Risk analysis in terms of implementation of large scale cogeneration power plant

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Abstract. The introduction of large-scale technology carries a number of risks. This paper presents the risks associated with the introduction of a system for combined production of electricity and thermal energy (CHP) through direct combustion of biomass. It is envisaged that the residual amount of heat energy will be converted into electricity through the use of an ORC module. All possible risks have been identified based on the technology specifics, and the possible consequences of the risk have been indicated. A risk matrix has been prepared for both site and technology specifics in order to identify the type of risk. Based on the outputs, a proposal for reducing the risk has been made.

1. Introduction
The last few decades have seen increased interest in the use of biomass for combined heat and power production. The extensive research performed shows that quantities of unused waste wood material worldwide are significant, which is a prerequisite for the development of technologies of this type [1-3].

In the process of developing the investment plan to build power plants using wood biomass, technical and engineering decisions were driven by the available raw materials and their calorific values. This is usually done to ensure the smooth operation of the plant while minimizing raw material risk.

There are different types of technologies available in terms of processing of biomass. Usually the one technology is related with direct combustion of biomass and further utilization of the thermal energy produced [4-6], and the second one with indirect utilization of biomass through process like pyrolysis, gasification and etc. [7-10].

A significant number of the above-mentioned cogeneration systems are installed in remote areas, which makes the use of thermal energy very difficult. Up to 30% of the thermal energy is used for preparation (drying) of the wood material, while the rest is released into the atmosphere. This significantly worsens the financial performance of the project, which is why methods to utilize the remaining amount of thermal energy are often sought. Additional modules (ORCs) are often used to transform heat energy into electricity [11-14].

The different technologies related to the utilization of biomass have a number of different risks in terms of operation, both of the individual modules and of the system as a whole. For this reason, accurate risk assessment during the process of implementation of such facilities is essential for the profitability of the project. In technologies related to the utilization of biomass, there are risks that are common to
all technologies, but the majority are strictly specific and relevant to the respective technology. Partial risk identification is presented in [15], where the main focus is on the biomass gasification process. An risk assessment regarding the operation of the facilities is presented in [16], and the risk in the financing of such facilities is presented in [17].

The study shows that proper risk assessment is essential for the implementation of a successful project. Therefore, in the present work, a methodology for risk assessment during the implementation of a large scale power plant operating with directly burned wood biomass is presented. The significant factors to be taken into account are indicated, as well as the possible consequences.

2. General information of the combined heat and power (CHP) power plant

The current study focuses on risk analysis in terms of implementation of CHP power plant running on direct combustion of a biomass. The information for the use of waste wood as a fuel for the biomass boiler is presented. The heated thermal oil will be used for heating of organic fluid, which will be used for combined electricity and thermal energy production by Organic Rankin cycle (ORC) module.

The town where the plant will take place is a part of Pazardzhik municipality. It is located in the south-western part of Bulgaria, about 200 km from Sofia city. The timber industry is well developed in the region. The majority of the population from the near towns and villages is occupied with logging. There are many workshops and enterprises dealing with woodworking.

2.1. Description of the selected technology

Overview of the entire installation is presented in Figure 1. The diagram in Figure 2 represents the main flows in the installations.

![Figure 1. Overview of the cogeneration system.](image1)

![Figure 2. The main flows in the system.](image2)

2.1.1. Fuel flow

- **Moving plate sylo**
  The fuel is unloaded by mechanical means into a right-angled containment tank made of cement. An extraction system with racks is installed at the bottom of the tank; each rack is operated by a hydraulic piston that sets the rack in forward and backward motion. Thanks to the special design of the rack, through this movement the fuel is conveyed towards the front unloading zone. The functioning programming is operated by the central unit located in the electrical switchboard of the boiler in relation to the fuel demand of the system.

- **Fuel Redler conveyor**
  The reception, conveying and dosing of the fuel from the silo to the boiler will be performed by: double chain drive conveyor (Redler) with bottom metal carriers supplied with scraper made of Teflon, the Teflon is self-lubricating for the noise reduction, and the efficiency of the fuel handling action, supplied with corresponding infrared sensors of work and security and anti-blockage levels.

