PITAGORAS Sustainable urban planning with innovative and low energy thermal and power generation from residual and renewable sources

D5.3: Second version of Market analysis and business models

- Sensitivity Analysis of Market Potential –

Project acronym:	PITAGORAS
Project full title:	SUSTAINABLE URBAN PLANNING WITH INNOVATIVE AND LOW ENERGY THERMAL AND POWER GENERATION FROM RESIDUAL AND RENEWABLE SOURCES
Grant agreement no.:	314596
Doc. Ref.:	PITAGORAS-WP5-Task 5.2-D5.3-V3.0.docx
Responsible:	AIGUASOL
Author(s):	AIGUASOL
Date of issue:	11/10/2017
Status:	V3.0
Security:	Public

Change control:

Version and date	Changes
V1.0, 04/08/2017	First draft available
V2.0, 15/09/2017	First finalized version
V3.0, 31/10/2017	Final version

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ABBREVIATIONS

BOP	Balance of Plant
CF	Capacity Factor
CHP	Combined Heat and Power
CO_2	Carbon dioxide
DH	District Heating
DR	Discount rate
EAF	Electric Arc Furnace
GHG	Greenhouse Gas
NPV	Net Present Value
OAAT	One at a time
ORC	Organic Rankine Cycle

1. INTRODUCTION

1.1. SUMMARY

One of the main targets of the Pitagoras project consortium has been to foster the replication of the waste heat recovery concept based on ORC technology, in a similar way as the developed in Brescia demo plant. In PITAGORAS-D5.2, a quantification of the market potential in the target countries of the project, namely Austria, Czech Republic, France, Germany, Italy, Poland, Slovakia, Spain and Sweden, was performed. Such task was carried out as a preliminary step for business model establishment.

The work here presented aims at further developing the business model establishment, a goal that is pursued by performing a sensitivity analysis of the model previously developed and used. The mentioned model tested three different hypotheses of operation to check the market potential of them:

- Only electricity generation: in this scenario, only an electrical valorisation of the waste heat stream is considered
- Only heat generation: only heat recovery is assumed so no turbine investment is expected, neither electricity revenues
- Hybrid generation: this scenario is the same as the one implemented in Brescia; during winter, heat is sold to the district heating network and during summer, when urban heat demand drops, waste heat is used for generating electricity self-consumed by the plant, thus generating electricity savings upon the facilities electrical bill

A sensitivity analysis is a methodology used to study the influence of a number of explanatory variables – inputs – to one or more response variables – outputs. In the case here presented, the influence of 7 independent variables (electricity and heat prices, carbon emissions cost, capacity factor, percentage of investment borrowed, bank credit interest rate and discount rate) on 1 dependent variable (market potential) has been studied. It is worth noting that the market potential could be expressed in several ways. According with the model previously developed in PITAGORAS-D5.2, the market potential can be seen as monetary investment executed to put in operation heat recovery plants, as energy produced with the proposed mechanism or even as carbon emissions saved. For the sake of clarity, in this work the market potential has been presented as the share of the total theoretical market that could be generated if all the Electric Arc Furnace (EAF) steel manufacturing plants present in the studied countries adopted the proposed heat recovery technology.

In this document, it is shown that the capacity factor (CF) is by far the most relevant parameter affecting the market potential. However, the applicable energy prices (the electricity price in the "Only electricity generation" mode, the thermal energy price in the "Only heat generation" mode or both in the "Hybrid" mode) are also revealed as highly relevant.

The cost of financing the required investment, being it expressed as percentage of money that must be borrowed or the interest rate of a bank credit to finance such investment also show a relevant significance, being less than with the previously mentioned inputs, though.

On the contrary, the CO_2 emissions cost and the discount rate show very little importance and none at all, respectively.

As previously claimed in this Work Package, one of the main concerns for the steel sector in general is the production overcapacity, which is directly linked to the capacity factor which is proven to be fundamental to get a profitable return. This situation confirms that the goal of reaching CF as close to 100% as possible should definitely be the major concern of active EAF plants adopting the Organic Rankine Cycle (ORC)-

based heat recovery model proposed. The heterogeneity of CFs reached by different plants throughout different countries and even within each country can pose a barrier to the spread of this model.

It is also shown in this sensitivity analysis that thermal energy price is of great importance in both “Only heat generation” and “Hybrid” modes. As this input is closely related with the presence or not of a District Heating (DH) network close to steel manufacturing facilities, this conclusion tells us about the importance of finding and promoting the presence of remunerated DH schemes near manufacturing plants. Regarding the electricity price, as relevant as thermal energy price, there is much less control on its value since it is affected by the electricity market fluctuations. However, a conclusion that can be drawn from its relevance is that “Only electricity generation” and “Hybrid” modes have great potential in countries with more expensive electricity prices.

Last, it has also been proven that incentives facilitating the initial investments required to put in operation the ORC heat recovery scheme could have great returns in terms of market potential improvement, therefore being of crucial relevance in the business model establishment. In Deliverable D.5.5, the existing subsidies or financial aids will be explored as well as the possibilities with better potential returns will be analysed.

1.2. PROJECT CONTEXT AND TASK PURPOSE

The present document is contextualized in the WP5 as the second version of the Market analysis and business models, from which the first version was previously released.

- In the first version of the “Market analysis and business models”, PITAGORAS-D5.2, the economics of this concept were modelled and simulated for all the existing steel manufacturing plants in the studied countries. Afterwards, the potential market in the countries of study was obtained according with the viability criteria of obtaining a positive Net Present Value (NPV) with a discount rate of 5% and a lifetime of 10 years.
- This second version of the “Market analysis and business models” consists on a sensitivity analysis of the model developed and validated in the previous deliverable. A study of how the most important input parameters of the model affected the market potential has been carried out.
- Also, the main findings drawn from this sensitivity analysis will be used further in the project, in particular in the “Final version of Market analysis and business models”, PITAGORAS-D5.5, an impact analysis on publicly supported financing policies for the Pitagoras concept of electricity and heat generation from heat recovery in the steel manufacturing industry. Using the model developed and here sensitivity tested, the effects of three possible financing policies on the market potential will been studied.

The work here performed is significant to two subtasks within WP5-Task 5.4:

- The business models, since it analyses the relevance and effect of several inputs to the potential and the profitable market available
- The individual exploitation plans

2. INVESTMENT PROFITABILITY AND MARKET POTENTIAL SENSITIVITY ANALYSIS

2.1. SENSITIVITY ANALYSIS DESCRIPTION

A Sensitivity Analysis is a study of how the uncertainty of outputs – or dependent variables – in a mathematical model is correlated with the uncertainty in its inputs – or independent variables. This process is carried out by introducing certain variations in model inputs to analyse the changes observed in the outputs.

In this section, it is presented the sensitivity analysis performed to analyse the response of the model presented in PITAGORAS-D5.2 and better understand which variables affect most the economic potential and climate change mitigation potential performance of the proposed medium-temperature heat recovery in steel industries in the EU. This study will facilitate the understanding of how the economic performance and climate change mitigation of these steel manufacturing plants would change as a result of changes of the boundary conditions, and will help to better know what to expect in the future of this industry.

Following the argument exposed in PITAGORAS-D2.13 (see §2.1), the sensitivity analysis has not been performed under a "One at a time" (OAAT) scheme, since such methodology would leave a great portion of the solution space unexplored. The OAAT is based on the variation of one input variable keeping all other inputs constant, i.e. it is a *ceteris paribus* analysis. Instead, a strategy of all possible scenarios study has been used, providing a more comprehensive and thorough study of all the solution space.

2.2. STUDIED OUTPUT

The output addressed in this sensitivity analysis is the market potential in the studied countries. The market potential is defined in PITAGORAS-D5.2 as "the energetic, environmental and economic aggregated quantities for all the EAFs that fulfil a certain return of investment criteria", being such criteria defined by a positive net present value (NPV) at a certain discount rate (DR) and exploitation period.

They are studied under the three proposed hypotheses of plant operation, namely the "Only electric generation", the "Only heat generation" and the "Hybrid electricity and heat generation" which is a Combined Heat and Power (CHP) production scheme.

The aggregated investment, energy production and carbon dioxide (CO_2) emissions savings for all viable plants will behave similarly in terms of increases and decreases as a result of input parameters change, even though the three parameters will have their own variation scale. This is because if a steel manufacturing plant is economically viable under certain input hypotheses, i.e. its NPV is positive, its required investment, energy production and carbon emissions savings will be added to the aggregated metrics and vice versa. Because of that, instead of studying the three outputs independently, the measure of "percentage of profitable market" has been selected as the output to study. By doing so, instead of having three outputs with different magnitudes but equivalent behaviour to study, only one output is required to be analysed. Such output synthetizes the behaviour and shows the same trends as all other, since it is a representation of the number of viable plants that would contribute simultaneously to the aggregated investment, energy production and carbon emissions savings.

