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TEPLATOR:
Basic Economic Study for the Construction and Operation

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ABSTRACT

Competitiveness of district and process heat production based on fossil fuels is challenging. Costs of fuel, technology improvement for reaching the emission limits and carbon credits purchasing increase price of produced heat. The TEPLATOR concept is an innovative way to eliminate all these costs by using the spent nuclear fuel for future zero emission district heating.

This article is focused on economics of the TEPLATOR concept. The objective was to investigate economic feasibility of the project. Initially, the summary of worldwide heat production and consumption and overview of district heating systems is provided for a study of TEPLATOR applications. Then complex construction costs study has been carried out and evaluated. All the financial aspects have been compared with conventional district heating plants. Finally, the feasibility is summarized and total investment costs and produced heat price are presented.

1 INTRODUCTION

The TEPLATOR is an innovative concept for future district heat production. TEPLATOR facility will use already spent fuel from commercial nuclear power plants. Consequently, this concept will produce heat without any emissions and with minimal fuel costs. The first TEPLATOR DEMO design with output power 50 MW of thermal energy will use 55 PWR (VVER) spent fuel assemblies. This fuel loading will be operated for two years [1]. The amount of produced heat for one heating season (9 months) will be sufficient for residential heating of a large city with 100 000 citizens (estimated using Czech Republic district heating systems data).

The aim of this study is the evaluation of competitiveness of TEPLATOR against conventional heat production plants. Current district heating based on fossil fuels is facing a number of challenges. Due to worldwide emission reduction efforts costs of fossil fuel-based heat production are significantly higher every year because of the investments into technology improvements of the outdated facilities and mainly the tax for carbon allowances.

This causes increasing prices of delivered heat and decreasing number of district heat consumers, even though district heating is the most effective way for heat production. Consequently, a number of old heat plants will be decommissioned in the near future for their economical unsustainability. District heating systems based on carbon free technologies (e.g., nuclear power) should be the way of future district heating.

The presented overview of district heating in Europe shows a great potential for future TEPLATOR applications in many European countries. Detailed analysis of heat demands of Czechia and Slovakia provides a number of possible locations within these countries for the first TEPLATOR facility. The comparison of investigated final consumer heat prices in the EU with calculated TEPLATOR heat price demonstrates economic feasibility of the project.

2 DISTRICT HEATING TODAY

This study is focused on district heating systems only in Europe. Future studies will analyse district heating potential in the rest of the world and another study will also deal with the possibilities of TEPLATOR utilisation in district cooling systems applicable also in African and Middle Eastern countries.

Total heat energy consumption in the European union provided by Eurostat data is 2133 PJ (for 2018) [2]. Popularity of district heating varies across Europe. Figure 1 shows a share of district heating in total heating and cooling energy demand in European countries.

