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INVESTING IN CHP PLANTS: ESTIMATING EXTERNAL COSTS AND BENEFITS

Abstract

Purpose: The purpose of this paper is to identify and evaluate the environmental impacts and estimate the external costs and benefits of building and operating a combined heat and power (CHP) plant. This research will contribute to the scientific literature in the field of public capital investments in CHP plants and facilitate the evaluation of similar assessments and studies by identifying relevant factors that affect society and the environment.

Methodology: The ExternE methodology and Impact Pathway Approach (IPA) were used to estimate the externalities of building and operating the plant. The ExternE methodology considers environmental impacts, global warming impacts and accidents, and it is widely accepted in the estimation of externalities of CHP plants.

Results: The main external benefits refer to the savings from the reduction of CO2 emissions per unit of energy produced, savings from the reduction of energy losses in the transmission of electricity, reduction of Croatia's dependence on electricity imports, improvement of the balance of payments, and fiscal benefits. The main external costs arise from Croatia's increasing import dependence on natural gas and changes in the use of agricultural land.

Conclusion: It is estimated that the external benefits are higher than the external costs. In addition to the estimation of external costs, their internalization is done through various taxes and fees, thus affecting the unit cost of electricity. Further research should extend the estimation of external benefits and costs to consider broader social impacts and conduct a full cost-benefit analysis.

Keywords: CHP plants, cost-benefit analysis, external costs, external benefits, green accounting

1. Introduction

In 2019, the European Union (EU) introduced the Clean Energy for all Europeans package (EC, 2019a). Alongside Energy Union (EC, 2015), which provides a framework for ensuring energy security, sustainability and affordability, the Clean Energy package includes key measures to enable the energy transition and make the EU carbon neutral by 2050.

According to COGEN Europe (2020), highly efficient combined heat and power (CHP) plants could provide a solution to achieve carbon neutrality. Indeed, energy efficiency is the pathway to significant reductions in greenhouse gas (GHG) emissions. CHP plants, also known as cogeneration, include simultaneous production of electricity and thermal energy. COGEN Europe (2020) stresses that CHP plants "can be optimised to maximise system energy/resource efficiency and flexibility" (p. 38). Besides the fact that they can achieve 90% energy efficiency (EC, 2014a), these plants bring numerous benefits to the EU; they reduce annual system costs by about €4-8 billion, lead to primary energy savings of 154-221 TWh and reduce CO2 emissions by about 3.8-5.5 million tonnes (COGEN Europe, 2020).

In this context, EU countries are required to carry out a cost-benefit analysis of the potential of using cogeneration for investments in plants with heat or electrical thermal input higher than 20 MW, in industrial plants producing waste heat with thermal input over 20 MW, and in a district heating and cooling network exceeding a total thermal input of 20 MW (EC, 2012). In terms of promoting energy efficiency, the cost-benefit analysis should provide an assessment „to establish the most cost-effective and beneficial heating or cooling option for a given geographical area for the purpose of heat planning" (EC, 2012).

When conducting a cost-benefit analysis, environmental and health impacts must be considered and externalities must be included (ExternE, 2005). The estimation of external costs and benefits, and consequently their internalisation, is one of the most important issues in energy investment projects. Externality can be defined as „any cost or benefit that spills over from the project towards other parties without monetary compensation" (EC, 2014b). Therefore, the purpose of this paper is to identify and evaluate the environmental impacts and estimate the external costs and benefits in the construction and operation of a natural gas-fired CHP plant in Croatia. In addition to electricity generation, this plant will also produce process steam and district heating for the city. Although natural gas is a fossil fuel, the GHG emissions of this energy source are significantly lower than those of coal or oil and when combusted in a highly efficient cogeneration plant, it can be considered a clean energy source. This research will contribute to the scientific literature in the field of public capital investments in CHP plants and facilitate the evaluation of similar assessments and studies by identifying relevant factors that affect society and the environment.

This paper is organized as follows. After the introductory section, the second section presents the problem of estimating externalities in the European context. In the third section, the methodology used is described, followed by a section on the environmental impact evaluation and estimation of external benefits and costs for a CHP plant. Finally, conclusions and recommendations for further research are given.