2.2.1. Percentage of Profitable Market

The concept of "Percentage of Profitable Market" is defined as the rate of all potential market in each country that is profitable according with the predefined criteria of having positive NPV at the selected DR during the exploitation period of 10 years.

Therefore, this metric is expressed as percentage (non-dimensional) varying between its lower value of 0% in all those scenarios without any viable plant at all and its upper value of 100% in the scenarios.

The potential market has been calculated as the maximum aggregated investment that could be "activated" if all the EAF steel manufacturing plants adopted the proposed scheme. Consequently, the calculation of the percentage of profitable market is calculated by dividing the aggregation all the viable investment in each country by the maximum possible investment in such country. Similar calculations could be made with the other two market potential metrics, i.e. the aggregated energy production and the aggregated CO_2 emissions savings, and the same result would be obtained.

Thus, the proposed metric is a country-wise normalization that allows comparing the effects of each input parameter on this proposed response variable removing the difference in scale resulting from the asymmetry of installed capacity throughout studied countries.

2.2.2. Market potential

The proposed metric of "Percentage of Profitable Market", as claimed, refers to the potential market in each country according with the criteria of having positive NPV at the selected DR during the exploitation period of 10 years. Such potential was assessed and presented in PITAGORAS-D5.2.

For reader's reference, it is detailed below for the three modes of operation (see Tables 1-3):

Table 1: Market potential: "Only electricity generation" operation

	Number of systems	Total furnace capacity (t)	Waste heat power recovered (MW)	Electric power (MW)	Investment (M€)	Electricity production (GWh)	CO_2 emissions saved (t)
Austria	4	145	23.56	4.71	23.57	25.70	1545
Czech Rep.	11	488	79.30	15.86	71.43	35.22	13235
France	25	1836	298.35	59.67	234.67	216.68	7540
Germany	27	2351	382.04	76.41	287.42	411.16	174703
Italy	88	4678	760.18	152.04	653.48	705.81	161772
Poland	17	1293	210.11	42.02	162.59	175.56	117733
Slovakia	1	60	9.75	1.95	8.44	8.27	736
Spain	35	2950	479.38	95.88	365.13	349.70	106310
Sweden	11	720	117.00	23.40	96.30	95.69	1005
Total	**219**	**14521**	**2359.66**	**471.93**	**1903.03**	**2023.83**	**584579**

Table 2: Market potential: "Only heat generation" operation

	Number of systems	Total furnace capacity (t)	Waste heat power recovered (MW)	Investment (M€)	Heat production (GWh)	CO_2 emissions saved (t)
Austria	4	145	23.56	18.26	77.12	8653
Czech Rep.	11	488	79.30	55.33	105.66	11855
France	25	1836	298.35	181.77	650.05	72935
Germany	27	2351	382.04	222.63	1233.49	138398
Italy	88	4678	760.18	506.17	2117.44	237576
Poland	17	1293	210.11	125.94	526.69	59094
Slovakia	1	60	9.75	6.54	24.83	2786
Spain	35	2950	479.38	282.82	1049.11	117710
Sweden	11	720	117.00	74.59	287.077	32210
Total	**219**	**14521**	**2359.66**	**1474.04**	**6071.48**	**681220**

Table 3:Market potential: "Hybrid" operation

	Number of systems	Waste heat power recovered (MW)	Electric power (MW)	Investment (M€)	Electricity production (GWh)	Heat production (GWh)	CO_2 emissions saved (t)
Austria	4	23.56	4.71	24.55	12854	44990	5820
Czech Rep.	11	79.30	15.86	74.41	17610	61636	13533
France	25	298.35	59.67	244.45	108342	379195	46316
Germany	27	382.04	76.41	299.39	205582	719538	168084
Italy	88	760.18	152.04	680.71	352907	1235173	219473
Poland	17	210.11	42.02	169.36	87782	307238	93339
Slovakia	1	9.75	1.95	8.79	4139	14485	1994
Spain	35	479.38	95.88	380.35	174852	611982	121819
Sweden	11	117.00	23.40	100.31	47846	167461	19292
Total	**219**	**2359.66**	**471.93**	**1982.32**	**1011914**	**3541699**	**689670**

2.3. INPUT PARAMETERS

Several parameters have been identified as relevant for the model output and with potential to experience variations in the near futures or in different financing scenarios. These are: thermal energy price (€/MWh), electricity price (€/MWh), carbon dioxide (CO_2) emissions cost (€/tnCO_2), capacity factor (CF) (%), investment percentage to be financed (%), investment credit interest ratio (%) and discount rate (%).

For the sake of clarity, these variables can be grouped in three categories: energy prices, including thermal energy and electricity prices; performance parameters, in which CO_2 emissions cost and capacity factor could be classified; and financial parameters, including investment percentage to be financed, credit interest and discount rate.

2.3.1. **Energy prices**

The energy prices identified as relevant for this model sensitivity analysis are the price of thermal energy sold to a hypothetical DH network near the steel plant facilities, and the price of electricity produced, and thus saved from be purchased to a utility. It is important to remark that the electricity is considered to be produced and consumed at the facilities, so its price and therefore its variation to be expected, is a consumption price. Although the consumption prices paid by such energy-intensive industries is at the low range in all countries under study, the savings will be greater than the revenues from electricity sale at market pool would be.

The range of variation for energy prices is set to ±25% in both cases, thermal and electrical energy, a value representative of the mid-term fluctuations experienced by the energy markets throughout the EU.

Thermal energy price (€/MWh)

The base-case value selected for this input variable is 15 €/MWh, obtained from the demo plant in Brescia (Ori Martin).

The proposed parameter variation is, as said, ±25%, giving 11.25, 15 and 18.75 €/MWh as possible values.

It is important to note that in the case of thermal energy, the price at which it can be sold to a DH network is strongly affected by the local context of the plant, specially by the possible competitors as thermal energy sellers. Therefore, rather than being related with energy markets fluctuations, the price of thermal energy is more affected by the possibility of finding a remunerated DH network near the steel manufacturing plant.

Electricity price (€/MWh)

The base-case value selected for this input variable is the national electricity price for industrial consumers with annual consumptions on the order of 100 GWh for June, 2017 [1].

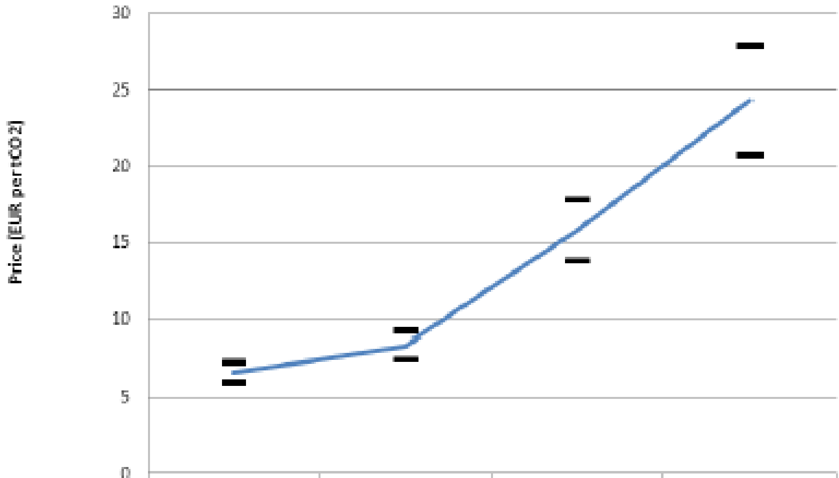
The proposed variation of ±25% leads to values in the range between 33.6 €/MWh for Sweden, the country with the cheaper electricity, with a -25% hypothesis and 127.5 €/MWh for Germany, the country with the most expensive electricity, with a +25% hypothesis. These values could be easily reached in the mid-future because the proposed variation is a representative value of market fluctuation over the last decade, according with [2].

2.3.2. **Performance parameters**

The parameters classified under the category of performance parameters are the carbon dioxide emissions cost, which is related with EU performance in CO_2 emissions savings, and the capacity factor, related with the competitivity of the steel factor.

CO_2 emissions cost (€/tnCO_2)

The CO_2 emissions market is strongly regulated by the European Commission. Their price depends on the emissions rights granted to industries. To the extent that less rights are granted to highly polluting industries, the price of these rights will rise accordingly. According with [3], three different scenarios of CO2 emissions price rise could be expected: lower, mean and upper price scenarios. The three different scenarios are shown in the figure below (see Figure *1*):



	Dec 2013	Dec 2014	Dec 2020	Dec 2030
Upper Conf. Int. (95%)	7,280	9,240	17,810	27,900
Price Expectations	6,620	8,360	15,820	24,310
Lower Conf. Int. (95%)	5,970	7,470	13,820	20,720

Figure 1: Projected carbon price in the EU trade system

The base-case CO_2 emissions cost is a linear curve derived from the mean price scenario in [3] for the 2020 – 2030 period. For variations of this parameter, the linear curve coefficients derived from the lower and upper price scenarios in [3] have been used.