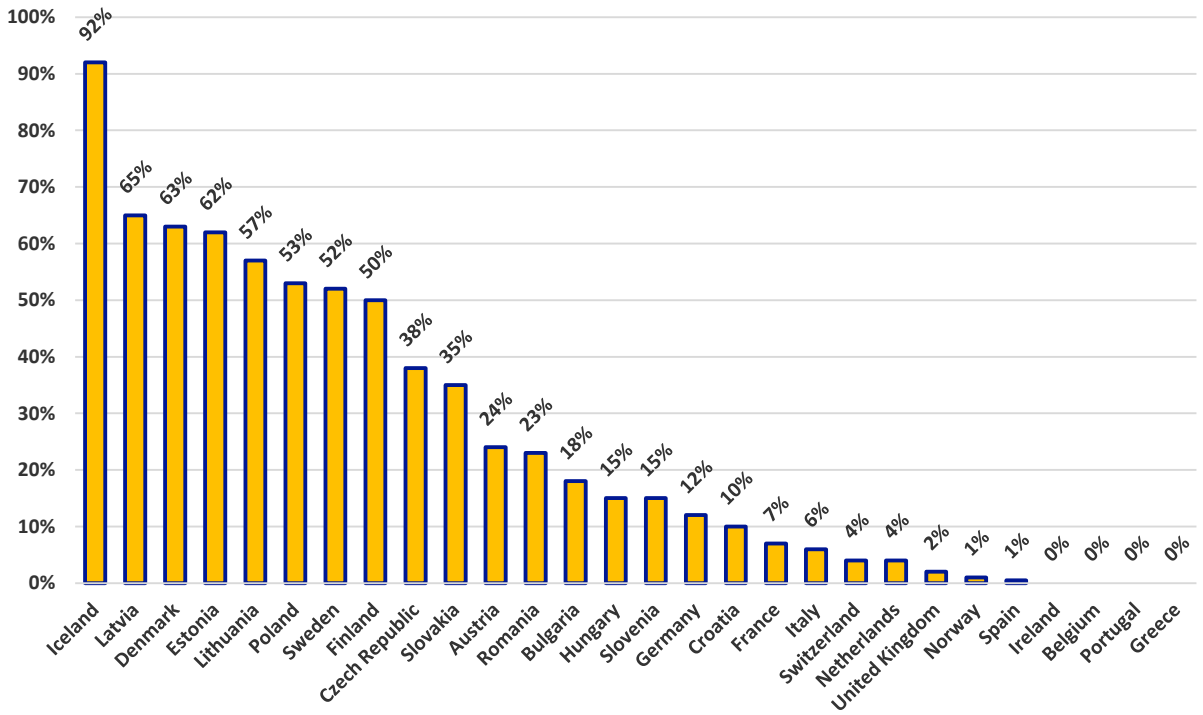

Figure 1: Share of district heating in total heating and cooling energy demand [3]

Higher utilization of district heating can be generally found in the north-eastern part of Europe. Primary fuels used for district heating plants in Europe (2017) are natural gas (37%), coal (25%), biomass (20%) and waste (10%) [4]. Preferred TEPLATOR application is in countries with widely used district heating systems, where the old fossil fuel-based technologies need to be replaced and the heat distribution can be provided by existing systems.

2.1 District heating pricing

For competitiveness evaluation of the TEPLATOR project the price of marketed heat energy has been investigated. Because the latest statistical data about district heating pricing in Europe come from 2013 [5], the Eurostat Harmonised index of consumer prices (HICP) [6] has been used for 2019 price estimation showed in Figure 2. These values represent the final consumer prices (EUR/GJ) including all the fees for the production and distribution of heat energy without VAT.