2. Estimating externalities in the European context

In 2005, the European Commission developed the ExternE (Externalities of Energy) project intending to assess the external costs of energy. The ExternE methodology (EC, 2005), based on the Impact Pathway Approach, has gained wide recognition in the scientific community for estimating the external costs of energy production. The following is an overview of the main papers in this field based on the ExternE methodology for European energy production.

Bozicevic Vrhovcak et al. (2005) calculated the external costs related to the environmental impact of thermal power plants on human health in Croatia for the year 2000. The power plants studied were differentiated by installed capacity, electricity generation, fuel, and location. The results showed that the average cost per unit of energy generated was US$ 3 million/kWh and that external costs depend largely on power plant emissions and plant location. Likewise, Georgakellos (2010) analysed the environmental externalities in thermal power plants in Greece for the period 2003-2004. He compared the impact of the internalisation of these externalities on electricity generation costs for different energy sources and found that external costs are particularly high for lignite-fired power plants. Streimikiene et al. (2009) studied the external costs of electricity in the Baltic States and reported that the highest external costs were in the Estonian electricity sector as it was based on oil shale, while the lowest external costs were recorded in the Lithuanian electricity sector.

These studies show that fossil fuels have high external environmental costs. External costs also affect unit electricity costs, as demonstrated by Czarnowska and Frangopoulos (2012). They assessed the environmental external costs of a pulverised coal power plant in Poland and concluded that these costs have a significant impact on unit electricity costs, increasing them by about 566% for a variation of plant with no abatement equipment and by about 70% for a plant with abatement equipment. Likewise, Streimikiene (2021) analysed the external costs of electricity generation in the Visegrad countries (Czech Republic, Slovakia, Poland, Hungary). The results showed that Poland has the highest weighted average external costs of electricity generation due to the high share of coal in electricity generation. Poland and Hungary recorded decreasing external costs during 2010-2018 due to the increasing share of renewables in their electricity generation structure, while external costs in the Czech Republic and Slovakia remained stable.

In contrast to fossil fuels, the external environmental costs of renewable energy are significantly lower. Patrizio et al. (2017) studied the environmental impacts of biogas-based technologies in Italy. Their results showed that the external costs of biogas-based technologies are lower than those of fossil fuel-based technologies. Streimikiene and Alisauskaite-Seskiene (2014) estimated the external costs of electricity generation in Lithuania for the period 2010-2030 and found that, as expected, renewables have the lowest external costs. More specifically, hydropower and wind power have the lowest external costs, followed by solar power. Rabl and Rabl (2013) compared the external costs of nuclear power with those of wind power and concluded that shutting down nuclear power plants and replacing them with wind power would have high private costs that would not be compensated by lower external costs. Zerrahn (2017) conducted a literature review to examine the external costs of wind power generation, which is generally used to mitigate the external costs of conventional power plants. He found that wind energy also has external costs and affects people's quality of life, mainly due to noise. In addition, it can have a negative impact on the employment and security of the energy supply.

Electricity generation from renewable energy sources, especially solar and wind power, results in intermittent energy supply. An unreliable power supply can pose a risk to the business, safety, and health (EPA, 2021). Therefore, renewable energy sources often require baseload capacity to support them. Potential capacities include highly efficient natural gas power plants. Although natural gas is a fossil fuel, it can be considered a clean energy source due to its lower greenhouse gas emissions compared to coal or oil, as noted by Yang et al. (2017). According to IEA (2017), natural gas generates 40% less CO2 emissions per unit of energy output when compared to coal. A study by Rabl and Spadaro (2016) makes a strong case for natural gas as a clean(er) energy source. They analysed the costs of environmental damage in Europe and found that the damage costs for fossil fuels are significantly higher than those for renewables. However, the highest costs are for coal, oil and lignite, while natural gas is cleaner, and damage costs are between those of coal and renewables. Therefore, high-efficiency natural gas power plants could be considered as baseload capacity for energy transition (for more details see Pekanov Starcevic et al., 2021) and are used as a case study in this paper.