A constant price throughout all the countries has been considered as the CO_2 emissions rights market is a common market for all the EU.

Capacity Factor (%)

In the base case, the capacity factor was calculated for each country as a function of the annual steel production and the available capacity calculated as the maximum hours of operation times the tap-to-tap ratio.

As the CF is not constant throughout each country, but representative of the competitiveness of each steel manufacturing plant, for this sensitivity analysis its values have been forced to certain figures to address this parameter in terms of productivity goals and their economical paybacks. Moreover, since each manufacturing plant has its own CF, it seems reasonable to deal with this parameter in terms of productivity goal.

Specifically, the capacity value has been varied between 50%, 70% (close to base-case scenario average CF in the studied countries) and 100%.

2.3.3. **Financial parameters**

The parameters considered to be finance-related are the investment percentage that is financed through bank credit, the interest rate of such hypothetical credit, and the discount rate.

Percentage of investment financed via bank credit (%)

The percentage of investment financed via bank credit is set to 70% in the base-case scenario. This is a rather large figure but for this kind of industrial investments certainly not the upper limit. In fact, the 100% of investment could be financed since an industrial facility can be activated and, therefore, amortised. Moreover, publicly supported financing programs could be expected or, at least, seem to be worth studying for the purpose of the present study in terms of their hypothetical payback in terms of economic performance improvement of the European steel sector.

In the sensitivity analysis here presented, a variation of ±50%, with a cap of 100% is proposed. Thus, the simulated figures are 35%, 70% and 100%.

Bank credit interest rate (%)

In the base-case scenario, the bank credit interest rate is 5%, which is a representative value of mid-term financing credit interest. However, such figure is strongly linked to changes in economic policies in the EU, and lower or upper values could be expected in case of changes in the policy of the ECB. Therefore, it has been identified as a relevant parameter to analyse its affectations to the outputs of the model, specially to potentially viable plants.

Although much lower interest rates are difficult to expect from commercial banks, it could be reached if a financing program consisting of soft loans from the administration was implemented. Therefore, the changes in the economic potential due to a fall in interest rates supported by European governments is worth studying, especially considering that the main driver of such support could be, indeed, the improvement in the economic potential of the steel sector.

The analysed fluctuation range is ±50%, being the figures of 2.5%, 5% and 7.5% the simulated values.

Discount rate (%)

The discount rate of such an industrial investment is reasonable to be expected at about 7%. It could be argued to be a conservative value since financial expectations are usually greater for such investment return periods. Again, it makes sense the study of the relative importance of this parameter because lower discount rates could be assumed by governmentally supported financing programs as well as greater discount rates would make easier to find private financing alternatives.

According to the explanation above, the variation range proposed for the sake of this sensitivity analysis is ±50%, having 3.5%, 7% and 10.5% as the discount rate values to be addressed.

3. RESULTS

The results here presented are a synthesis of the entire set of data extracted from the simulation results. As previously claimed, the analysis performed has considered all the possible combinations of each parameter value with all other parameter values.

The number of plausible scenarios is obtained as the power with base equal to the number of possible parameter values and exponent equal to the number of parameters under study. Hence, a total number of scenarios of 3 raised to 7 is obtained, as each parameter is varied between 3 possible values and there are 7 input variables being analysed simultaneously. This means that 2187 scenarios have been simulated. Each scenario addresses all the potential market, that means analyses the 219 EAF steel manufacturing plants in the studied countries.

With aim to make the analysis of results more understandable and to facilitate the emergence of trends and information out of the raw data, the analysis was performed fixing one parameter as 'reference' and studying all the scenarios generated with the three variations of it. This process allows interpreting the trends generated as a result of changes in each parameter values and was performed for each of the selected inputs.

The studied output is the one proposed in the previous section: the percentage of profitable market calculated as the total investment that would be required to put in operation all economically viable plants in a certain scenario divided by the total investment that would be required in case all existing EAF steel manufacturing plants had a profitable ORC heat recovery scheme.

The results have been analysed in terms of variation in this proposed outcome under the three modes of operation proposed by the PITAGORAS concept. The best methodology to visually analyse the data are the boxplots and the comparison between them in terms of total (aggregation of all countries) figures and country-wise figures. For the sake of clarity, only the results for the "Hybrid" mode are presented in this document, except in those cases where the other modes of operation are specially relevant, i.e. the "Only electricity generation" mode to study the effect of electricity prices and the "Only heat generation" mode to address the effect of thermal energy prices. The Hybrid mode of operation is the one with more affecting input parameters as both energy prices are of importance, so a more comprehensive analysis is possible. Moreover, this is the operation mode of the Brescia demo plant, which is intended to serve as reference for other plants within Italy or in the other studied EU countries.

The total aggregation of all countries is used to show the influence of the inputs addressed, although they have been analysed in a country basis as well, and the main findings related with this analysis are presented in the following subsections along with those findings obtained from the aggregated results.

The results are shown in a country basis for the capacity factor because that is the most affecting parameter and the variations and trends are more easily observed.

3.1. TOTAL (AGGREGATED) RESULTS

The total results are, as claimed above, the normalized aggregated figures for a certain scenario of each of the 9 countries studied, namely Austria, Czech Republic, France, Germany, Italy, Poland, Slovakia, Spain and Sweden. Therefore, these results provide measure of the influence of an input parameter in the market potential throughout the analysed EU countries in aggregated terms.

3.1.1. **Performance parameters**

Capacity Factor

According with the results obtained, the CF is by far the most relevant input parameter in all the technological models' outcomes. It can be easily observed in the Figure below, showing the distribution changes for the "Hybrid" mode:

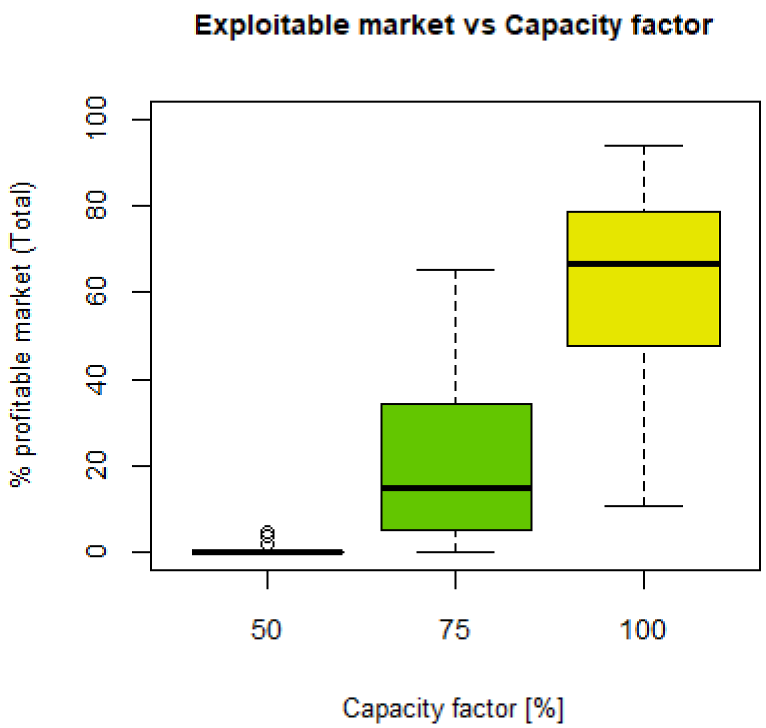


Figure 2: Aggregated Exploitable market vs Capacity Factor

It is easily appreciated that with a 50% CF there only but a few plausible combinations of the rest of variables that would activate some of the potential investments. However, an increase to a 75% CF make the possible scenarios much more profitable. When the ideal situation of 100% CF is simulated, it is seen that all the resulting possible scenarios are viable and the obtained distribution has a median of about 66%, meaning that with half of the resulting combinations of the rest of inputs, in two thirds or more of all existing EAF steel plants would be viable to install an ORC-based heat recovery plant.

With models based on the generation of electricity or heat alone, similar effects are observed. Therefore, it is clearly shown that the CF is the most important input parameter.