- **Duplo system**
The fuel is then conveyed from the conveying system to the double chain feeding system called “Duplo”. The main purpose of Duplo is to move from the outside to the inside of the boiler the solid fuel which is inconsistent and not aggregate by nature. The process is performed by overcoming the possible friction forces due to the passing on a closed channel and cutting the incidental parts exceeding their own working area. This way it is possible to operate with very heterogeneous materials; this makes the machine flexible to be fed by big-sized pieces. A Duplo system consists of 2 feeding screws with bearing on shaped seats and transmission with flexible coupling, ideal for the introduction of ground fuel and able to receive the incidental load of scrap lumber up to cm 30 cm long and 8 x 8 cm of section, thanks to the opportunity of the screws to vary the rotation axis avoiding blockages of the system.

- **Combustion chamber**

  The fuel is then brought onto a combustion chamber. The combustion is performed on a moving grate through the forced inflow of combustion air which is mixed with the gases in three different phases: primary air (under-grate), secondary air (over-grate) and tertiary air (post-combustion chamber). The grate is characterized by independent handling in the different zones of the grate. This allows an independent adjustment at the different phases: fuel drying, preheating, lighting on, combustion completion and ashes evacuation. The elements of the grate are made of special Nickel alloy. The combustion chamber supports structure with forced water cooling. The load bearing structure is made of steel plates with thickness of 10 and 12 mm. This structure will be able to bear both the heat stress and the operation pressure. The combustion chamber reaches temperatures ranging 900 to 1300 °C and it has several doors for periodic cleaning of the brazier. The combustion chamber is completely coated with refractory material to grant a high and constant temperature of the smokes. The external surface combustion chamber is insulated with mineral wool (150 mm in thickness, with density of 100 kg/m³). The ashes after the combustion chamber are conveyed from the moving grate towards the ashes extraction and management system.

- **Heat exchanger**

  The hot gases (fumes) generated by the combustion chamber passed through a coil heat exchanger where they heat thermal oil Therminol 66. The nominal final temperature of the oil is 320°C. The exchanger efficiency is granted by a special automatic cleaning system.

- **Economizer 1**

  In order to increase the overall efficiency of the plant and recover the maximum thermal energy of the hot gases, they passed through gas/oil economizer to preheat the incoming oil in the main exchanger. The exchanger efficiency is granted by an automatic cleaning system.

- **Economizer 2**

  In order to increase even more the overall efficiency of the plant and recover the maximum thermal energy from the fumes, they pass through second gas/oil economizer to preheat the oil of the low temperature circuit. The exchanger efficiency is granted by an automatic cleaning system.

- **Economizer 3 – combustion air preheater**

  Once completed the maximum thermal recovery on the oil side, a further recovery is realized by means of a fumes/air recuperative heat exchanger that allows the preheating of the air before bringing it to the boiler as a combustion air. This has an important advantage as far as efficiency of the system is concerned as it enables either to dry the humid biomass in the combustion chamber, or to raise the temperature of the air in the boiler.

2.2. **System summarized technical data**

The boiler, type Global/G 500 OD, is engineered for combustion of biomass (waste wood) by an Italian manufacturer Uniconfort s.r.l. The boiler is coupled with Italian ORC module Turboden 12-HRS Split W.A., engineered for combined production of electrical and thermal energy. Thermal power of the boiler is 5 140 kW, and oil capacity – 10 600 l.

The technical data of the ORC module is as follow:

- Thermal oil inlet temperature at nominal load – 305 °C;
- Thermal oil outlet temperature at nominal load – 210 °C;
The principle of operation of the biomass boiler is as follows:

1) Wood waste is fed into the combustion chamber. Primary, secondary and tertiary air flows are fed into the chamber.

2) The hot flue gases, product of the combustion process, are used for heating of thermal oil. The main heat exchanger plus Economizer 1 are used for heating of thermal oil coming from the High temperature heat exchanger of the ORC module – from 254 °C to 314 °C. The Economizer 2 is used for heating of thermal oil coming from the Low temperature heat exchanger of the ORC module – from 154 °C to 254 °C. Economizer 3 is used for preheating of the supplied air (primary, secondary and tertiary).

3) The heated thermal oil (Q=174 m³/h, T=314 °C) is fed to the High temperature heat exchanger of the ORC module and it is used for heating of the organic fluid. After this heat exchanger the thermal oil is divided into 2 streams with temperature of 254 °C: 163 m³/h are returned to the heat exchangers of the biomass boiler and 11 m³/h are fed to the Low temperature heat exchanger of the ORC module. These 11 m³/h are cooled from 254 °C to 154 °C and they are transported to the Economizer 2 of the boiler.

The biomass boiler and the ORC module are the main parts of the system. In order to work properly the installation includes other machinery and equipment that are described below.