3. Methodology

This research followed the ExternE methodology for assessing the externalities of electricity production. The methodology covers externalities by considering environmental impacts, global warming impacts, and accidents. It is widely accepted in the assessment of external costs of CHP plants (see Fahlén & Ahlgren, 2010; Streimikiene & Alisauskaite-Seskiene, 2014; Jorli et al., 2018) and consists of five stages, as described in ExternE (EC, 2005, p. 1):

1. "Definition of the activity to be assessed and the background scenario where the activity is embedded. Definition of the important impact categories and externalities.
2. Estimation of the impacts or effects of the activity (in physical units). In general, the impacts allocated to the activity are the difference between the impacts of the scenario with and the scenario without the activity.
3. Monetisation of the impacts, leading to external costs.
4. Assessment of uncertainties, sensitivity analysis.
5. Analysis of the results, drawing of conclusions."

In addition, the Impact Pathway Approach (IPA) was used. This approach is carried out in several stages. The specification of emissions from the source is followed by the estimation of impacts in physical units and further conversion of these impacts into monetary values (EC, 2005).

The case study used in the paper refers to the high-efficiency CHP plant that generates 500 MW of electricity, 160 MW of district heating, and up to 40 t/h of process steam. The efficiency of the power plant is reported to be 63.3% (for more details, see Borozan and Pekanov Starcevic, 2015). The estimated electricity price is €60/MWh, which is the monthly baseload electricity price in Central Eastern Europe in 2018 (EC, 2019b). The estimated natural gas price is €25/MWh, as the average European natural gas hub price in the fourth quarter of 2018 (EC, 2019c), and the CO2 emission quota €25/tCO2, as the price at the end of 2018 (Trading Economics, 2021).

4. Estimation of the external benefits and costs resulting from the construction and operation of a CHP plant

External benefits are any effects of the project that increase the economic (social) potential of a unit of local self-government, a region, or a state. External costs, on the other hand, are the effects of the project that have a negative impact on society. This section estimates the external benefits and costs that construction and operation bring to society, including its environment.

4.1 External benefits

The external benefits generated during the construction and operation of the CHP plant are manifested in the form of savings (reduction of CO2 emissions per unit of energy produced and energy losses during transmission to the grid area), reduction of Croatia's dependence on electricity imports, and in the form of fiscal benefits (increase in revenues for the state budget and local budgets).

1. **Savings from lower CO2 emissions per unit of energy produced.** The external benefit of the construction and operation of the CHP plant are the savings resulting from the reduction of CO2 emissions per unit of energy produced. Gas-fired cogeneration plants significantly reduce greenhouse gas emissions, primarily CO2 (IEA, 2017). In addition, natural gas is the cleanest form of energy among fossil fuels.

   The benefits of natural gas-fired CHP power plants include (EPA, 2021):

   - higher overall efficiency compared to conventional generation,
   - avoided transmission and distribution losses,
   - environmental benefits of reduced fuel consumption and avoided transmission and distribution losses,
   - economic benefits such as lower energy costs and avoided capital costs,
   - reliability benefits.

   Moreover, CHP power plants achieve an overall efficiency of 60 to 80 percent, while conventional technologies reach 50 percent (EPA, 2021). The existing power plant, which is to be replaced by the new CHP plant, annually generates 115,000 MWh of electricity. It emits between 0.6 and 0.7 tCO2/MWh. The new high-efficiency CHP unit will emit about 0.35 tCO2/MWhe. Considering the stated difference of about 0.3 tCO2/MWhe, and an estimated emission price of €25/tCO2, we can talk about the savings of **€862,500.00** per year resulting from the reduction of CO2 emissions per unit of energy produced.

