PITAGORAS

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

D5.2: First version of market analysis and business models

- Market potential –

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ABBREVIATIONS

ORC	Organic Rankine Cycle
EAF	Electric Arc Furnace
BOF	Basic Oxygen Furnace
GHG	Greenhouse Gas
CHP	Combined Heat and Power
NPV	Net Present Value
BOP	Balance of Plant

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 developed in Brescia demo plant. In this context, the present document summarizes the quantification of the potential in the countries target of the project (Austria, Czech Republic, France, Germany, Italy, Poland, Slovakia, Spain and Sweden), which is seen as the preliminary step to establish a business model for the concept as well as the exploitation of the project results.

In the document, we show that there is a high amount of the potential market that has a profitability relatively close to the investment criterion set as a reference, and also, that the economic performance of the system shows a high sensibility when operational conditions change. In the next versions of the deliverables, we will show how the economic performance can be improved at a minimum cost, considering energy prices, carbon savings and plant capacity factor.

The main concern for the steel sector in general, so also for the ORC recovery potential, is the production overcapacity. As we show in the document, the capacity factor of the plant is fundamental to get a profitable return, and this variable has droped overall in the EU a 23 %, while at the same time, the EU has become the 5th major net steel importer in the world. Although single plants may have a good performance, the context, marked by the overcapacity, poses a serious threat to the risk perception for this particular investment. On the other way, the ORC can be seen as an energy saving measure aligned with the commission environmental policy, but also, a tool to improve the European steel sector competitiveness, since the improved efficiency on the process improves also the operational results from an economic point of view.

The potential is quantified by two different concepts, that we call technology potential and market potential respectively. The first one is the capacity of the technology assuming that all EAFs in the studied countries include a heat recovery system and yields a potential of 219 systems, with a carbon emissions abatement potential of more than 0.58 Mtonne of CO_2 yearly. This is approximately 0.015% of the total GHG emissions of the EU28 for the year 2015, which was approximately 4400 Mtonne.

The second one, the market potential, is the capacity of the technology assuming that a certain profitability criterion is meet by the investment associated with the system. The criteria selected is to have a positive NPV for a 10 years exploitation period and a 7 % discount rate, and for the studied countries, there is a potential of 44 systems, with a carbon emissions savings of more than 0.24 Mtonne of CO_2 yearly. This represents only 20 % of all the plants studied, but represents more than 40 % of the carbon abatement potential for the technology, what points that the situations with highest economic potential somehow correlate with the highest carbon savings potential. Regarding furnace capacity, the selected systems represent 31 % of all the EAF capacity of the studied countries.

1.2. PROJECT CONTEXT AND TASK PURPOSE

The purpose of this document is to characterize the market potential of the ORC technology in the steel sector as an input in general for WP5. The information included here is of key significance to two tasks within WP5:

- the business models, since it sizes in practice the potential and the profitable market available
- the individual exploitation plans

Also, the economic model developed within this task will be used further in the project, in particular for the findings shown in D5.5 and D5.6.

2. INVESTMENT PROFITABILITY ANALYSIS

2.1. MARKET OVERVIEW

2.1.1. Plant Capacity

In order to size the potential market for the concept within the analysed countries data, a commercial database [1] of steel plants was gathered as the starting point. The database includes 668 entries, and includes the following information:

- Site and company geographic information
- Furnace starting, upgrading and closing date (if closed, otherwise empty)
- Process
- Product
- Capacity
- Production (estimation)

The database was filtered to the operative equipment, and two entries with missing information where removed. Also, to get the working sample, all furnaces with a capacity equal or smaller to 10 ton of heat where removed, since the associated ORC turbines would be too small. This limited the data set to 243 furnaces, of which 219 are EAF and 24 BOF.

The installed capacity on the studied countries, split in EAF and BOF facilities is summarized in the next figure:

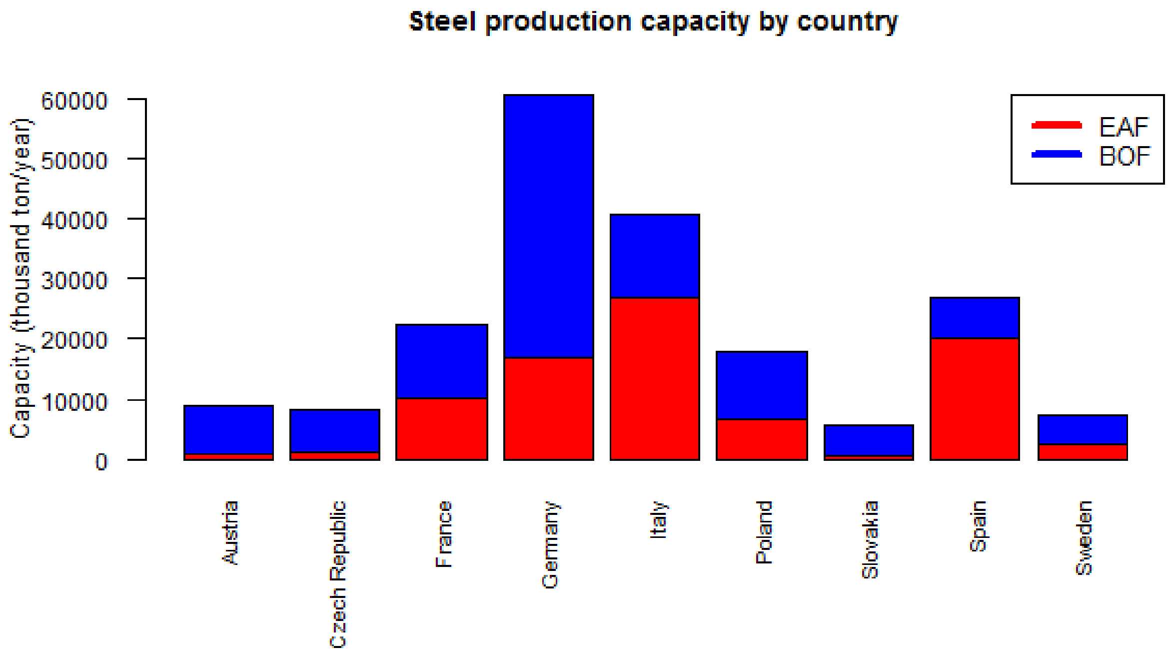


Figure 1: Steel production capacity by country

Overall, since the potential is related with the EAF capacity, we can see that most of the potential for heat recovery is in France, Germany, Italy and Spain, and to a lesser extent, Poland. The potential for Austria, Czech Republic, Slovakia and Sweden is marginal in comparison with the previous countries.