A building (industrial hall) will be constructed. It will be used for fuel storage. If the dimensions of the supplied wood waste are not appropriate, a new chipper will be used. The wood waste will be loaded/unloaded and transported by new wheel loader. New trailer and car will be purchased, too.

The quantity of the supplied biomass will be controlled by new constructed industrial scale. It will be used for measuring the incoming trucks with trailers at the entrance of the project site. Water tank for cooling water will be constructed. It will be complied with the system requirements. A backup electricity generator will be installed, if any problems on the system site occur.

2.3. Total project benefits
The manufacturers guarantee that the entire system can be in exploitation for 8 000 hours per year. In current study conservatively are adopted 7 500 hours per year. 7 500 h/yr are also used in all the documents published by the State Energy and Water Regulatory Commission.

The boiler is designed to operate with all kinds of chipped wood waste with moisture content of up to 55%. Closed fuel storages will be constructed, therefore the expected moisture content of the used wood waste should not be higher than 30%. The granted efficiency of the biomass boiler without the economizers is 88% and it can be increased with up to 5%, if the economizers are provided (as in our case). The main requirements of the biomass boiler are:

- Moisture content of the fuel: up to 55%.
- Ash content of the fuel: up to 8%.
- Max fuel size: 80 x 80 x 200 mm.

The average fuel consumption will be about 2 tons per hour. The calculations show that the required quantity of waste wood will be 15 000 tons per year (for 7 500 h/yr). If the plant is in operation for 8 000 h/yr, the required quantity of biomass should be about 16 000 tons per year. Three independent contracts for waste wood delivery have been signed: subject of each of the contracts is delivery of up to 600 tons of wood waste per month so the total amount of waste biomass that can be delivered to the project site is 21 600 tons per year.

The electricity power capacity of the ORC module is 1 156 kW and the thermal power capacity is 3 660 kW. The nominal electricity production of the system is 8 670 MWh per year and the nominal thermal production is 27 450 MWh per year. The own electricity demand of the system is 1 983.5 MWh per year.
Both the Italian companies Uniconfort s.r.l. and Turboden s.r.l. guarantee that there will not be any reduction of the efficiency of the system during the exploitation period. The main problem of the biomass boiler is the deposits that reduce the heat transfer surfaces but the selected boiler is equipped with sensors and cleaning installations. The experience shows that no deposits are found in boilers of such type. The reduction of the efficiency of the ORC module can be regulated by regeneration or refilling of the organic fluid. Also some adjustments or maintenance operations can be provided in order to reach their contractual performances.

After project implementation the following benefits are expected:
- The wood waste consumption will be 15 000 t/yr., amounting to EUR 268 428 per year.
- The electricity sold to EVN will be 6 686 MWh/yr., amounting to EUR 982 204 per year.
- The electricity sold to EVN will be 6 686 MWh/yr. thus the client should pay a transmission fee, amounting to EUR 9 812 per year.
- The annual operational and maintenance costs will be EUR 53 000 per year.
- The total revenues after project implementation will be EUR 650 964 per year.

The allocation of cash revenues and expenses after project implementation is presented in Figure 3.

Figure 3. Cash revenues and expenses after project implementation.

3. Risk assessment
"Risk assessment" is a decision-making process about acceptability of the risk based on risk analysis, the provisions of the regulations and considering on factors such as technical development, psychological, economic and social aspects.

The risk assessment can be made using four and five parameters matrix in terms of risk assessment (figure 4).

Figure 4. a) 4 four parameters and b) 5 parameters matrix of visual representation of risk assessment.
The proposed in Figure 4 matrix according [17] is subdivided into three areas:

- **Acceptable region**
  
The risks that can be attributed to the specified region are generally described as insignificant and adequately and easily controlled. Usually these can be easily controlled to produce very low risks. Hence further actions in order to reduce the risks is not required.

- **As low as reasonably practical region (ALARP)**
  
  Risks that fall in this region are usually activities that people are prepared to tolerate in order to keep benefits. If the defined risky events fall into the ALARP region, this does not mean for sure that the total risk for the implementation is ALARP, but that it should be considered whether further risk reductions are needed or not. In all cases, the risk assessment should discuss the following points:

  - Is the remaining risk acceptable or not?
  - Is it possible to undergo additional actions in order to reduce the risk level?

  The risk that falls in this region should be reviewed on a regular basis to make sure that they still meet the ALARP condition.