2. **Savings in the reduction of energy losses in the transmission of the electricity required for the city transmission area.** The electricity consumption needs of the transmission area amount to about 2,300 GWh per year. The existing production units cover only about 5-5.5% of the demand. The rest of the demand is covered through a high voltage network (110 kV). Technical losses of the transmission system operator amount to 2.16% and losses in the transmission area network amount to 1.17%. A difference of 1% means savings due to the reduction of energy losses in transmission. If the estimated electricity price is 60 €/MWH_{el}, we can talk about the savings of **€1,297,890.00** per year.[1]

3. **Reducing Croatia's dependence on electricity imports from abroad and improving the balance of payments by reducing foreign exchange outflows.** Statistical data of the Ministry of Environment and Energy of the Republic of Croatia (2019) show that:

1 [(2,300,000 – 115,000) x (2.16% - 1.17%)] x 60 €/MWHel = 1,297,890 €

- Primary energy self-supply in Croatia in 2018 was 54.1%, while energy imports amounted to 317.79 PJ,
- In 2013-2018, energy imports in Croatia increased on average by 3.3% annually, with electricity imports increasing on average by 1.6% annually.

  In that sense, Croatia's energy dependence was 56.22% in 2018 (Eurostat, 2021). Looking at Croatia's position in the wider environment, we find that its import dependence in 2018 is slightly below the EU-27 average (60.70%) (Eurostat, 2021). Countries in the immediate neighbourhood, such as Slovenia, Hungary, and Italy, are also import-dependent. For example, the energy import dependence in 2018 was 58.12% for Hungary, 51.21% for Slovenia, and 76.34% for Italy.

  The CHP plant will generate an average of 3,300 GWh of electricity annually, which, compared to the average annual consumption of transmission area (2,300 GWh), means that about 1,000 GWh per year can be fed into the Croatian electricity grid and possibly abroad and results in the savings of **€60,000,000.00** per year.

4. **Fiscal benefits**. Fiscal benefits arise, on the one hand, from an increase in the revenue side of the (state and local) budget through the collection of various taxes and, on the other hand, from a reduction in the expenditure side (e.g., through a reduction in the total amount of unemployment benefits). Tax revenues, contributions for compulsory insurance, revenues from assets, revenues from fees and charges, and other revenues constitute the revenues from the operation of the state budget.

   The construction and operation of the CHP plant will increase the revenue side of the state budget in the first year of the project by **€8.23 million** as follows:

   - profit tax (**€3.8 million**),
   - VAT (**€4.3 million**),
   - tax on employees' salaries (**€0.13 million**).

4.2 Identification of environmental impacts and estimation of external costs

According to ExternE (EC, 2005), one of the purposes of using external costs is to identify health and environmental impacts, i.e. environmental (green) accounting. Companies not only consider the impact of externalities caused by their activities, but these are also becoming visible in their financial reports, as noted by Hartwig et al. (2019).

4.2.1 Identification of environmental impacts

The following is a brief summary of the impact of the project on environmental components, to provide a general insight into the external costs that will be generated by the construction and operation of the CHP plant. The external energy costs are not included in the price, but society still has to take them into account.

1. **Air**. During the preparation and construction of the project, increased air pollution from exhaust gases from construction equipment used for this purpose, as well as increased dust due to the movement of motorized vehicles and work during construction, can be expected. However, it is expected that exhaust emissions will not exceed the permissible levels, as only the mechanization that meets all the requirements of technical control may be used, and as for dust, its range is not particularly large. Moreover, the construction period is limited, so the harmful effects of construction work on the air are estimated to be short term.

   During the operation of the CHP plant, emissions are produced into the air, which gets polluted. These emissions are partly regulated by law, and the costs incurred by the investor in the process represent internalized costs. These are primarily the purchase of an emission quota for carbon dioxide and fees for the emission of nitrogen oxides, expressed as nitrogen dioxide (NO2).

   Combined heat and power plants increase fuel efficiency by replacing the separate generation of electricity and heat with a single plant that produces both forms of energy. Since less fuel is needed to produce the same amount of energy, emissions of CO2, NOx and SOx (air pollution) are lower. The CHP plant uses natural gas as fuel, so emissions of SOx, volatile organic compounds (VOC), PM10 and dust are negligible.

