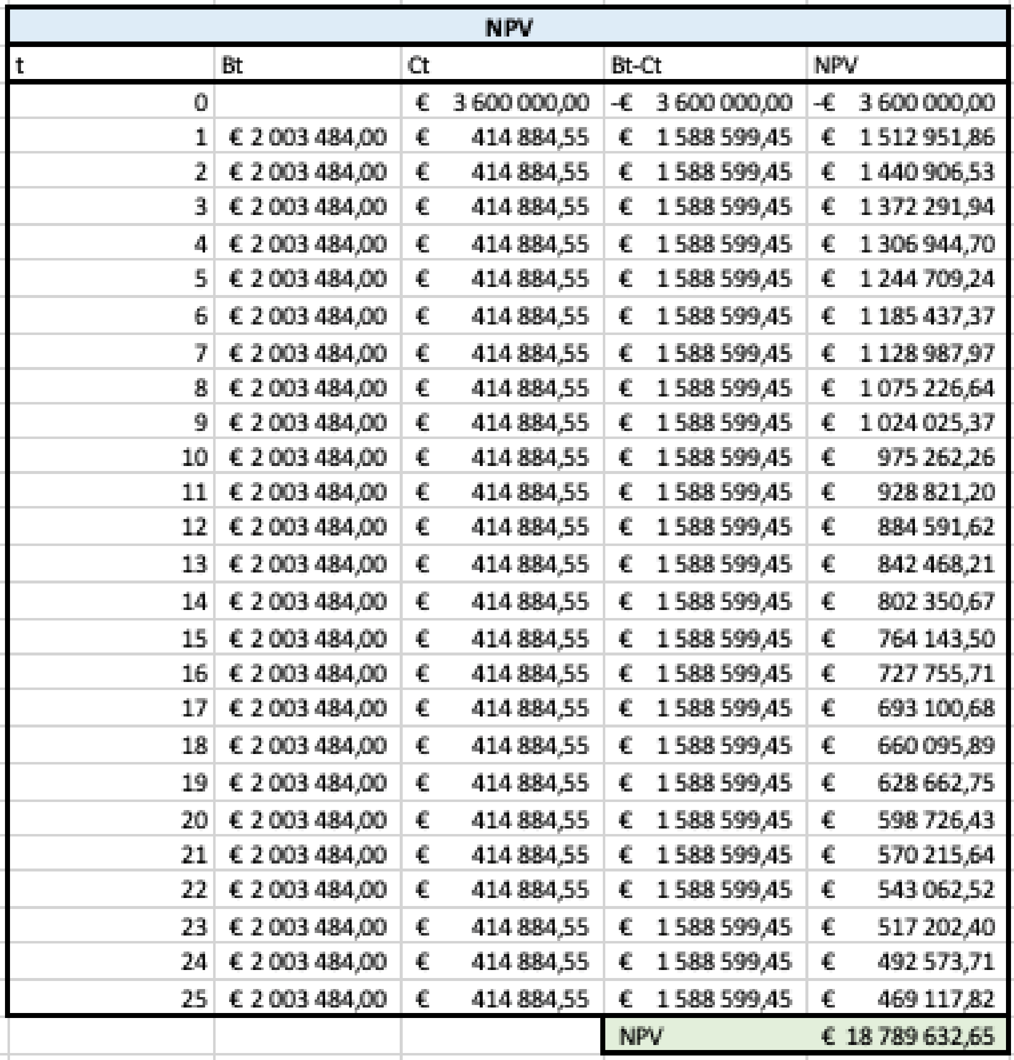
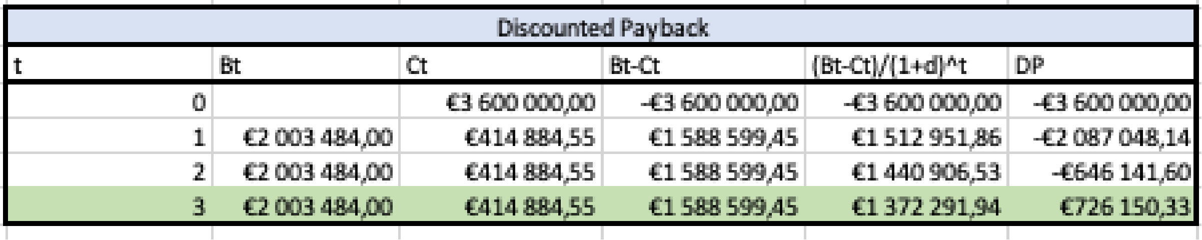
Appendix:

Net Present Value ORC



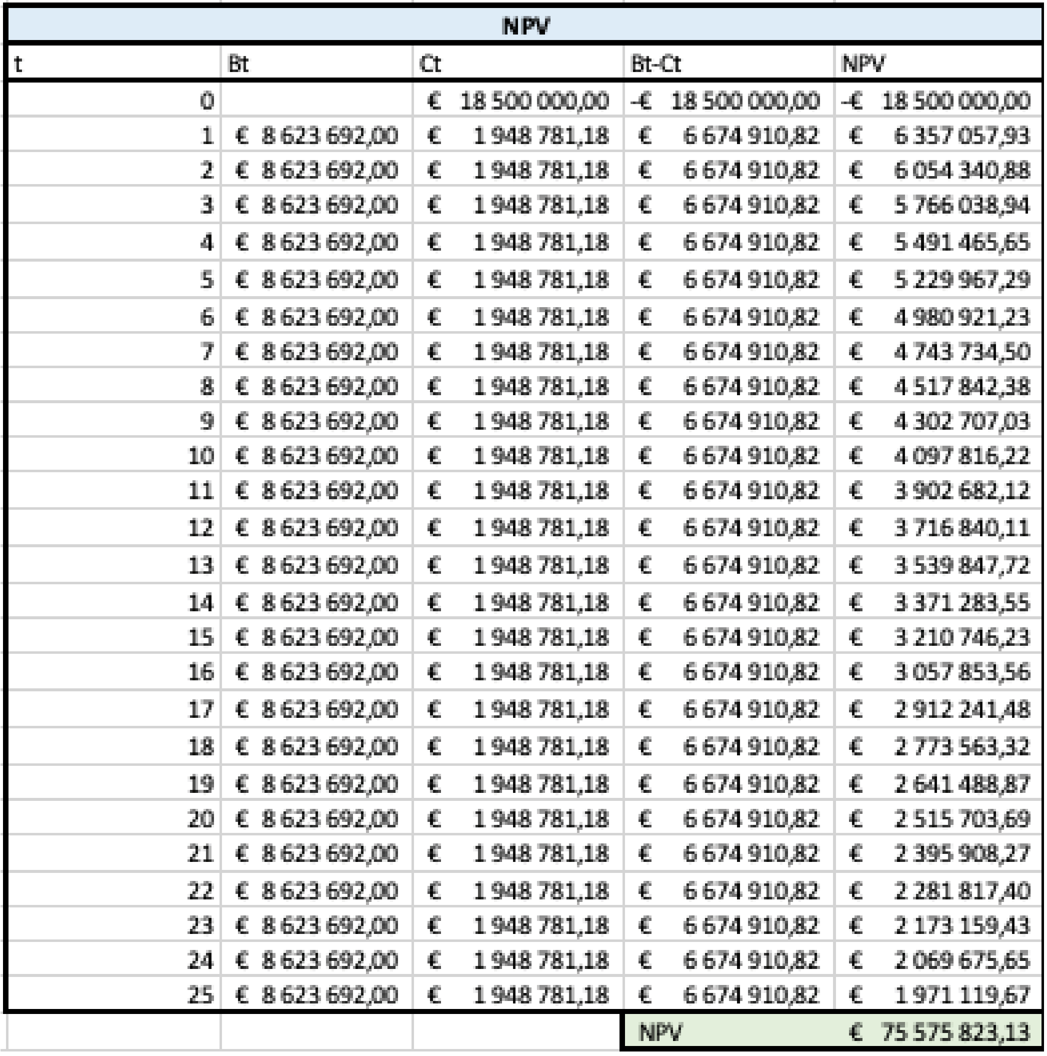
NPV				
t	Bt	Ct	Bt-Ct	NPV
0		€ 3 600 000,00	-€ 3 600 000,00	-€ 3 600 000,00
1	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 512 951,86
2	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 440 906,53
3	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 372 291,94
4	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 306 944,70
5	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 244 709,24
6	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 185 437,37
7	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 128 987,97
8	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 075 226,64
9	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 1 024 025,37
10	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 975 262,26
11	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 928 821,20
12	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 884 591,62
13	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 842 468,21
14	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 802 350,67
15	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 764 143,50
16	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 727 755,71
17	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 693 100,68
18	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 660 095,89
19	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 628 662,75
20	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 598 726,43
21	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 570 215,64
22	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 543 062,52
23	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 517 202,40
24	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 492 573,71
25	€ 2 003 484,00	€ 414 884,55	€ 1 588 599,45	€ 469 117,82
			NPV	€ 18 789 632,65