We work from now on with the sample subset corresponding to the EAF data. Besides the total capacity installed, we are interested in the number of systems potentially deployed, since the individual size of the systems is relevant to the potential due to economy of scale. In the next image, we show for each country the number of EAFs as well as the capacity:

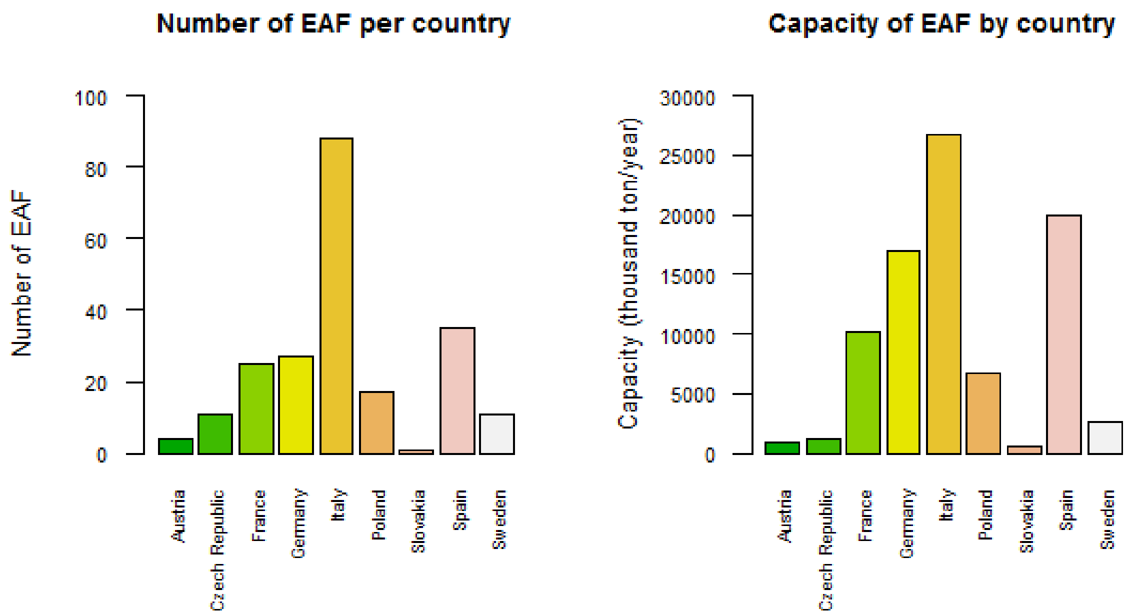


Figure 2: Number and capacity on EAF by country

The figure shows that Italy is the country with the highest installed capacity, in part due to the high number of sites deployed. However, looking at the mean capacity per furnace for each country (roughly, the ratio between the bar lengths on each of the previous graphs) we see that, on average, for Italy we have smaller sized furnaces while Germany and Spain show a higher capacity per furnace, followed by France and Poland. Sweden, Austria and Czech Republic have, as well as Italy, a smaller sized furnace park. This is relevant for the economic potential since better investment recover is expected for bigger systems. The next image shows the size distribution of furnaces for the countries with most facilities

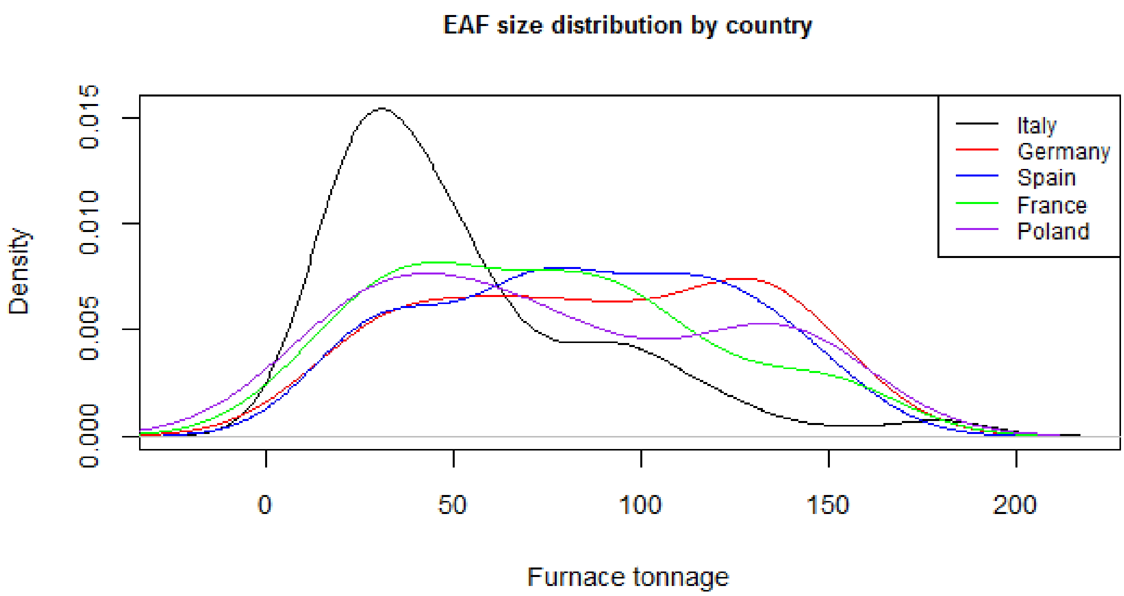


Figure 3: EAF size distribution for country

To summarize the information of the EAF sample, the following figure shows the main characteristics of the data grouped by country.

Table 1:Steel production by country

Country	Crude Steel production (Mio ton)	EAF steel production (Mio ton)	EAF Capacity (Mio ton)	Capacity factor
Austria	7.68	0.667	0.880	0.757
Czech Republic	5.26	0.360	1.167	0.308
France	14.98	5.159	10.229	0.504
Germany	42.67	12.621	16.887	0.747
Italy	22.01	17.227	26.717	0.644
Poland	9.19	3.877	6.681	0.580
Slovakia	4.56	0.325	0.552	0.589
Spain	14.84	10.143	20.023	0.506
Sweden	4.37	1.484	2.613	0.567

2.1.2. Capacity Factor

One of the key factors in the technology deployment is the capacity factor of the plants. This is an indicator of the number of operating hours of an EAF in a year. To put it simple, the development of a project has from an economic point of view two major driving forces: on one side, the plant capacity drives the investment associated with the project, while on the other, the running hours of the plant drives the revenues coming from the energy saved or sold.

The table below, taken from [6], shows the evolution of the EAF route production in the countries object of the Pitagoras project from 2007 to 2015; all data is in thousands of tonnes:

Table 2: Production of EAF steel by country, period 2007-2015

	2007	2008	2009	2010	2011	2012	2013	2014	2015	Variation	% variation
Austria	708	723	588	637	689	674	664	691	667	**-41**	**-6%**
Czech Republic	662	630	339	418	455	371	367	354	360	**-302**	**-46%**
Germany	15015	14639	11336	13215	14204	13789	13459	13062	12622	**-2393**	**-16%**
France	7442	7213	5164	5601	6128	6102	5491	5498	5159	**-2283**	**-31%**
Italy	19996	19679	14036	17163	18843	17939	17295	17200	17227	**-2769**	**-14%**
Poland	4434	4503	3893	3998	4356	4132	3551	3492	3877	**-557**	**-13%**
Slovak Republic	396	380	204	339	380	381	339	362	326	**-70**	**-18%**
Spain	14809	14573	11270	12503	11660	10216	10042	10042	10144	**-4665**	**-32%**
Sweden	1923	1757	967	1517	1675	1443	1418	1443	1485	**-438**	**-23%**
European Union (28)	84708	82740	61226	71147	75825	70487	66292	66039	65497	**-19211**	**-23%**

In order to help to grasp the data, the following figure shows the data from the table in graphic form:

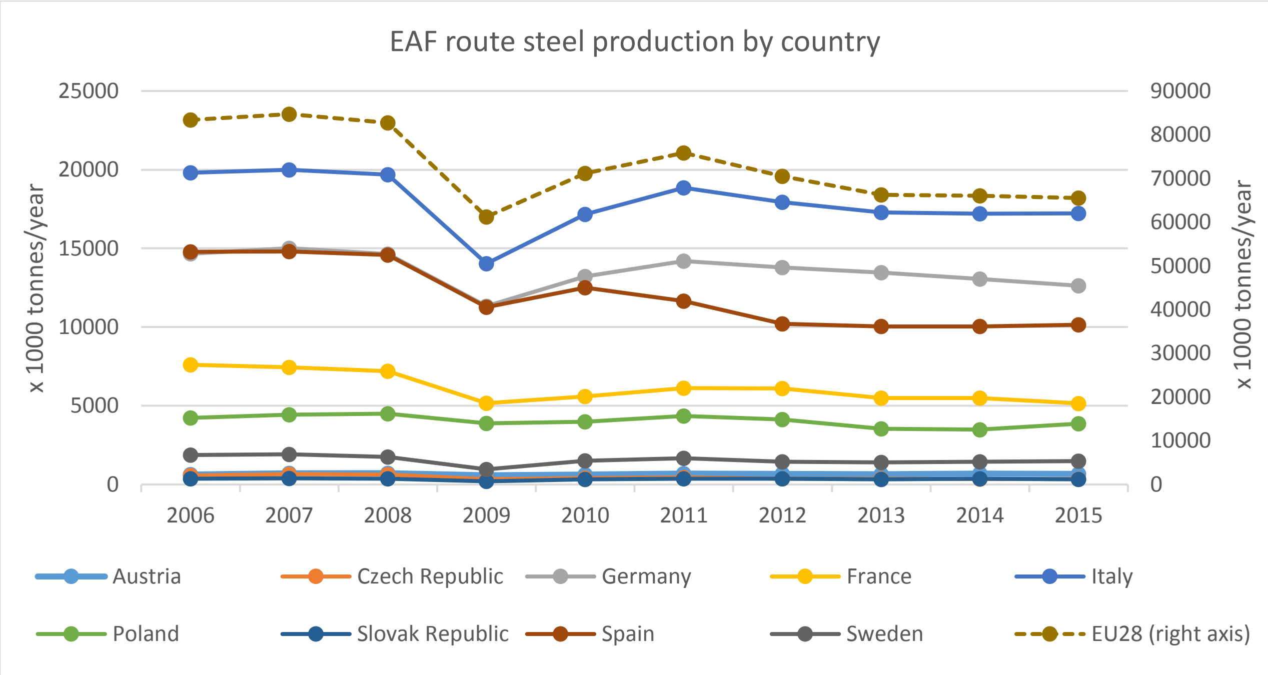


Figure 4: EAF route steel production by country

The graph shows a more or less common trend for all the countries involved in the study; on 2009, a huge drop of around 30 % of the total production in the EU, that recovered on the following years but stagned around 15 % under the pre-crisis figures. The countries with bigger drops are Czech Republic, France and Spain, while the ones with a smaller reduction are Austria, Poland and Italy.

Assuming that in this period no new capacity has been added in Europe, and considering the idle EAFs are not dismantled, thus could be potentially reactivated, we can estimate the evolution of the capacity factor on a country basis with the information contained in the tables 1 and 2. The next figure shows the evolution within the studied period; some of the countries have been removed to help visualize the data since tendencies are quite similar for most of the countries (barring Austria and Germany, that show a more competitive steel capacity):

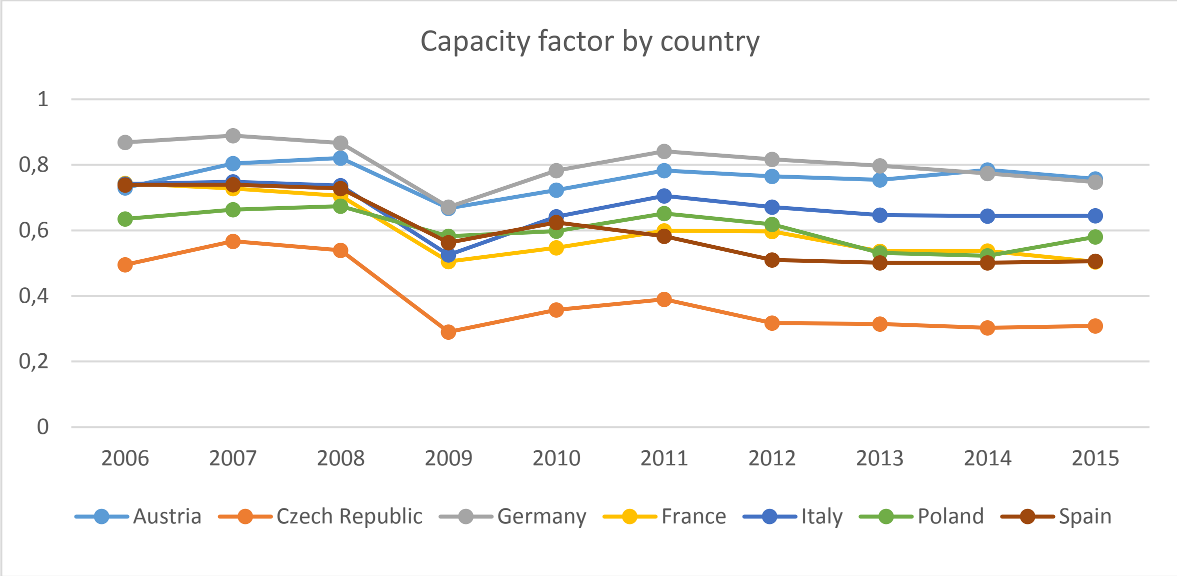


Figure 5: EAF capacity factor by country

The values show that there is an overcapacity on the steel sector, that for our purposes becomes a threat to the technological deployment of heat recovery applications, since it limits the potential of recoverable energy.

It is worth to mention that this trend is not a situation particular of the EAF route for steel production, instead, it affects the whole steel production sector. According to the statistics of steel production worldwide, the EU production evolved from a historical maximum of 201 Mtonne in 2007 to 160 Mtonne in 2015. In parallel, while this unused capacity in Europe is idle, the EU was the 5th worldwide major net importer (imports-exports) of steel in 2016, with more than 10 Mtonne. This means that in general, there is a loss of competitiveness in the European steel sector that may increase the risk perception associated with heat recovery investments, that usually require relatively long recovery times compared with the expectations of investors.

2.2. ECONOMIC MODEL

The basis of the economic evaluation of any investment lies on the projected cashflow associated to the project. To this end, an analytical model has been developed in R software to allow for the assessment of the economic performance of the Brescia concept in different facilities in Europe.

For each facility analysed, three different exploitation scenarios are considered:

- Mode 1: in this scenario, only an electrical valorisation of the waste heat stream is considered
- Mode 2: only heat recovery is assumed so no turbine investment is expected, neither electricity revenues
- Mode 3: 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.