2. **Land and water.** The spatial planning documents of the city and county in which the

investment is to be made allow the construction of infrastructure systems in addition to the existing power plant. The planned area is not fully owned by the investor, so privately owned land will be acquired. The use of some plots will be changed, and the natural surface cover and soil layer will be removed. Facilities, road infrastructure and manipulation areas will be built on part of the land, while the remaining part of the land will be covered with natural vegetation. If the usual protective measures are followed, no significant adverse impacts on the surrounding soil are expected during the construction phase. However, increased negative impacts on water (groundwater and surface water) are possible. Indeed, during the construction works, accidents may occur, contaminating the soil with various liquids (e.g., machine oils, fuels, etc.). Since the soil of the construction area is permeable to a significant degree, there is a possibility of groundwater contamination that may reach the nearby river. However, with proper implementation of protective measures, the risk of the project impacting water during construction is acceptable. Temporary and relatively weak impacts of pollution of the river are possible during the construction of pumping stations and accidents.

Negative impacts are also possible during the operation of the plant due to the increased temperature of the water discharged into the river. The impact of the operation of the CHP plant on water results from the use of water for cooling the power plant and its return to the river as well as from the use of water to supply the demineralization plant.

In addition, the plant will generate wastewater during its operations. Wastewater treatment is required by law; higher water pollution would result from accidents.

3. **Natural habitat, flora and fauna.** As the CHP plant will be largely located in the industrial zone, its operation will not have a significantly different impact on the conservation objectives and integrity of the ecological network and protected areas, and thus on the surrounding flora and fauna and habitat types if the usual safety measures are taken. The area where most of the work will take place is mostly agricultural land with a somewhat less mixed habitat. It is a habitat that is not of great importance from a nature conservation and biodiversity point of view.

   However, a limited impact is possible due to the construction of a pumping station. Adverse impacts on habitat (terrestrial and aquatic) and some songbirds, small mammals, as well as amphibians and reptiles inhabiting this habitat, are expected. Adverse impacts will result from habitat destruction, noise generated during construction, and pollution that will occur.

4. **Landscape.** The construction will affect the surface cover of the land. In addition, new infrastructure facilities and new industrial and administrative facilities (e.g., engine room, office building, etc.) will be constructed. Therefore, there will be significant changes to the landscape. However, the location of the proposed project is mainly in the part of the city where three landscape types meet: residential, industrial and agricultural areas. Since each of these areas is under direct human influence and there is already a power plant at the project site, the structure of the surrounding area will not be drastically affected.

4.2.2 Identification of other impacts

The impact of the project is evident both in the population and the economy.

1. **Population.** It is estimated that there will be approximately 1,800 people, mostly local residents, during the construction phase of the new facility and 32 newly employed permanent employees during the operational phase. Therefore, the project is not expected to have a significant negative impact on the natural and mechanical movement of the city's population and its demographic structure. However, traffic on the access roads is expected to increase during the construction phase, which in turn will increase the likelihood of traffic accidents. Moreover, there is a residential area on the southern edge of the land intended for future infrastructure systems, and the preparation of plans and project documentation must consider the systems of protection against noise and harmful emissions.

   During construction, the nearest residences will be adversely affected by increased dust and exhaust emissions from construction equipment and vehicles, increased noise and ground vibration levels, and traffic intensity. However, these adverse effects will be short-lived.

Beneficial effects will be achieved through the creation of new jobs during construction and the increase in the standard of living and purchasing power of the new employees and the local population in general.

2. **Economy.** A positive impact on the economy of the city and its dynamization through new investments is expected. This will have a multiplier effect on other sectors of the economy (e.g., construction, transport, and various service sectors). There will be a positive impact on the budget of local self-government units due to various fees that they will collect (e.g. the land use fee for power plants).

The land to be acquired, which is used for agricultural activities, will no longer be used for agricultural production as it will become the property of the investor. Therefore, this conversion will generate external costs, i.e. costs for the change of agricultural land use.

3. **Waste**. During construction, various types of solid waste (e.g., glass, plastic, packaging, waste oil, etc.) will be generated, which may have a negative impact on the environment if not disposed of in the prescribed manner. The contractor is responsible for the disposal of this waste.