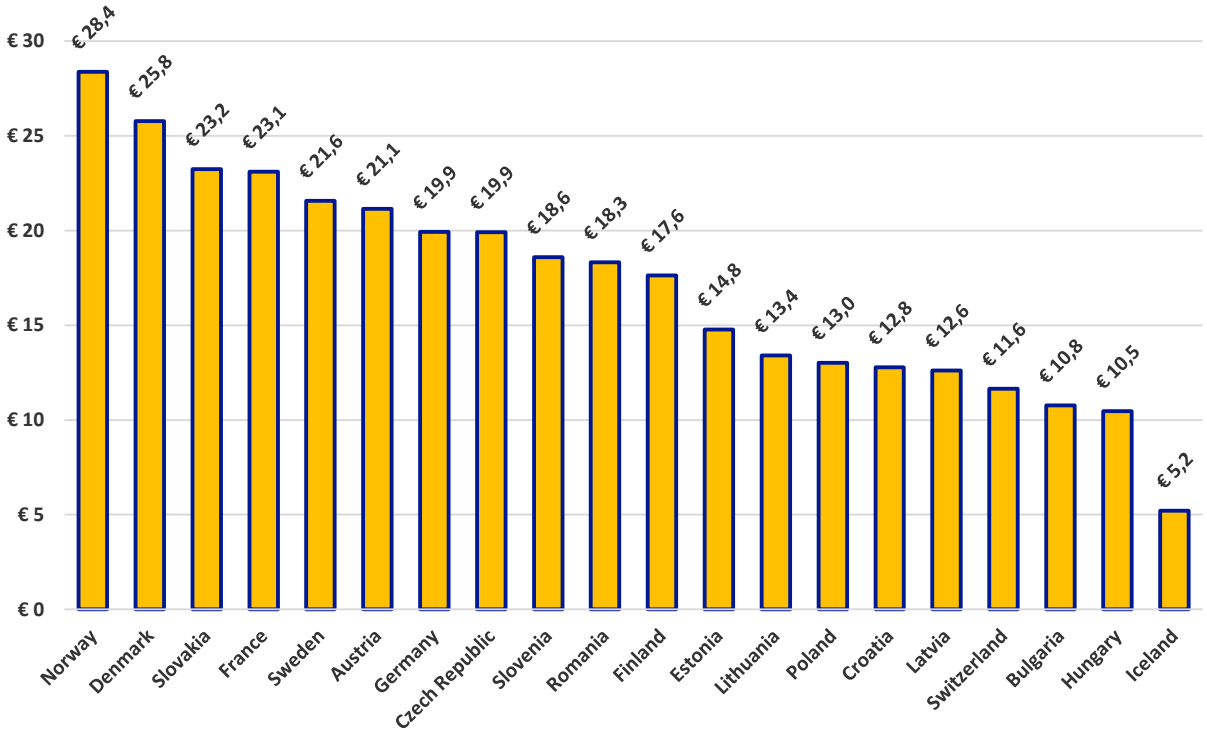

Figure 2: Consumer heat energy prices (EUR/GJ) [5][6]

There exist two extremes in the presented prices. The highest price 28.4 € per GJ is in Norway, where only 1% of the population is connected to district heating. On the other hand, the lowest price can be found in Iceland, where the highest percentage of citizens is served by district heating and the primary source of heat is geothermal energy (97%) [4]. Except for these two countries, all the heat energy prices are between 10 € and 26 € per GJ.

2.2 District heating financial aspects

Each district heating price presented in Paragraph 2.1 can be split into two parts. The first part represents energy distribution fees. Distribution fees have not been investigated in this study because a commonly used approach cannot be identified for heat distribution operation, unlike electricity distribution. These costs also do not depend on the primary source of heat energy and are not determining for heating plant economy. However, the second part, the costs for energy production, is a major issue for heat plant economy. This part consists of fuel costs, operation and maintenance costs, emissions taxes, fees and taxes. For analysis of these costs, the data from Czech Energy Regulatory Office (ERU) have been used.

The price of primary fuel is variable and depends on providers' contracts considering a number of factors. The average fuel expenses for all the coal heat plants in the Czech

Republic are 19% of consumer prices without VAT [7]. For the average heat price in the Czech Republic 19.9 EUR/GJ, the price of primary fuel is 3.78 EUR/GJ for coal-based heat plants. Nevertheless, it should be emphasized that in the Czech Republic, 65% of all heat is produced through combined heat and power generation (2019) [8]. It represents the most effective way of district heat production and total fuel costs are divided between the price of produced electricity and the price of heat energy. In the case of using coal just for heat generation, the share of primary fuel in final consumer price will be significantly higher. According to ERU data, these expenses are 52% of customer price on average for the other kinds of fuel [7], but this value encompasses also the very small gas heat generations, where the fuel costs represents the main operation cost.

The sticking point of conventional heating plants economy are emissions and the emission limits. Limits for exhausting of emission are becoming harder to meet every year. The primary approach to regulate the emissions are the emission allowances (carbon credits). Every ton of exhausted carbon dioxide (or equivalent amount of other greenhouse gases) by every facility operator must be covered with these credits. Some of the credits are allocated for free, but the number of them is decreasing every year, thus the heat plants must buy more credits on trading markets. Figure 3 shows the number of free allowances and the real exhausted emissions (both for Europe region) and also the average price of one allowance for one ton of CO_2. This price has been rapidly increasing in last years and in July 2020 the price of carbon allowance nearly reached 30 € per ton of CO_2 [9]. For illustration, this price is also visualised in the chart.