The model projects the expenses and incomes for the project within a user defined exploitation period, considering the following additive terms:

- Investment costs
- Financial expenses
- Operation and maintenance expenses
- Electricity savings incomes
- Heat selling incomes
- Carbon savings incomes

We describe next the quantification of each of the terms in the yearly cashflow

Investment expenses

The investment associated with the ORC turbine is calculated as a function of the installed capacity following a correlation derived from [3]:

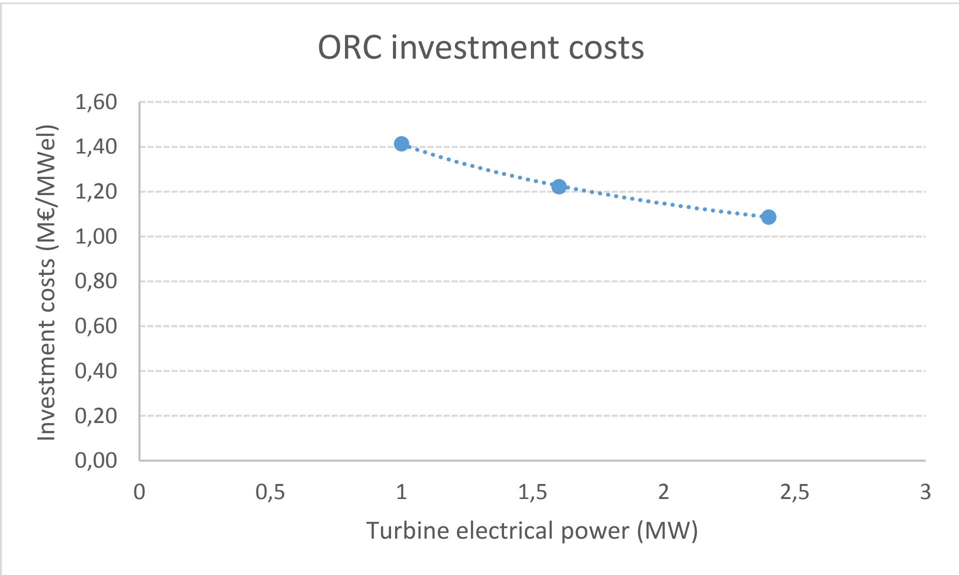


Figure 6: ORC Investment costs

For the full investment costs, including heat recovery, district heating heat exchanger and all necessary ancillaries we use the concept of BOP, which we use as a multiplier of the turbine costs to find the total system costs. Based on the experience gathered in the Brescia demo as well as published references we have set this value equal to 2.9.

Within the calculation of the cashflow, the investment cost is supposed to take place in the year 0 of exploitation, that is, one year before the starting of the operations of the system, thus revenues. We call it year 0 since this is not considered part of the exploitation period; however, not all the of the investment costs takes place in this year 0, instead, only a user-defined part of this amount (by default, 30 %) is expended in the year 0 while the rest is assumed to be financed, and returned as the principal term of the credit within the period of finance return (which by default is set to 5 years).

Financial expenses

The financial expenses are calculated as a constant interest and yearly payments of a single credit. Both the interest and the capital are returned within the user defined period of duration of the credit.

Operation and maintenance costs

The operation and maintenance costs of the system are a user defined parameter; the default value is taken from information provided by Ori Martin based on the operational experience of the Brescia demo plant. Although the limited time since the start-up of the system makes this value slightly uncertain, it is the most appropriate proxy to this quantity. The value selected is expressed as a percentage of the system investment cost and set by default to 1.5 %.

Electricity savings income

The operation of the system yields revenues in the form of saved electricity consumption to the industrial plant. The valorisation of this quantity is difficult to predict given the big differences among plants, and also hourly or seasonal variations of the electricity market. In the model, a simplified approach assuming a constant (yearly average) electricity price is used, since this is available from different sources at EU level. In the model, we use country electricity price values taken from [4]. The values correspond to users with consumption over 100 GWh/year and include market, distribution and taxes costs excluding VAT.

Heat sellings income

In some of the operational modes of the system, part of the waste heat stream of the industry is used to feed a district heating network directly, instead that transforming it to electricity by means of a ORC turbine. In these cases, revenues from the sold heat are included as an income to the investor, but the quantification is uncertain since this will be the result of the agreement achieved by the district network operator and the plant manager, so it varies depending on the specific exploitation framework from site to site.

For the model, we assume this quantity as a user-defined parameter, and the default value is set according to the information provided by Ori Martin on the exploitation of the Brescia demo plant. It is estimated to be on the range of 15 €/MWh.

Carbon savings valorization

On 2015 the EC developed a new proposal for the period starting on 2020 of the EU emission trade system, which is the third phase on the development of the carbon emissions market. This is expected to have a significant impact on the carbon market prices, as the emissions cap for the sectors involved will be constrained further.

The steel sector is one of the most relevant ones within the trading systems, mainly because of the high consumption of fossil fuels in the reduction process of ferrous materials into pig iron, as well as the emitted carbon due to the firing of BOF and finally the so-called indirect emissions associated to the EAF route. They are called indirect emissions since they are not associated to the EAF process, instead, they came from the electricity generation necessary to the operation of furnaces, hence the emissions are not generated directly in place, instead the electricity generator is the direct generator of the carbon emissions. The following image, taken from [5], helps to size the impact of the steel sector on the carbon emissions system:

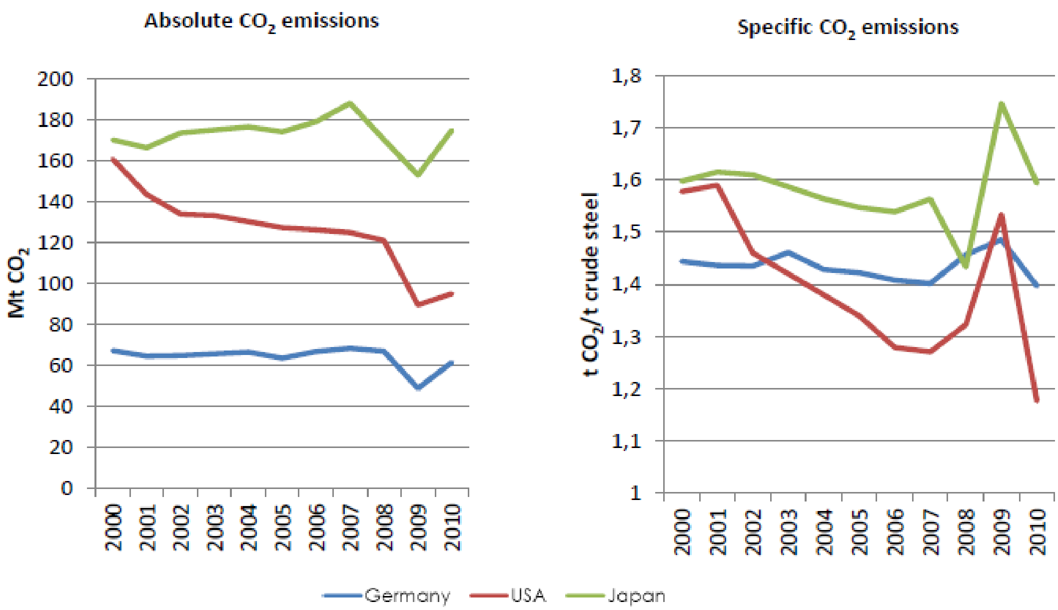
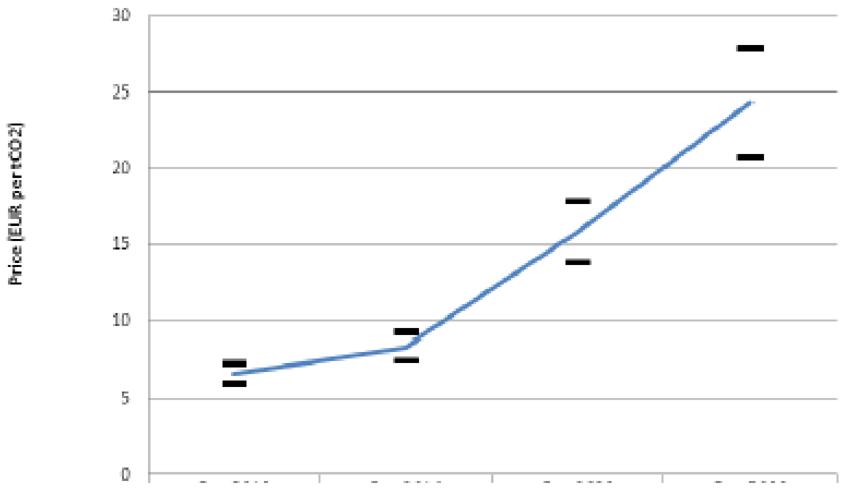