Carbon emissions cost

The changes in the ratio of aggregated market potentially existent with CO2 price changes are shown in the following plot:

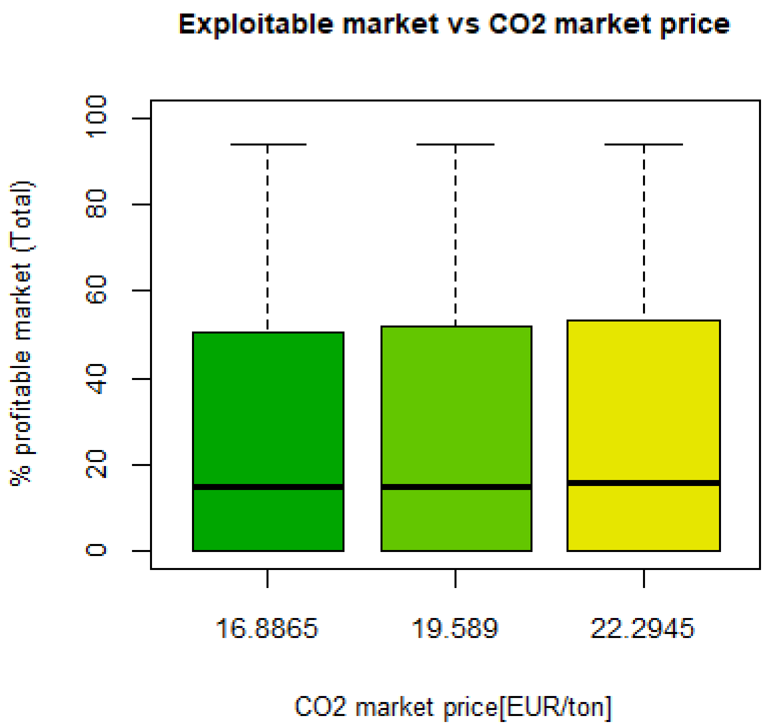


Figure 3: Aggregated Exploitable market vs CO_2 emissions cost

As the CO_2 market price does not have a constant price, but shows and evolution during the analysed period, the price labelled in the plot above is the price at middle of the lifetime, 5 years.

With the range of variations considered in this case, this input shows very low impact on market potential changes.

3.1.2. **Energy Price input parameters**

Thermal energy price

The thermal energy price does not affect the “Only electricity generation” mode, obviously. However, it is of great importance in the “Only heat generation” and “Hybrid” modes.

The effects of changes on the price of thermal energy sold to a DH network in the “Hybrid” mode are shown in Figure 4:

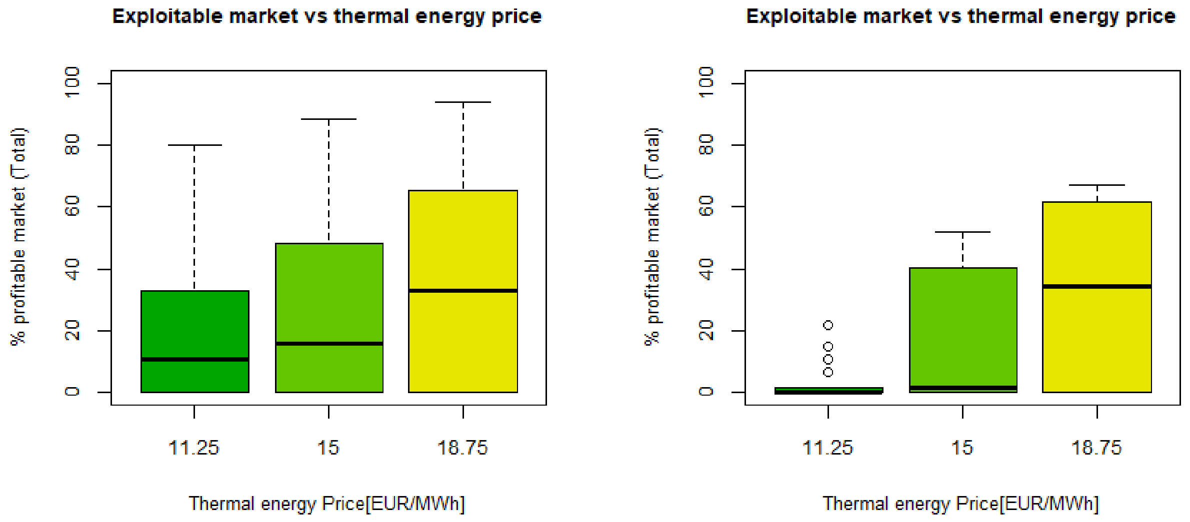


Figure 4: Aggregated Exploitable market vs Thermal energy price "Hybrid" (left) and "Only heat" (right) modes

Here it can be observed that thermal energy is of significant importance for the model currently implemented in the demo plant in Brescia (Figure 4, left). In fact, its importance is only surpassed by the CF (as shown above) and the electricity price (as shown below).

In the "Only heat generation" mode (Figure 4, right) its effect is dramatically increased. With low-price scenarios, positive ratios of market viable hardly exist. With base-case scenario prices, only a few of possibilities show viability, and with high thermal energy prices, the distribution's median value is around 40%, showing a significant potential.

In both cases, the results show the importance of having a remunerated DH network near the EAF steel manufacturing plant to increase the possibilities of market profitability.

Electricity price

As with the thermal energy price, the electricity price obviously does not affect the "Only heat generation" mode, but it is of significant relevance for the other two operation modes.

The changes in the response variable observed for the "Hybrid" and "Only electricity generation" modes are shown below:

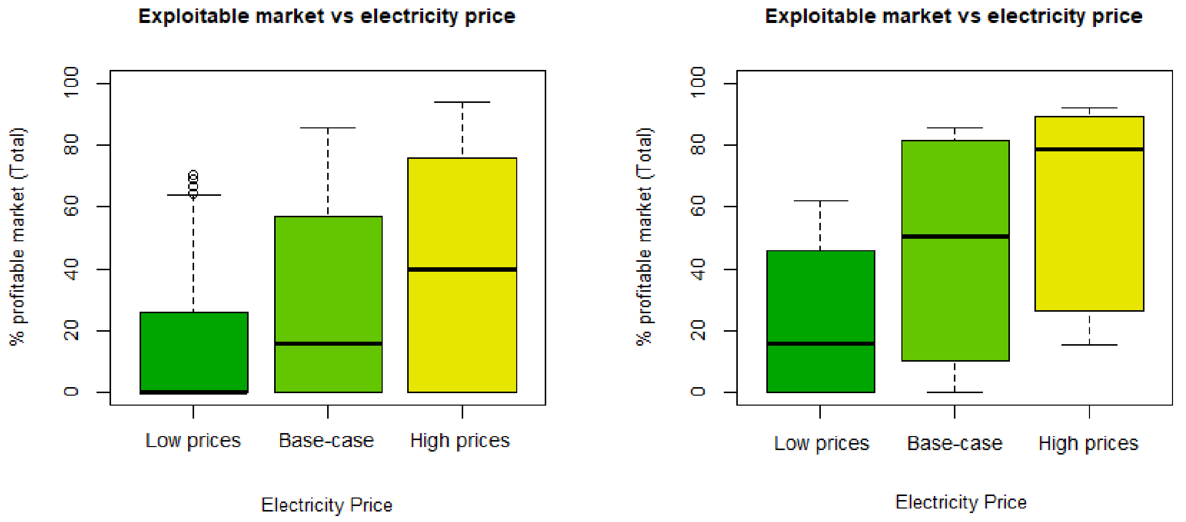


Figure 5: Aggregated Exploitable market vs Electricity price in "Hybrid" (left) and "Only electricity" (right) modes

The mode of operation based on electricity production (Figure 5, right) is very sensitive to the price of electricity. In fact, from having a median value of about 20% of potential market viable with the electricity prices of the base-case scenario, a rise to a median value close to 50% in the scenario of high electricity prices is observed.

In the hybrid mode of operation (Figure 5, left), these improvements are in the order of more than 300% in terms of median values, although such figure comes from comparison between base case and +25% electricity prices because in the -25% electricity price case the obtained median is 0 (lots of the possible scenarios do not give positive outcomes).

However, it is worth highlighting that the "Only electricity generation" mode shows more potentially viable scenarios than the "Hybrid" mode. In addition, the distribution's median value is about 80%. As the median value splits the sample in half, statistically this means that for half of the possible scenarios with high electricity prices, it would be economically viable to install ORC-based electricity generation facilities to 4 fifths or more of existing plants in the analysed countries. Hence, the price of the electricity can be considered, together with the capacity factor, a critical parameter for this mode of operation: in the scenario of high prices, a significant number of plants would become economically viable despite having less favourable values for the rest of the inputs.

3.1.3. Financial parameters

Percentage of investment financed via bank credit and credit interest rate

These two parameters are presented together as the behaviour of market potential distribution changes is the same given that the same percentage variations of ±50% are considered. Both inputs are related with the cost of investment, and represent the price to be paid for money loaned.