The plant will use only natural gas. Apart from the fact that its use will bring economic benefits to the investor, it will also result in less pollution and damage to the environment, as it is the cleanest fossil fuel that is increasingly used for such purposes.

4.2.3 Estimation of external costs

The construction and operation of the CHP power plant will incur costs that will burden the environment and its components and have an adverse impact on human health, the economy, and society. These are primarily the costs associated with Croatia's increased dependence on imports of natural gas and the costs associated with the change of agricultural land use.

1. **Increasing Croatia's import dependence on natural gas.** Compared to the existing power plant, the new CHP plant will increase natural gas consumption. It is estimated that consumption will increase by more than 11 times. The new power plant will consume about 600 million m3 of natural gas per year, while the existing power plant consumed about 54 million m3 of gas. Considering the current situation and the estimates given by the competent authorities for the share of domestic gas production in 2030, this means an average annual increase in import dependence of 291,564,000 m3 per year.

Assuming a gas price of 25 €/MWh, i.e. 0.232 €/m3 gas, this ultimately means an increase of **€67,642,848.00** per year.

2. **The change of agricultural land use.** The change of land use results in a loss of value of the agricultural crops grown on that land. In other words, the yield obtained from this land is lost. Out of an area of approximately 175,000 m2 (intended for the construction of facilities, switchyards, and access roads), approximately 138,000 m2 is agricultural land, the use of which will be permanently changed.

The area on the banks of the nearby river (approx. 10,250 m2) will also change permanently due to the construction of a pumping station.

The temporary change (possibility of returning the land to a condition close to its original state) will affect the part of the land where the laying of the cooling water pipeline will take place, which is an area of approximately 45,000 m2.

It should be noted that in the spatial planning documents the entire project area is designated as a construction area. If we add the fact that the analysis revealed soil contamination in the area designated for the construction of the plant, the conversion can be considered a positive step, as contaminated agricultural land will be excluded from the food production system. It is estimated that the cost of agricultural land use change amounts to 0.1 €/m^2 and the total cost of the change of agricultural land use is **€13,800.00**.

It is estimated that the external benefits (€70,390,390.00) exceed the external costs (€67,656,648.00) by €2,733,742.00. Apart from the estimation of external costs, their internalization is done through various taxes and fees, which affect the unit cost of electricity. In addition, Kudelko (2006) concluded in his study that the internalisation of external costs in the energy sector can significantly increase social welfare.

5. Conclusion

As the European Union seeks to achieve energy security, sustainability and affordability, investment in energy efficiency is encouraged. In this sense, when investing in power plants, EU countries must carry out a cost-benefit analysis to assess the potential of using cogeneration. In the context of a cost-benefit analysis, a particular emphasis should be placed on the identification of environmental and health impacts and the evaluation of external benefits and costs.

In this paper, an example of a high-efficiency CHP plant was used as a case study. Based on the ExternE methodology and Impact Pathway Approach, the environmental impacts, external benefits and costs of construction, and operation of the CHP plant were evaluated. The analysis showed that the main external benefits include savings from the reduction of CO2 emissions per unit of energy produced, savings from the reduction of energy losses in the transmission of electricity required in the city transmission area, reduction of Croatia's dependence on electricity imports from abroad, improvement of the balance of payments through the reduction of foreign exchange outflows, and fiscal benefits. As regards the environmental impact of the project, this is primarily in terms of the impact on air, soil, water, the natural habitat, flora and fauna, and the landscape. In addition, the project has an impact on the population and the economy. The main external costs arise from Croatia's increasing import dependence on natural gas and changes in the use of agricultural land. It is estimated that external benefits exceed external costs by €2,733,742.00.

For future research, it would be interesting to extend the estimation of external benefits and costs to consider broader social impacts and to conduct a full cost-benefit analysis, which is also the main limitation of the analysis performed in this paper. Such an extended analysis would give a more comprehensive insight into the full social impact of investments in a CHP plant.

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