Figure 7: Comparative emissions from steel production

There are many studies available dealing with the evolution of the emission costs for this third phase of the carbon market, both at global as well as specific sector levels. We use the reference [5], by TU Delft for the EC to estimate the evolution of the carbon market price, since it is an EU publication and also has the appeal that the evaluation of the market price is based on estimations by companies involved rather than consultancy analysis. The next image shows the expected market price presented there:



	Dec 2013	Dec 2014	Dec 2020	Dec 2030
Upper conf. Int. (95%)	7.28	9.24	17.81	27.9
Price expectations	6.62	8.36	15.82	24.31
Lower conf. Int. (95%)	5.97	7.47	13.82	20.72

Figure 8: Projected carbon price in the EU trade system

For the quantification of carbon emissions avoided we use grid national emissions factors available from [7]. For the emissions factors of heat supplied by the system we use data for natural gas taken from [8], and assume that the district heating has a supply mix 50 % removable and 50% generated by direct burning of natural gas by boilers with an efficiency of 90%. This is just a synthetic reference that can be far from real mix for a given district, but at the moment, the European Environmental Agency doesn't provide country specific heat emission factors.

3. MARKET POTENTIAL

3.1. TECHNOLOGY POTENTIAL

We characterize the technology potential as the energetic, environmental and economic figures consequence of the hypothetic situation that all the EAFs in the studied countries have installed a waste heat recovery system. As previously described, we analyze three different scenarios for exploitation of the waste heat so we will show three technological potentials, each one corresponding to these scenarios. As a reminder, the defined scenarios are:

- Mode 1: in this scenario, only an electrical valorisation of the waste heat stream is considered
- Mode 2: only heat recovery is assumed so no turbine investment is expected, neither electricity revenues
- Mode 3: 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.

We present next the figures for each of these scenarios.

3.1.1. **Mode 1: Only electric generation**

In this scenario, the waste heat stream is used exclusively to generate electricity by means of a ORC turbine, and no heat is delivered to a district heating network. The interest of this approach is that it allows to reuse the waste heat without the need of having a surrounding district heating network, a situation that can arise due to several reasons, mainly:

- The steel factory is not close enough to an urban environment to pay off for the transport costs
- The available district heating has already met the demand by means of other heat sources and is contractually bind with other heat providers or investments
- The geographic area doesn't have district heating infrastructure due to the climatic conditions, as can be the case for the south of Italy or Spain

Table 3: Market potential: only electricity generation

	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**

For the studied countries, there is a potential of 219 systems, with a carbon emissions abatement potential of more than 0.58 Mtonne of CO_2 yearly. As a rough reference, this is approximately 0.015% of the total GHG emissions of the EU28 for the year 2015, which was approximately 4400 Mtonne.

There are differences in the effectiveness of the system depending on the country both from an environmental and also an economic point of view. These differences came from the wide variation in the national electrical grid emissions factor as well as the particularities of the steel sector in each country. We can get an idea based on the following graph, where we show the electrical production and the emissions avoided yearly per each million € investment on a country basis. It is important to remark that no conclusions can be drawn for an individual plant, instead, it represents a general trend on each country. In other words, individual plants may have very different values for these variables.

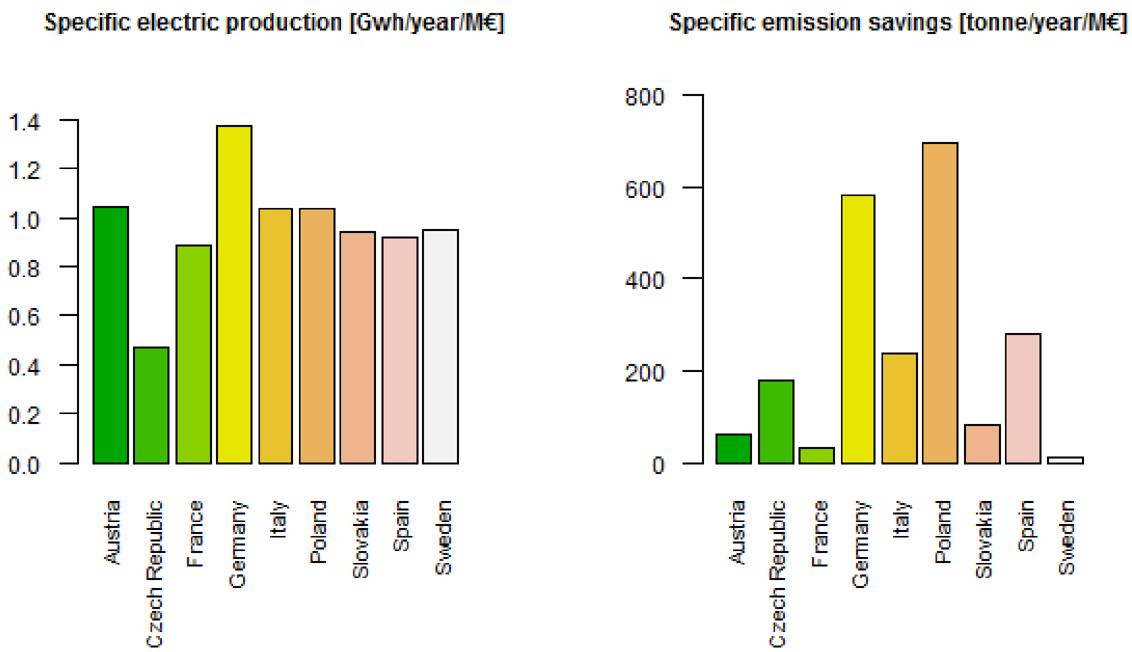


Figure 9: Specific electrical production and emissions savings for purely electrical concept

We can see that from an energetic point of view, the country with highest return, in electricity generated per € invested is Germany, followed by Austria, Italy and Poland, while from an environmental point of view, the countries with highest returns are Poland, Germany and in a smaller degree Spain and Italy. For the rest of the countries, the emissions savings per investment looks comparatively small, particularly for Sweden and France.

3.1.2. **Mode 2: Only heat generation**

In this scenario, there is no ORC turbine in the system and the recovered heat from the furnace flue gases is consumed directly, without further transformations. This can be advantageous in some situations, since investment is smaller and the system becomes simpler and requires less space to be deployed. However, it has a severe limitation, that a nearby heat consumer must be available in the form of either district heating or other industrial facilities. Keep in mind that this scenario is alternative to the previous one, not an addition to. The next table shows the summary figures for the heat recovery potential

Table 4: Market potential: only heat generation

	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**

For the studied countries, there is a potential of 219 systems, with a carbon emissions abatement potential of more than 0.68 Mtonne of CO_2 yearly, which is approximately a 15 % higher than the purely electrical scenario, although in this case the reference could vary widely from plant to plant so the figure must be taken with care. Moreover, this potentially increased carbon savings comes with an associated investment that is roughly 25 % smaller, so from an environmental point of view it is notably more cost effective.

However, looking on a country basis there are some of them with higher carbon savings when the system is a purely electrical generator. This is obviously an effect inherited from the national CO_2 emission factors, which is becoming more and more a fundamental parameter of the energy policy. A greater limitation tough for this approach is the limited applicability due to the need of line up geographically with an appropriate heat consumer.