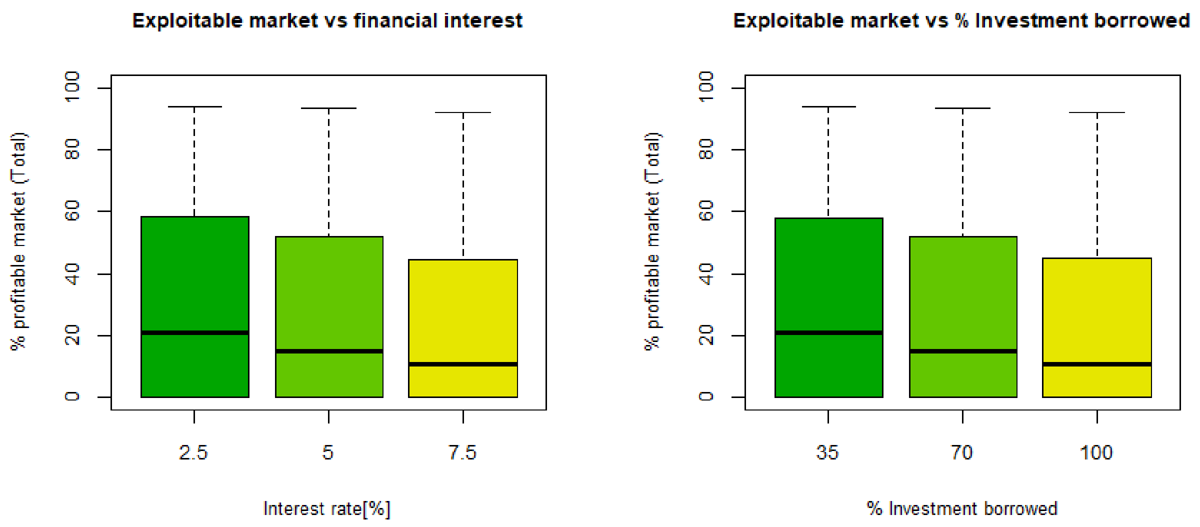


Figure 6: Aggregated Exploitable market vs Interest rate (left) and Percentage of investment financed (right)

For "Only electricity generation" and "Hybrid" modes, similar changes are observed: the effect of money cost depreciation is not appreciable in the distribution range change, but shows a significant effect on median value change. Particularly, a decrease of about 50% in distributions' median values is observed between the best case (2.5% IR or 35% of financed investment) and the worst case (7.5% IR or 100% of financed investment). This means that, although the range of possible outcomes of viable scenarios do not vary, the number of them does, so there are more possible input combinations resulting in positive viability with favourable financing conditions.

For "Only heat generation" operation, variations are hardly observed, but since the plausible scenarios are very bad, this difference could exist and cannot be appreciated.

Discount rate (DR)

The DR does not show any influence in any of the studied modes. The distributions of possible scenarios do not express any variation when this input is modified in the range analysed (between 3.5% and 10.5%).

This can be explained by the pass/fail criterion set to count a plant as viable or not. Always that a case has a positive NPV, it is accounted as feasible and its associated required investment, energy production and carbon emissions savings are added to the country-wise and total aggregated figures of these parameters. The discount rate will change the magnitude of the NPV thus increasing or decreasing the internal rate of return of the required investment, but not changing the "sign" of the cashflow nor the pass/fail test result.

Changes in the lifecycle of the installation could have the potential of changing the performance of a certain plant in front of the pass/fail criteria set, but this input parameter was not considered because its influence would affect dramatically the results hiding or reducing the visualisation of the effect of most or all other input parameters changes.

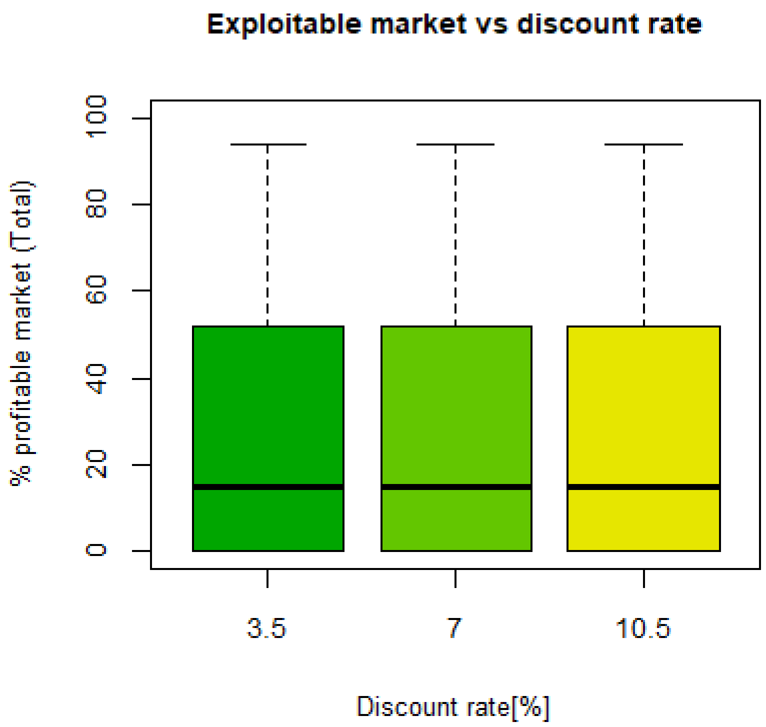


Figure 7: Aggregated Exploitable market vs Discount rate

3.1.4. Multiple linear regression of total results

A multiple linear regression is a predictive analysis methodology used to explain the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data.

The analysis of the multiple linear regression fitting coefficients provides information about the appropriateness of input parameters selection and their relative importance in explaining the response of the dependent variable. To consistently do so, the multiple linear regression has been performed with normalized independent variables so the effects of their difference of variation scale are removed. Such normalization is done by scaling (dividing by sample mean) and centring (subtracting mean so the distribution means are displaced to zero) the distributions.

With normalized and centred variables, the coefficients corresponding to each are proportional to their significance in the multiple linear regression, i.e. to their affectation to the response variable. Therefore, the signs of all linear regression coefficients express direct (if positive) or indirect (if negative) proportionality whereas their magnitudes (absolute values) express relevance.

By doing the multiple linear regression with scaled and centred independent variables, the following linear regression coefficients to predict the response of the dependent variable are obtained:

Table 4: Multiple linear regression data

Coefficient	Estimate “Only electricity”	Estimate “Only heat”	Estimate “Hybrid”
Intercept	$5.086\cdot10^{-16}$	$-2.236\cdot10^{-15}$	$-3.163\cdot10^{-16}$
Thermal Energy Price	$-1.240\cdot10^{-15}$	$5.249\cdot10^{-01}$	$2.120\cdot10^{-01}$
Electricity Price	$5.101\cdot10^{-01}$	$-4.803\cdot10^{-16}$	$3.376\cdot10^{-01}$
CO_2 emissions cost	$1.709\cdot10^{-02}$	$3.459\cdot10^{-02}$	$2.694\cdot10^{-02}$
Capacity Factor	$8.130\cdot10^{-01}$	$6.713\cdot10^{-01}$	$8.307\cdot10^{-01}$
Percentage of Inv. Financed	$-8.013\cdot10^{-02}$	$-7.785\cdot10^{-02}$	$-9.005\cdot10^{-02}$
Interest Rate	$-8.787\cdot10^{-02}$	$-8.502\cdot10^{-02}$	$-9.729\cdot10^{-02}$
Discount Rate	$-3.708\cdot10^{-16}$	$-5.491\cdot10^{-16}$	$-6.530\cdot10^{-16}$
R^2	**0.9355**	**0.7399**	**0.8669**

Graphically, it can be plotted as shown in Figure 8 and Figure 9.

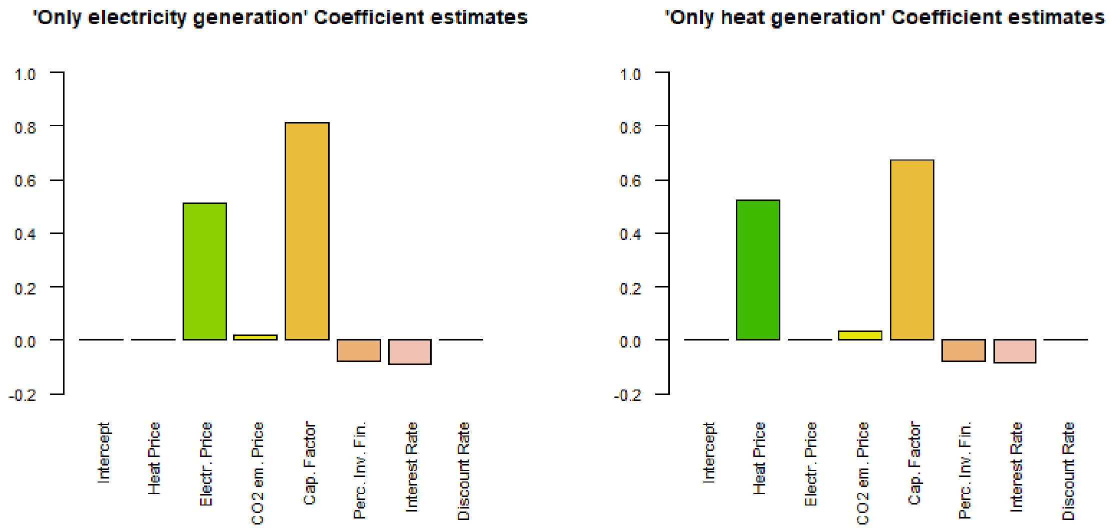


Figure 8: Coefficient estimates for “Only electricity generation” (left) and “Only heat generation” (right) modes

The first fact that is worth noting is that R-squared measure linear regression adjustment to the sample is in all the three cases very high. Taking 0.7 as the threshold value from which it can be ensured that there is a cause-effect relationship, all the three modes of operation lineally express such kind of relationship with the selected inputs. In the case of “Only electricity generation” and “Hybrid” operation modes, the selected inputs even show a high linear adjustment to the response variable, given the obtained R^2 figures.