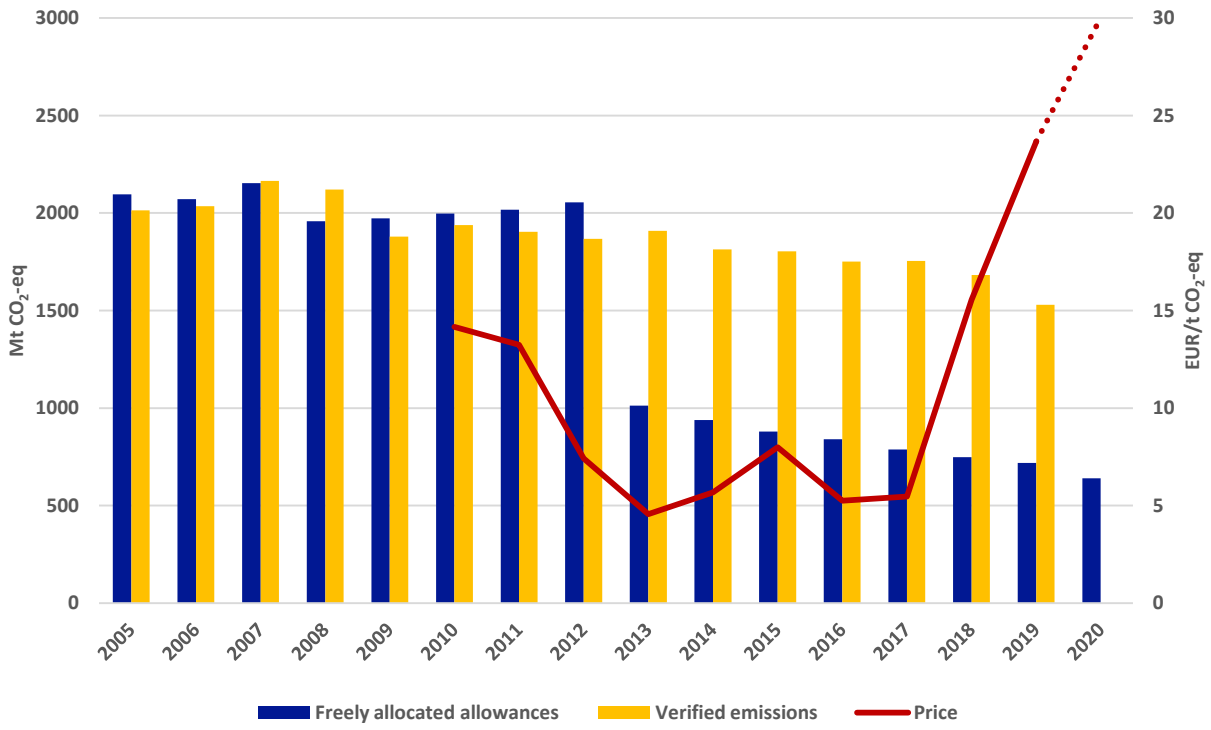

Figure 3: CO_2 allowances EU data [9][10][11]

The final number of produced emissions per GJ of heat energy is difficult to determine, because it is variable for fuel, technology, size and multiple other factors. The Czech Energy Regulatory Office regularly announces the maximal allowed costs directly proportional to allowance price. For the 2019 allowance price average, these costs are 2.22 € per GJ for coal and 0.79 € per GJ for other fuels [12]. This is the highest price, which may be accounted for final consumer price and this price is therefore in accordance with the least effective and most

outdated heat plants emissions. In this case, for the average heat price in the Czech Republic 19.9 EUR/GJ, the share of emission allowances is up to 11.2% of the final consumer price without VAT.

Table 1: Analysed financial aspects of conventional heat plants

	Fuel costs	**Emission allowances**	**Other costs**	**% Share**	
Coal	3.78 EUR/GJ	2.22 EUR/GJ	13.90 EUR/GJ	30%	70%
Other fuels	10.35 EUR/GJ	0.79 EUR/GJ	8.76 EUR/GJ	56%	44%

Table 1 shows investigated financial aspects of fossil fuel-based heat plants. For the conventional coal plants the share of fuel costs including emission allowances is 30% of the final consumer price. This value will be used for the TEPLATOR preliminary competitiveness evaluation in Part 3. The remaining 70% of the heat energy price is comprised of distribution costs, operation costs, repairs and maintenance, investments, salaries, fees and owners profit. Detailed analysis of these costs for fossil fuel-based plants will be provided in the further separate study for the TEPLATOR operation.

3 TEPLATOR ECONOMICS

3.1 TEPLATOR project study

The preliminary economics study for the TEPLATOR construction and operation has been carried out. For this paper just the final highlights are presented. The methodology and detailed results will be provided in further study. The calculated investments costs for the first TEPLATOR DEMO 50 MWt facility is 30 M EUR (using prices of 2019). Then the final price of produced heat is 4 EUR/GJ. As to the sensitivity analyses, the heavy water price plays the most important part, whereas the fuel costs, with usage of spent nuclear fuel, is negligible [1].