3.1.3. Mode 3: Hybrid electricity and heat generation

We call this scenario hybrid to differentiate it from a conventional CHP where heat and electricity are delivered simultaneously by the system. In our case, which was the selected exploitation scenario for the Brescia demo plant, the system delivers heat to the local district heating network during wintertime, when there is a maximum demand of heat, and during summer, as the district heating can't absorb the additional waste heat, the ORC turbine consumes it generating electricity in the process.

Table 5: Market potential: hybrid generation

	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**

For the studied countries, there is a potential of 219 systems, with a carbon emissions abatement potential of more than 0.68 Mtonne of CO_2 yearly, which is approximately a 15 % higher than the purely electrical scenario (mode 1), and very similar to the heat exploitation scenario (mode 2). However, again, the high uncertainty inherent to the carbon savings associated to the heat generation must be remembered.

3.2. MARKET POTENTIAL

We characterize the market potential as the energetic, environmental and economic aggregated quantities for all the EAFs that fulfill a certain return of investment criteria. The criteria it's been set to show a positive net present value for an exploitation period of 10 years at a discount rate of 7%. The full list of economic hypotheses is defined in Annex I.

As previously described, we analyze three different scenarios for exploitation of the waste heat so we will show three technological potentials, each one corresponding to these scenarios. As a reminder, the defined scenarios are:

- Mode 1: in this scenario, only an electrical valorisation of the waste heat stream is considered
- Mode 2: only heat recovery is assumed so no turbine investment is expected, neither electricity revenues
- Mode 3: 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.

For each of the EAF we calculate the cashflow as described in section 2.2 for the 3 operation modes, calculate the NPV of the associated investment and them select the plants with a positive NPV. The aggregated figures by country of the plants fulfilling this criterion is shown next, for each operation mode

3.2.1. Mode 1: Only electric generation

In the case of a purely electric system, the next table show the market potential; missing countries have 0 plants with a positive return:

Table 6: Market potential: only electricity generation

	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)
Germany	22	2216	360.10	72.02	263.38	387555	164672
Italy	22	2355	382.69	76.53	276.41	355321	81440
Total	**44**	**4571**	**742.78**	**148.55**	**539.79**	**742875**	**246111**

For the studied countries, there is a potential of 44 systems, with a carbon emissions abatement potential of more than 0.24 Mtonne of CO_2 yearly. This represents only a 20 % of all the plants studied, but represents more than 40 % of the carbon abatement potential for the technology, what points that the situations with highest economic potential somehow correlate with the highest carbon savings potential. Regarding furnace capacity, the selected systems represent the 31 % of all the EAF capacity of the studied countries.

Most of the studied countries have no plants with market potential, what might be difficult to understand. The reason is that the plant capacity factor used in this analysis is calculated on a country basis, rather than using plant specific values. The reason is the difficulty to find information regarding capacity factor by plant; but also, the fact that a plant is actually operating under a certain capacity factor doesn't mean that it will keep working under the same operating regime in the future: it may raise or decrease depending on market evolution.

In this context, the capacity factor must be interpreted as an indicator of the competitiveness of the steel sector for a given country, so the market potential in a country basis shows the concurrence of a set of conditions (electricity price, capacity factor, emission factors…) needed to meet the minimum economic return required, so individual plants in countries not present in table 7 might have economic potential.

The results distribution, that is, the NPV distribution for all the plants is shown as a histogram on the next graphic; those plants with a positive NPV are the ones consolidated in the market potential:

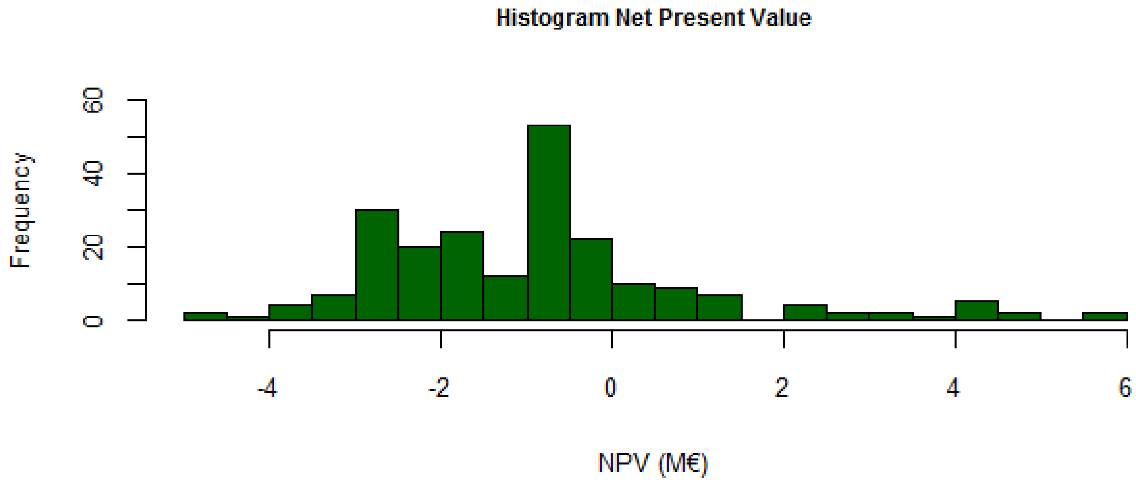


Figure 10: Histogram NPV, only electricity generation

It is interesting to see that the most frequent NPV is negative, but relatively close to 0, the boundary value to assess profitability. This means that little modifications within the cashflow provoked by incentives (like direct subsidies or soft financing) or market changes (for example, energy prices or carbon emissions valorisation) can have a significant impact on market potential for the system. We can see how this distribution looks if we focus on a country basis; the next boxplot shows the distribution by country. The systems located over the red line are profitable from an economic point of view:

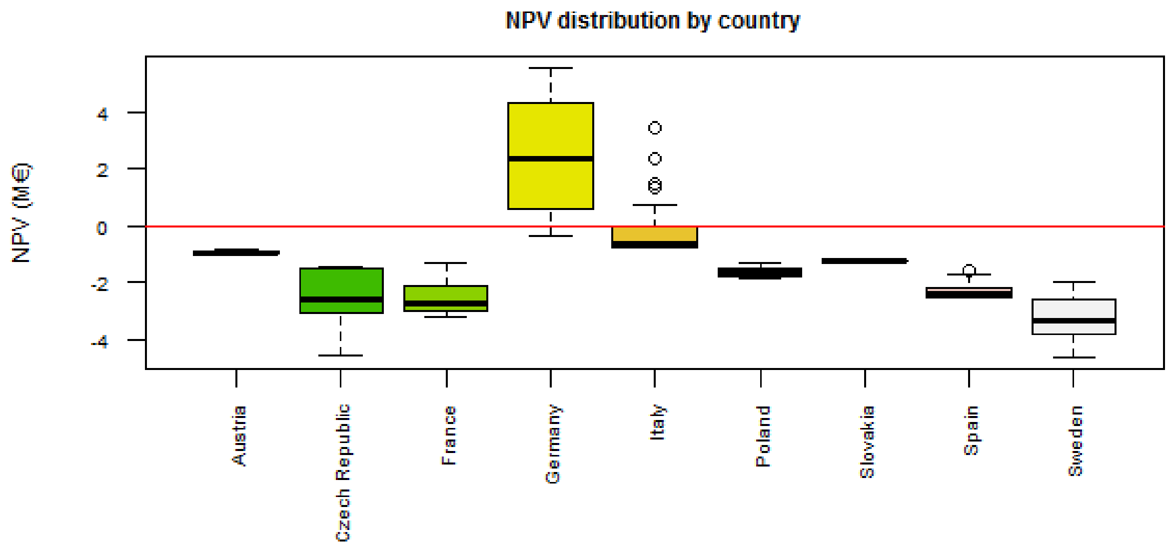


Figure 11: NPV by country, only electricity

We can see that most of the German market meets the profitability criteria, as well as roughly 25 % of the Italian market. Some countries, as Spain or Sweden look pretty far of showing any investment potential.