According with the results obtained, the discount rate is confirmed to be irrelevant and in all the three modes would have an indirect proportionality relationship. So are the price of electricity in “Only heat generation” operation and the price of thermal energy in “Only electricity generation” operation, as expected, but in this case the proportionality would be direct.

The capacity factor is confirmed as the most relevant factor in all the three modes, with a direct proportionality relationship meaning that the higher the CF, the greater the accumulated market potential.

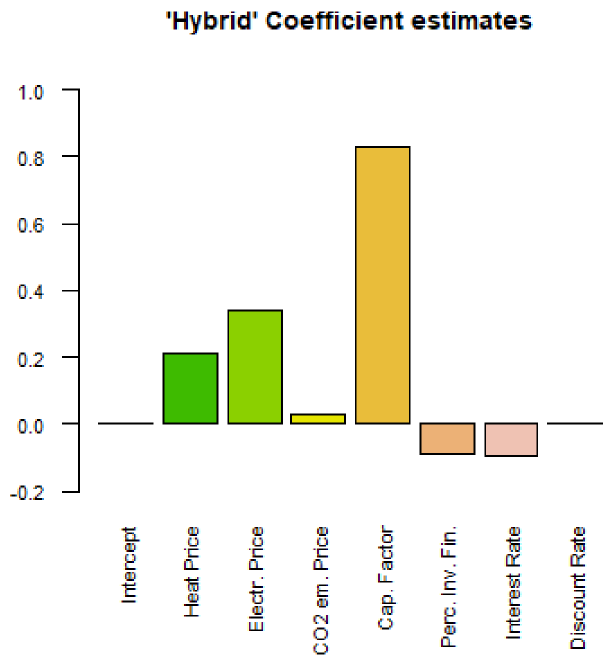


Figure 9: Coefficient estimates for "Hybrid" mode

This parameter is closely followed in relevance by the applicable energy prices, i.e. electricity price in "Only electricity generation" operation, thermal energy price in "Only heat generation" operation and both of them in "Hybrid" operation. As with CF, energy prices show a direct proportionality with aggregated market potential.

The interest rate of investment credit and the percentage of investment financed via such credit show a similar behaviour for all modes, being in all of them the 3rd and 4th in order of relevance respectively, after CF, and applicable energy prices. In this case, the proportionality relationships are negative, meaning that the higher the cost or quantity of money to be loaned, the worse the market potential.

For all the relevant parameters, the cost of CO_2 emissions is the least relevant parameter for the three modes. A direct proportionality is observed between CO_2 emissions cost and market potential.

3.2. COUNTRY-WISE RESULTS

In this case the results are analysed per country. This means that the aggregated market potential of each country is studied independently from the other ones. With this kind of analysis, it is intended to see not only which country has better conditions for the proposed mid-temperature heat recovery and valorisation, but also the different impact that the different input variables addressed have on each country's market potential.

As claimed before, the country-wise results are only shown for the capacity factor to reduce the number of plots presented in this document and make it more readable. However, they have been analysed for all the inputs studied.

3.2.1. Performance parameters

Capacity Factor

The distribution of the ratio of profitable market “activated” for the three values of Capacity factor are plotted for each of the 9 studied countries in Figures 10-14 shown below:

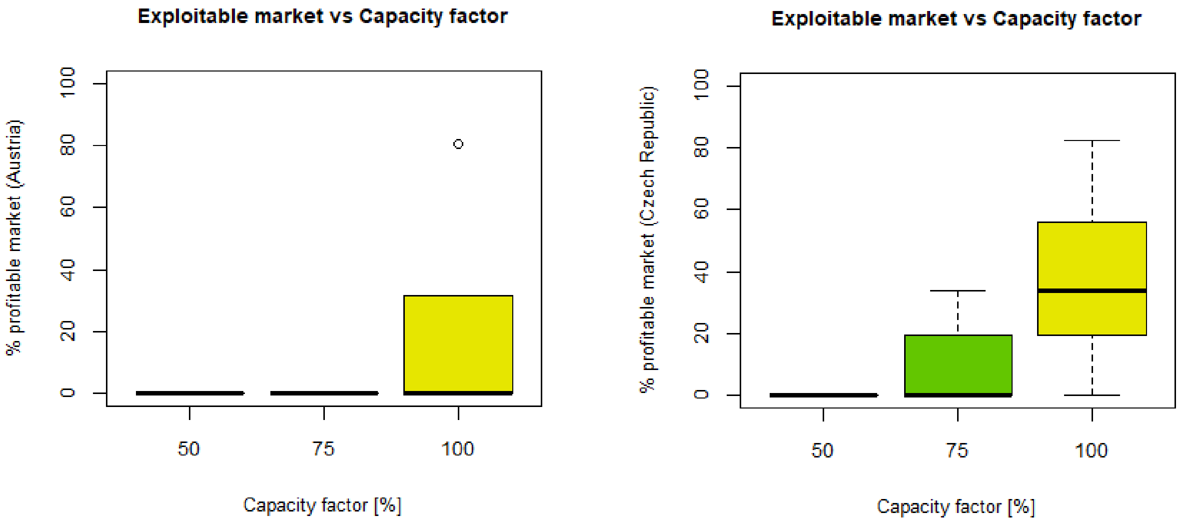


Figure 10: Country-wise boxplots for Exploitable market vs Capacity Factor for Austria (left) and Czech Rep. (right)

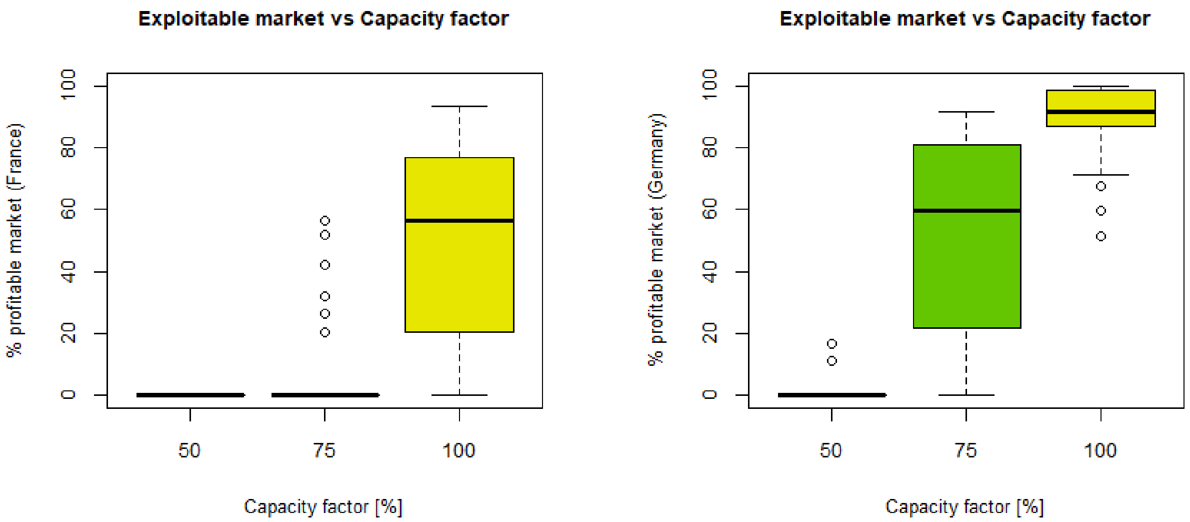


Figure 11: Country-wise boxplots for Exploitable market vs Capacity Factor for France (left) and Germany (right)