Discounted Payback ORC



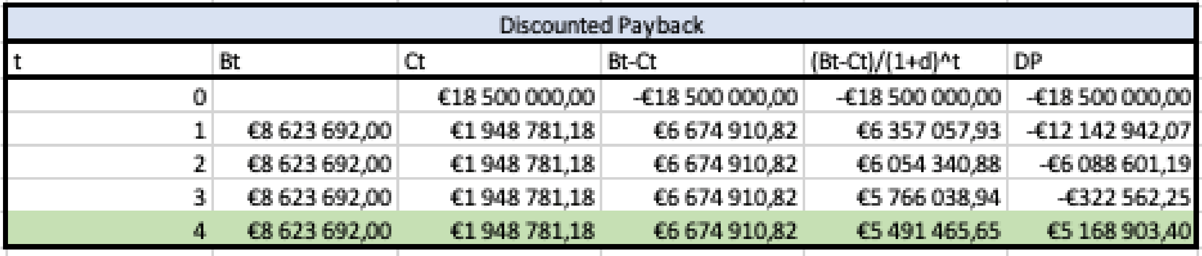
Discounted Payback					
t	Bt	Ct	Bt-Ct	(Bt-Ct)/(1+d)^t	DP
0		€3 600 000,00	-€3 600 000,00	-€3 600 000,00	-€3 600 000,00
1	€2 003 484,00	€414 884,55	€1 588 599,45	€1 512 951,86	-€2 087 048,14
2	€2 003 484,00	€414 884,55	€1 588 599,45	€1 440 906,53	-€646 141,60
3	€2 003 484,00	€414 884,55	€1 588 599,45	€1 372 291,94	€726 150,33

Net Present Value Steam Cycle



NPV				
t	Bt	Ct	Bt-Ct	NPV
0		€ 18 500 000,00	-€ 18 500 000,00	-€ 18 500 000,00
1	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 6 357 057,93
2	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 6 054 340,88
3	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 5 766 038,94
4	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 5 491 465,65
5	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 5 229 967,29
6	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 4 980 921,23
7	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 4 743 734,50
8	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 4 517 842,38
9	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 4 302 707,03
10	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 4 097 816,22
11	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 3 902 682,12
12	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 3 716 840,11
13	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 3 539 847,72
14	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 3 371 283,55
15	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 3 210 746,23
16	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 3 057 853,56
17	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 912 241,48
18	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 773 563,32
19	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 641 488,87
20	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 515 703,69
21	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 395 908,27
22	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 281 817,40
23	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 173 159,43
24	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 2 069 675,65
25	€ 8 623 692,00	€ 1 948 781,18	€ 6 674 910,82	€ 1 971 119,67
			NPV	€ 75 575 823,13

Discounted Payback Steam Cycle



Discounted Payback					
t	Bt	Ct	Bt-Ct	(Bt-Ct)/(1+d)^t	DP
0		€18 500 000,00	-€18 500 000,00	-€18 500 000,00	-€18 500 000,00
1	€8 623 692,00	€1 948 781,18	€6 674 910,82	€6 357 057,93	-€12 142 942,07
2	€8 623 692,00	€1 948 781,18	€6 674 910,82	€6 054 340,88	-€6 088 601,19
3	€8 623 692,00	€1 948 781,18	€6 674 910,82	€5 766 038,94	-€322 562,25
4	€8 623 692,00	€1 948 781,18	€6 674 910,82	€5 491 465,65	€5 168 903,40