3.2 TEPLATOR competitiveness

Existing district heating systems in the Czech Republic and Slovakia have been analysed for appropriate TEPLATOR locations. Heat energy demands of Czech and Slovak cities have been determined, based on heat plants owners' and operators' data. TEPLATOR DEMO 50 MWt operating on full-power (with proposed energy storage system) for the entire 9-month heating season will produce 1183 TJ of heat energy. This heat demand has been identified in 8 locations with the number of citizens between 75 000 and 100 000. Heat consumption of these locations is roughly between 1200 TJ and 1600 TJ. This is the optimal range for the TEPLATOR, that will be used as base load source of heat in cooperation with small sources for peaks covering. Another 8 possible locations in the Czech or Slovak Republic represent cities (or agglomerations) with more than 100 000 citizens, where more than one TEPLATOR DEMO units could be placed. The majority of currently produced heat for all these locations comes from fossil fuels mainly from coal (in the Czech Republic on average, 57% of the total 87.5 PJ of consumed heat comes from coal and 25% from gas in 2019) [8].

Overview of district heating share in total heat demand shows the preliminary potential of TEPLATOR application in many European countries. However, a number of further factors have to be considered. Current primary fuel mix for district heating of Sweden, Iceland and Switzerland (and partially Denmark and Austria) is based mainly on biofuels, waste or geothermal energy, thus there isn't actual effort for replacing the current heating sources. Italy, France and Germany have lower share of district heating in total demand but

the total amount of consumed heat and share of fossil fuels is significant. Number of countries evinces high percentage of district heating use but total demand of heat energy is quite low and also the share of fossil fuels in these countries is lower. The most promising countries for TEPLATOR applications should have the higher total heat demand that is based mainly on fossil fuels – Poland, Finland, Czech Republic, Slovakia, Romania, Bulgaria, Hungary [4]. The last important factor are reserves of PWR spent fuel assemblies for the TEPLATOR facility. Countries without PWR nuclear power plants in operation (Poland, Romania and also Denmark and Austria) are not considered for primary TEPLATOR application because of issues with fuel supply and transportation.

As final consumer price of district heating in EU countries is above 10 EUR/GJ, heat produced by TEPLATOR for 4 EUR/GJ (i.e. no more than 40% of current consumer price) is fully competitive for all European countries (except Iceland). Comparison of calculated price for TEPLATOR with obtained data for conventional heat plans shows evident financial advantage of TEPLATOR. The final calculated price of heat energy 4 EUR/GJ is lower than standard costs of fuel and emissions allowances 6 EUR/GJ for coal-based heat plant and likewise for other fuels plants with significantly higher fuel costs. Due to rapidly increasing price of emissions allowance and decreasing share of free allowances allocated to heat plants the price of fossil fuels-based heat generation will be higher every year. Aside from the economic advantages of TEPLATOR, it will provide savings of mega-tons of produced carbon dioxide and other emissions from fossil fuels combustion.

4 CONCLUSIONS

TEPLATOR is a perspective way of future district heating. This technology will be a 100% emission free source of heat energy with negligible costs for fuel. The preliminary competitiveness of the project has been evaluated considering current district heating systems' popularity, the mix of primary fuels used for heat generation and prices of produced heat in Europe.

In many European countries, district heating is the preferred way of heat production for residential and industry use. Great potential for TEPLATOR application has been identified in countries with high heat energy demand based on fossil fuels – Czech Republic, Slovakia, Germany, Italy, France, Finland, Bulgaria, and Hungary. All these countries currently operate PWR nuclear power plants, thus providing reserves of already spent fuel for TEPLATOR. In the Czech Republic and Slovakia 16 locations for one or more TEPLATOR units have been determined.

Consumer prices of heat in the European union in 2019 range between 10 € and 26 € per GJ. The share of primary fuel in total heat costs is 30% for coal-based generation and for other fuels, it is significantly higher. This value includes fees for carbon emissions allowances, which are becoming more expensive every year. Comparison with the price of heat produced by TEPLATOR for 4 GJ/EUR clearly shows economic feasibility of the concept.

Current primary fuel mix for district heating in the European union is 37% of natural gas, 25% of coal, 20% of biomass and 10% of waste. Application of the TEPLATOR facility as replacement of the old conventional fossil fuels-based heat plants will save significant amount of polluting emissions in accordance to EU climate policy.

This study confirms preliminary economic feasibility of the project in district heating systems. Further studies of TEPLATOR economics will be focused on detailed analysis of all particular operation costs of conventional power plants and comparison with TEPLATOR

facility. Another perspective application is utilisation of TEPLATOR for district cooling systems, which will also be investigated and presented in a further study.

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