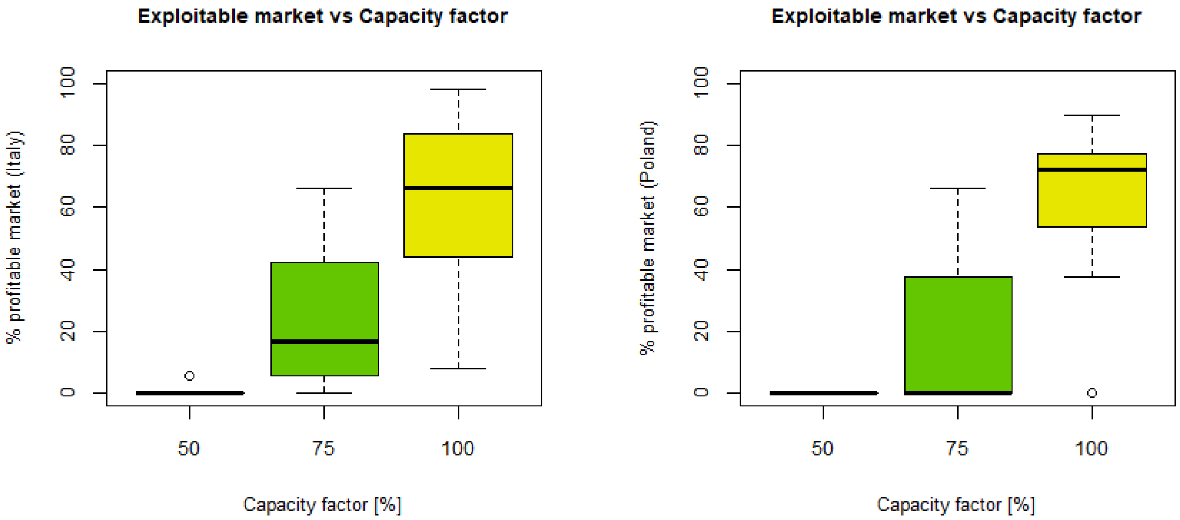


Figure 12: Country-wise boxplots for Exploitable market vs Capacity Factor for Italy (left) and Poland (right)

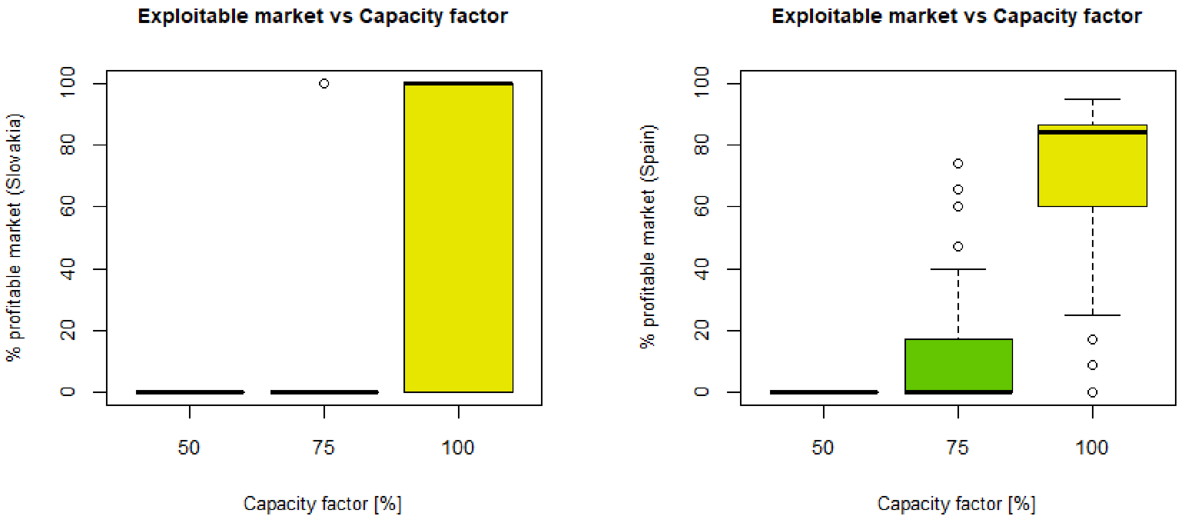


Figure 13: Country-wise boxplots for Exploitable market vs Capacity Factor for Slovakia (left) and Spain (right)

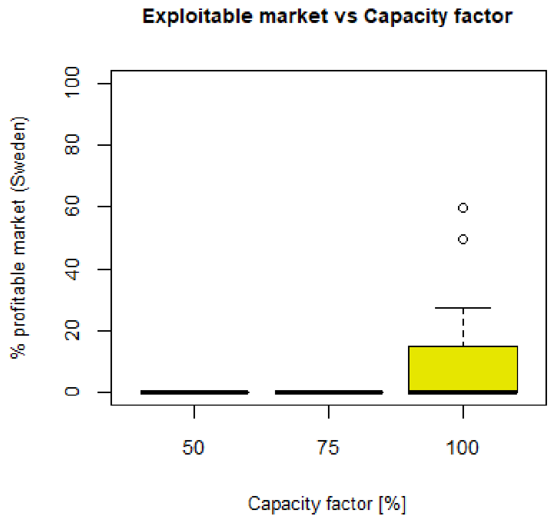


Figure 14: Country-wise boxplots for Exploitable market vs Capacity Factor for Sweden

The capacity factor shows a uniformly distributed behaviour throughout analysed countries. In all cases, it proves to be the most relevant input factor, reaffirming its capital importance as a goal for all industries eager to adopt the heat recovery scheme here addressed.

It is also noticeable that only Czech Republic, Germany, Italy, Poland and Spain have a number of viable scenarios with a CF of 75%, similar to the base-case scenario CF in the EU. From these, only Germany and Italy have a median over 0%, being those countries the ones with more possibilities with base-case scenario CF, as shown in PITAGORAS-D5.2. The rest of the cited countries would have only a few combinations of all other parameters that would lead to a viable scenario with this CF.

On the other hand, a 100% CF leads to a great number of feasible scenarios for all the studied countries and in some of them – Czech Rep., France, Germany, Italy, Poland, Slovakia and Spain, the median values of the distributions are greater than 66%, which means that half or more of all possible combinations of the rest of inputs result in more than two thirds of potential market activated.

Carbon emissions cost

The carbon emissions cost shows the same influence in all the three modes of operation. Roughly, it has the potential to improve the median value of Germany's distribution if the high-price scenario became real, but in general terms, its influence is hardly appreciable.

3.2.2. **Energy Price input parameters**

Thermal energy price

The thermal energy price is of great significance in "Only heat generation" and "Hybrid" modes. With the "Hybrid" mode, Germany and Italy prove to be profitable in a relevant number of potential scenarios even with the low heat prices case. The median values of distributions for these two countries are placed at about 50% and 10% of potential market respectively.

In addition to the previously mentioned countries, Czech Rep., Poland and Spain plants could be profitable in a few number of low heat price scenarios, probably those in which they could benefit from high electricity prices and capacity factors. However, their possibilities are scarce as the median values of their profitable market distributions are zero.

With prices of the base-case scenario, some favourable situations could enhance the viability of France's plants – probably in combination with high CF and electricity price – and with higher prices, in addition to a generalized improvement response in all mentioned countries, there could be found some viable schemes in Slovakia. Sweden and Austria only show punctual situations viable in the high price scenario.

Generally, the greater influence for this mode is observed in France and Czech Republic changing the situation from a non-viability distribution to a distribution with a number of viable scenarios; but also improve significantly the distributions in Poland, Italy and Spain.

For the "Only heat generation" mode, France, Germany, Italy, Poland and Spain are highly affected and at a lesser extent, it also improves the viability of plants in Czech Republic and Sweden. In the case of high heat prices, even Slovakia could have some viable plants, whereas in the case of lower prices than base-case scenario ones, only Italy would have a number of profitable plants and Germany and Spain would have a few punctual success cases. The differences of plant viability for this mode of operation are mainly due to plant scale and subsequent volume of heat produced.

Therefore, it seems a goal worth pursuing to find and encourage high remunerated DH networks near the steel manufacturing plants in all countries, but specially in Czech Republic, France, Italy, Poland and Spain.

Electricity price

High-prices scenarios have the potential to make viable the "Hybrid" mode in Czech Republic, France, Poland and Spain, which proved unviable in the base-case scenario, and to dramatically increase the number of viable plants in Italy and Germany which already had a number of feasible plants with base-case scenario prices – probably in higher CF and lower cost of financing situations. For all that, the electricity price can be considered the second most important input parameter, only surpassed by the capacity factor and closely followed by the thermal energy price.

In addition, Slovakia could have a few punctual success scenarios in the high electricity price scenario.

In the case of Sweden and Austria, the electricity price shows almost no effect on viability

In Sweden, it can be attributed to the fact that the current price is so low than even with 25% increase it would not be sufficient to make the model profitable, whilst in Austria the drawback is related with plant scale.