As expected, Germany and Italy are, in this order, the countries with a higher electricity price, so without surprise we can assume that the main driver for the system implementation would be the electricity price. Here we find some sort of contradiction recurrent on the European energy policy: on one side, energy prices for big industrial consumers are of capital relevance on fostering the industrial competitiveness on the global markets, so governments try to keep them low due to the impact on the economy. On the other side, this sort of protectionism blocks the deployment of a more carbon efficient industry due to the decreasing interest of efficiency measures under decreasing energy prices.

In this context, the carbon trade emissions system somehow increases selectively the energy prices, penalizing more the energy consumed with a highest carbon content. However, the impact of this mechanism on fostering the heat recovery for electricity generation with the ORC technology looks pretty small; the country with highest emission factor is Poland, with a value 3 times higher than Italy, but we can see in the previous graph that there is no investment potential there. This is probably due to the fact that electricity energy prices in Poland are 33 % smaller. In other words, a variation of electricity prices of a 33 % is far more than enough to completely overcome a variation of 300 % in the CO_2 emissions savings.

3.2.2. **Mode 2: Only heat generation**

In the case of a purely heating system, there is no potential under the boundary conditions fixed for the study since none of the 219 plants simulated yield a minimum return on the investment to mobilize the necessary capital. The reason is the low price assigned to the heat sold to the network (15 €/MWh), that is set according to the value applicable to the demo plant of Ori Martin in Brescia. This amount tough, may vary widely from one location to another, so again, individual plants may find profitability when a good price for the heat sold can be found. The next graph shows the results distribution as a histogram:

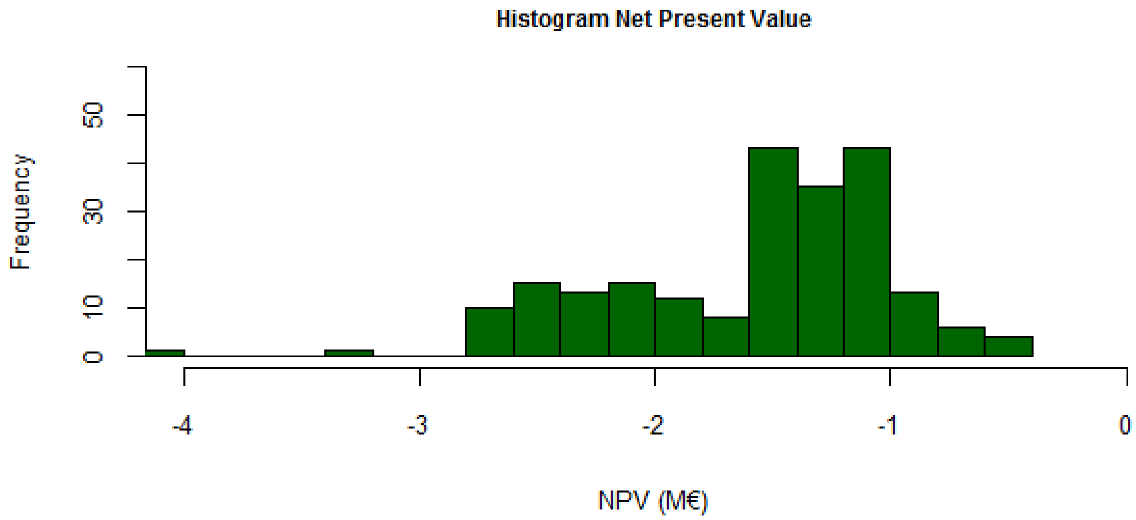


Figure 12: Histogram NPV, only heat generation

Most of the plants have a NPV very far from the threshold needed, so probably a significant increase in heat price is necessary to achieve profitability. By country, the results look as follows:

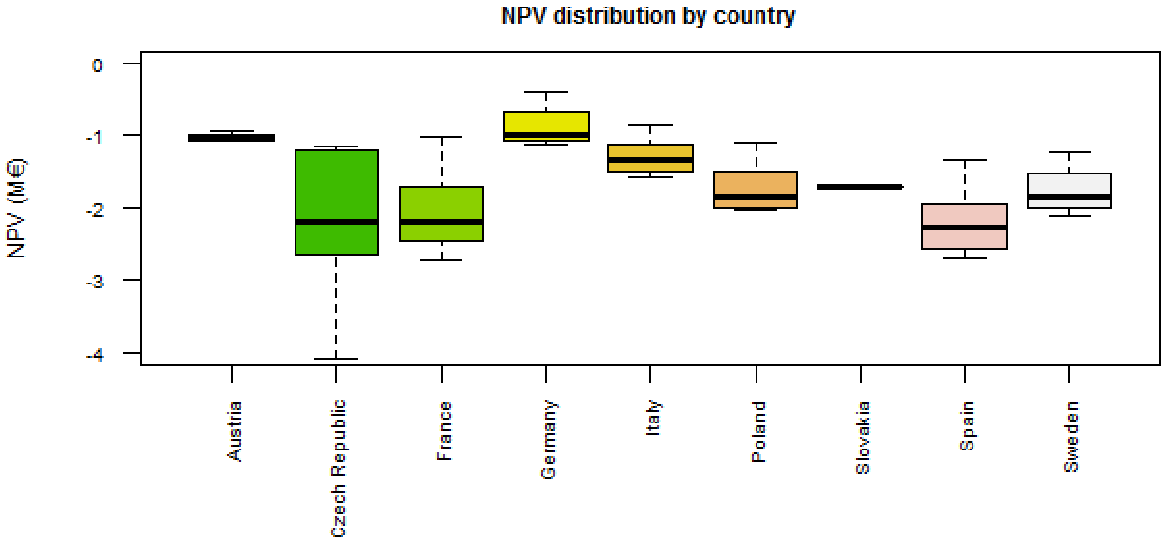


Figure 13: NPV by country, only heating

In this case, as we are using constant energy prices for the heat sold, the main driver of the results is the capacity factor of the plant, as the countries are sorted more or less following a similar pattern that the country specific capacity factor. Germany, Italy and Austria are the countries with the closer plants to market, but a higher heat price, over 20 €/MWh is necessary to find some profitability in this solution. Also, keep in mind that this approach is already penalized by the need to have a close district heating network with available demand.

3.2.3. **Mode 3: Hybrid electricity and heat generation**

In the case of a hybrid heating and electricity system, the next table show the market potential; missing countries have 0 plants with a positive return:

Table 7: Market potential: only electricity generation

	Number of systems	Total furnace capacity (t)	Waste heat power recovered (MW)	Electric power (MW)	Investment (M€)	Electricity production (GWh)	Thermal energy production (GWh)	CO_2 emissions saved (t)
Germany	12	1535	249.44	49.89	178.88	134.22	469.79	109744
Italy	2	360	58.50	11.70	37.92	27.15	95.05	16890
Total	**14**	**1895**	**307.93**	**61.58**	**216.8**	**161.37**	**564.84**	**126634**

For the studied countries, there is a potential of 44 systems, with a carbon emissions abatement potential of more than 0.12 Mtonne of CO_2 yearly. The sample represents only a 6 % of all the plants studied, and as happened with the purely electric scenario the potential is correlated with a combination of high electricity prices and plant capacity factor.