- **Unacceptable region**
  
  When the risks falls in this region they are classified as unacceptable and must be taken the actions to reduce the risk and to reach ALARP region.

  The classification of the regions should not over exceed the presented values in the risk matrix (Table 1).

  **Table 1.** Probability types.

| Notation             | Frequency range     |
|----------------------|---------------------|
| Extremely unlikely   | $<10^{-6}$ per year |
| Very unlikely        | $10^{-6}$ to $10^{-4}$ per year |
| Unlikely             | $10^{-4}$ to $10^{-2}$ per year |
| Improbable           | $10^{-2}$ to 1 per year |
| Probable             | $>1$ per year |

In term of the prosed technology the following risk can be identified:

- **Performance and technology related risks**

  A suitable equipment manufacturer / supplier must be selected. He must have the necessary experience in the production and commissioning of the equipment. It is obligatory to perform a study in terms of the number and quality of the projects completed by the manufacturer.

- **Performance Guarantees**

  This risk, all circumstances related to the construction of the installtion and its commissioning must be foreseen. If something is not fulfilled according to the current standards and norms of the country, then in the contract it is necessary to include these clauses. In addition, the contract must provide for clauses regarding the achieved operating parameters of the equipment. If the relevant performance is not reached, the manufacturer must be held responsible for this, and some penalties should be considered.

- **Completion Risk**

  Engineering, procurement and construction (EPC) contract for the plant site has the following major elements: project design; equipment provision; terms of payment; rules and rights of the contractor; the sequence of construction and assembly activities; testing; and the rights and duties of both the EPC contractor and Beneficiary.

- **Power Sales-Related Risks to the Owner/Lender, Review and Assessment**

  The assessment of this risk is extremely important. Energy produced from a renewable energy source is purchased at a preferential feed in tariff. That is why a contract for guaranteed purchase of energy is needed. The entire business plan is developed on this basis. In addition, it is necessary to make a study regarding the capacity of the network with a view to transporting the produced electricity.
• **Fuel related risks**
   Bulgaria’s current excess wood supply is not expected to change significantly over the next five years. The plant is favourably situated from a logistical standpoint because wood waste transportation distances of more than 10 km should not be required.

• **Site Related Risks**
   Risks related to the geological composition of the site should be considered here; availability of water source for the installation; risk of flooding on the site. With regard to the current site, geological analysis shows that failure is unlikely. The available drilling sources can meet the needs of the installation, as the lack of water is not critical for the operation of the installation. The lack of water basins or rivers is a prerequisite for the absence of possible floods on the site.

For the concerned biomass installation the risks are summarized in table 2.

| Risk identification | Probability | Consequences | Recommendations for risk management |
|---------------------|-------------|--------------|-------------------------------------|
| Permission for construction | Low | Average | Considering enough time to pass through all the procedures |
| Delay in delivering of the biomass equipment | Average | Low to average | Fixed initial delivery schedule with sufficient time reserve |
| Delay in construction works and set up the biomass installation | Average | Severe | Selection of experience and trained staff; hiring of Company with extensive experience in biomass plant construction |
| Damages and defects of the biomass elements during operation | Low | Severe | Proven companies and experienced contractors for design and construction of the biomass installation and additional elements |
| Reduced energy (electricity and thermal energy) production based on poor design or maintenance | Average | Severe | Hiring of experienced EPC and O & M contractors; warranty and provision of monitoring system for the entire installation operation in real time |
| Biomass installation damage caused by natural disasters | Low | Low | Insurance |

4. **Conclusion**
In the present work, a risk analysis in terms of operation of an installation for simultaneous production of thermal and electric energy through direct combustion of biomass is presented. The respective risks in terms of the following have been considered:
- site selection for the equipment;
- selection of basic and auxiliary equipment;
- commissioning and risk with regard to the performance of the equipment;

   In addition, the possible risks associated with the raw material used and the suppliers are considered. One of the most serious consequences can be mentioned is the choice of inappropriate technology and the subsequent impossibility of setting the equipment into operation. Impossibility to put the equipment into operation in time in view of the annually determined preferential feed in tariff is also should be a critical issue to deal with. Impossibility to quickly eliminate defects in the work equipment leads to serious financial issues. Impossibility to reach the operating parameters reflects the energy output and also the cash savings.
Of course, it is necessary to compile risk matrices for each identified risk and to indicate the ways to reduce them. In addition, these analyzes can be used to analyze the risk of other similar installations, taking into account the specifics of the new sites.

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