With the "Only electricity generation" mode, the electricity price effect per countries is similar than in "Hybrid" mode addressed above, being less important in countries with cheap electricity such as Sweden.

3.2.3. **Financial parameters**

Percentage of investment financed via bank credit and Interest rate

The percentage of investment financed via bank credit and the interest rate are presented together as they have very similar effects to the response variable, and both represent a measure of the monetary cost of initial investment.

The cost of money to invest, being it in form of less money to be loaned or a cheaper interest rate for such hypothetical loan, proves crucial importance in Czech Republic, France and Slovakia. In these countries, the upper half of the profitable market's distribution grows noticeably, although in the case of Slovakia, the response variable is more sensitive to changes in the interest rate rather than percentage of investment financed via bank credit.

In Poland and Spain, slight improvements are observed between the worst-case scenarios (7.5% interest rate or 100% of investment financed via loans) and the mid-case scenarios (5% interest rate and 70% of investment borrowed).

With the countries showing best shares of profitable market, Germany and Italy, relevant improvements are observed when financial conditions are more favourable. The ratio of profitable market improves significantly and the median of the distributions too.

Austria and Sweden are not affected by the possibility of having access to cheaper ways of financing.

The same situation applies to Slovakia for "Only heat generation" operation, in which lower interest rates or percentage to be financed result in significantly more feasible situations.

In general, these inputs have a greater effect in the "Hybrid" mode of operation for all countries aside from those mentioned above. Specifically, France, Germany and Italy distributions are benefited from low interest rates or percentages of investment financed via credit; whereas Spain and Poland perceive such benefits with mid-cost scenarios simulated.

Discount rate

The discount rate does not affect the performance of the scenarios in any country at all. The reasons behind are further developed in the previous section.

4. CONCLUSIONS

In PITAGORAS-D5.2, a model was developed to study the market potential of heat recovery in the steel industry for heat and electricity generation. A quantification of the technological potential for such energy efficiency concept was performed under three different modes of operation, namely “Only electricity generation”, “Only heat generation” and “Hybrid” operation. Afterwards, a base-case scenario was defined by allocating the most realistic values to all the inputs of the model, and the market potential was studied under such hypotheses.

This deliverable presents a methodology to carry out a sensitivity analysis to the previously developed and tested. This sensitivity analysis has been designed to analyse the performance of the market potential, under changes in several input parameters. The purpose is to understand the influence of selected inputs into the market potential, i.e. the increases or decreases in the number of viable plants according to input changes. Thereafter, the market behaviour can be characterised.

The inputs targeted as relevant for this analysis are the thermal energy and electricity prices, the carbon emissions cost, the capacity factor, the percentage of investment financed via bank credit, the interest rate of such credit and the discount rate of the investment.

All of these 7 parameters were varied to one upper and one lower value from the base-case proposed in the previously mentioned document, giving a total of 3 alternatives for each one. That leads to a total of 3 elevated to 7 (2187) possible scenarios addressed in this sensitivity analysis.

To compare the different influence of the analysed inputs, the ratio of potential market that becomes viable is used as the response variable. The use of this normalized distribution allows addressing and comparing the relative impact of a certain parameter change between different countries because the effect of the higher or lower capacities installed in each one is removed.

From PITAGORAS-D5.2, it was observed that market potential under the current context of energy prices, financial conditions, capacity factor and CO2 emissions cost is scarce and only allocated in Germany and Italy. The sensitivity analysis reveals that reasons behind that are:

- Low capacity factors in the EU, at least in average as considered
- Energy prices too low to monetize heat recovery via ORC
- Low carbon emissions prices that do not encourage carbon emissions savings in the context of the steel industry
- Lack of proper financing solutions especially for the upfront investment

What is probably the most relevant conclusion is that the viability of the plants for implementing the heat recovery solutions based on Organic Rankine Cycle and District Heating depends basically on plant’s Capacity Factor (CF – by far the most influent factor) and country’s energy prices for both electricity and heat (with similar influence much lower than CF’s relevance). In other words, the feasibility to implement the Pitagoras concept as an energy efficiency measure is characterised by these inputs.

In particular, the analysis of the CF influence shows that for “Only electricity generation” and “Hybrid” operation modes the maximum potential market under the hypotheses considered for the adoption of the proposed heat recovery system is around 90% of current EAF steel manufacturing plants, whereas for “Only heat generation” operation is around 60%. Hence, even in the idealistic case of having 100% CF in all plants of the studied countries, a small portion (10% for “Only electricity” and “Hybrid” and 40% for “Only heat”) would still be unprofitable for such concept.

As the study had assumed equal CF in country basis, the fact that a certain country does not show a market potential for certain scenarios does not mean that all the plants are not feasible. Those EAF steel manufacturing plants with CFs close to 100% (7000 hours in this study as a tap-to-tap ratio of 0.8 was considered), will perform well although in country terms this good performance is masked by low country averages.

A close look to heat prices' influence on "Only heat generation" and "Hybrid" modes reveals that, although lower than electricity prices, they have great relevance on plant viability. As heat prices are not set in a free market pool, their significance suggests that for both modes with heat sale to a DH network, it is of great importance to be able to find a moderately remunerated DH network near the steel manufacturing facilities. Such possibility would lead to lots plausible scenarios in which the proposed PITAGORAS concept would be highly profitable.

The electricity price is also very relevant, especially in the operation mode of "Only electricity generation". Given the high variability of this indicator observed during the last decade in the EU electricity markets, it seems reasonable to expect increases of the proposed order. The higher the electricity price is, the greater the economic viability of the analysed plants becomes.

The financial inputs are much less relevant to characterise the profitability of the Pitagoras concept in a certain steel manufacturing plant. However, such variations are not homogenously distributed along the studied countries, on the contrary, for more favourable financial indicators greater market potential improvements are observed for "Only electricity generation" installations in Czech Republic, France, Italy, Slovakia and Spain. These are the countries with higher electricity prices, so electricity production from waste heat recovery could show economic profitability with slight improvement of financial conditions since their plants are at a point close to economic viability. For "Only heat generation" plants, the only relevant improvement is seen in Italy. For the "Hybrid" operation, the best improvements are observed in Slovakia, Italy, Germany, France and Czech Republic. However, and given the different installed capacity in the analysed countries, in absolute terms the greater returns would be obtained in Czech Republic, France, Germany, Italy, Spain and Poland, together with some – punctual – cases that could be viable in Sweden as well.

This last fact is mainly due to the effect of plant number and capacity, which makes that a measure very efficient in terms of market potential increase in a certain country does not show noticeable impact in aggregated terms. For instance, although Slovakia shows higher plant viability improvements due to financial inputs than Spain or Poland (the number of new plants that become economically feasible are more in number than in other countries), the greater number of plants in the second ones give as a result a bigger market size, therefore making more advisable the consideration of these measures than in the first one. Indeed, an important conclusion drawn from this study is that the number and size of steel manufacturing plants installed in each country is a relevant factor that in some cases counteract the major effect of some parameters in certain countries.

The carbon emissions cost does not show to have a comparatively relevant influence on the market potential for neither of the proposed modes. This could be attributed to the small variation range that is expected in the mid-future according to [3], as well as to the relative low magnitude of this cost term with respect to other terms such as the ORC turbine and BOP.

In any case, such lack of relevance indicates the current and mid-term expected malfunction of the CO_2 emission rights trading system, at least for the context of EAF steel manufacturing plants. If, as shown, the price of CO_2 emissions rights does not significantly affect the market potential of a heat recovery and subsequent carbon emissions savings system in a high-energy consumption industry as the steel manufacturing sector is, it seems obvious that the system is not properly designed or put in operation.

If the differences between countries are scrutinised, results show that Germany and Italy are the countries with more successful scenarios, and those who have them even with less favourable conditions. They are followed by Spain, Poland and France, in this order, which did not show a positive NPV scenario in the base case proposed in PITAGORAS-D5.2, but only with certain inputs improvements, such as slight improvements on energy prices or capacity factor, would. As previously highlighted, in those plants that are operating at full capacity or close to, the heat recovery concept here studied is likely to be already feasible.

Only in some very particular situations, viable scenarios are found in Czech Republic and Sweden. In the case of Czech Republic, the required combination include improvements in the CF, increases in energy prices as well as subsidies or low-interest financing availability, whereas for Sweden greater thermal energy prices – the electricity price merely has effect in this case given the low electricity price – and capacity factors would be required.

As for Austria and Slovakia, they almost do not show any success situation and when they have been found, they were only isolated cases, not country-wise trends.

5. REFERENCES

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[2] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en

[3] Study on the Impacts on Low Carbon Actions and Investments of the Installations Falling Under the EU Emissions Trading System (EU ETS) (2015), TU Delft