From an environmental point of view represents more than 20 % of the carbon abatement potential for the technology, due to the fact that bigger EAFs have a higher return and those are also the ones with highest carbon savings. Regarding furnace capacity, the selected systems represent the 13 % of all the EAF capacity of the studied countries.

Compared with the previously studied operating scenarios, the hybrid operation lays in between both of them, what is reasonable since from a technical point of view should be similar to the average performance of those scenarios.

The resulting NPV distribution for all the plants is shown as a histogram on the next graphic; those plants with a positive NPV are the ones consolidated in the market potential:

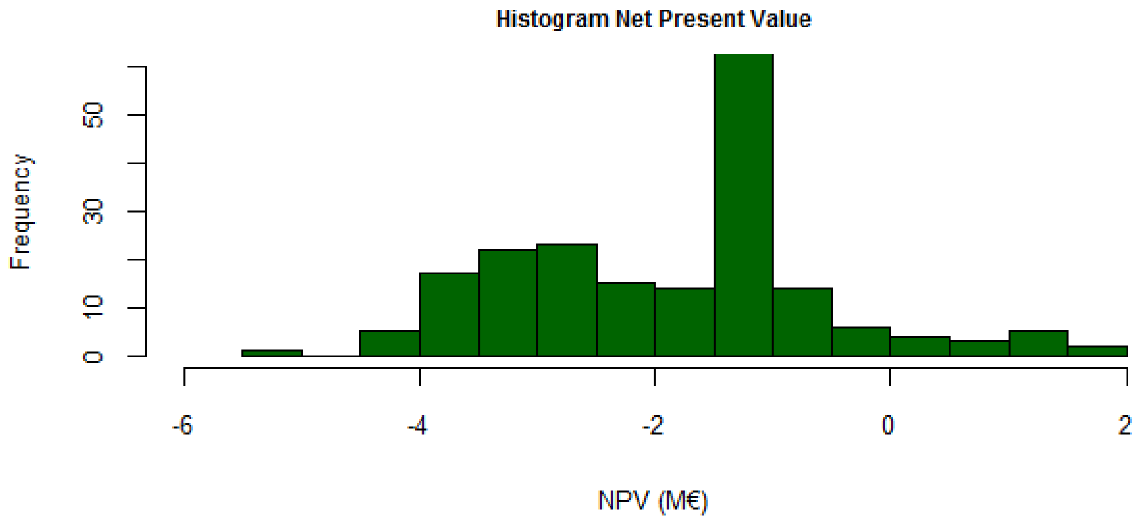


Figure 14: Histogram NPV, hybrid generation

As in scenario 1, we find that there is a noticeable amount of plants that show a NPV that is relatively close to the profitability threshold, in the range of 1 M€ (the investment range is between 3-19 M€), so little market variations can easily rise the potential market.

Again, we look at the NPV distribution by country, shown in the graph below:

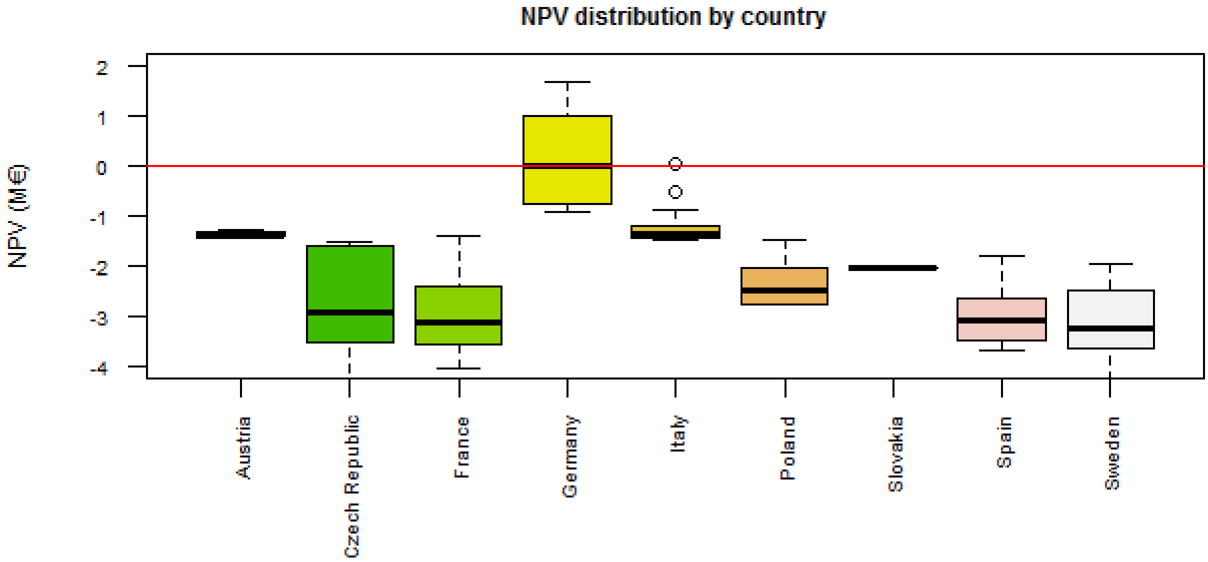


Figure 15: NPV by country, hybrid operation

From the figure, we can see that half of the German market can have attractive economic figures as an investment- Barring that, only a few of the Italian market plants have good enough results.

4. CONCLUSIONS

The waste heat recovery from the heavy industrial sectors is a technology that aligns with several targets of the European Commission policies; it reduces GHG emissions, increases industrial competitiveness and reduces foreign dependency on fossil fuels. In this document, we show that there is a potential of carbon abatement that reaches 0.6 Mtonne yearly in the EAF based steel production process within the countries studied (Austria, Czech Republic, France, Germany, Italy, Poland, Slovakia, Spain and Sweden), producing more than 2000 GWh/year of electricity from waste heat.

We conclude that there are several operational situations that make this option viable from an economic point of view, in particular, when certain conditions are found together: relatively high energy prices, high plant capacity factor and high furnace tonnage can make the system attractive from an investment point of view. We also, showed that under these conditions the highest carbon abatement potential per euro invested will be found; somehow, the highest profitability tends to match with highest carbon savings.

The main thread identified is the production overcapacity in the European steel sector. As we show in the document, the capacity factor of the plant is fundamental to get a profitable return, and this variable has dropped overall in the EU to 23 %, while at the same time, the EU has become the 5^{th} major net steel importer in the world. Although single plants may have a good performance, the context, marked by the overcapacity, poses a serious threat to the risk perception for this particular investment.

In the document, we show that there is a high amount of the market potential that has a profitability relatively close to the investment criterion set as a reference, and also, that the economic performance of the system shows a high sensibility when operational conditions change. In the next versions of the report, we will show how the economic performance can be improved at a minimum cost, considering energy prices, carbon savings and plant capacity factor.

5. APPENDIX: MODEL PARAMETERS

Consumer Price Index	2%
Discount rate	7%
Financial interest	5%
Explotation period	10 years
Financing period	5 years
Financed percentage of the investment	70 %
Plant operation and maintenance costs	1.5%
Heat sold income	15 €/MWh
Balance of plant investment	2.9
Mode 1 overall yearly electric efficiency	20%
Mode 2 overall yearly thermal efficiency	60%
Mode 3 overall yearly electric efficiency	10%
Mode 3 overall yearly thermal efficiency	35%

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