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D4.21 – European Sites Mapping

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Summary

This document presents results of task 4.2 of the NC2I-R project. The objective of this task is to report on conducted mapping task of heat intensive industrial sites in Europe that can be potential location for HTR demonstrator. This work is part of Work Package 4 of the NC2I-R project titled "End-users focus & Deployment scenarios". This document contains introduction to the nuclear cogeneration in Europe, siting methodology, mapping of adequate industrial sites in Europe and analysis of those sites.

Approval

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1 Introduction

EU-27 share in world energy production in 2012 was 6.5%. In EU-27 industrial sector final energy consumption is 26%. In 2011 final industrial energy consumption in EU 27 was as high as 287 Mtoe [6]. Transition to low-carbon energy mix 2050 according to SET-plan (Strategic Energy Technology Plan) requires alternatives to CO_2 emissive sources which will also results in increased security of supply and prices stabilization. Application of non-carbon CHP system is one of possible solutions to GHG emission reduction.

CHP, widely used in conventional power plant for medium and low temperatures application, has been deployed with success in EU and other parts of the world for years. Also nuclear cogeneration, not as popular as conventional CHP, has been applied in number of locations around the world. Cogeneration while reducing carbon footprint, increases overall efficiency of the process and allows supplying market in direct vicinity in process steam. In 2011.European Union CHP electrical capacity was 105.3 GW.

In 2011 there were 435 nuclear reactors under operation, 69 of them were producing heat for applications different than electricity production. They were localized mostly in Russia – 27, Ukraine – 13, Europe – 13, Japan – 9 and 6 in India. [1] Those reactors were deployed mostly for:

- District heating (6204 GWh in 2006)
- Industrial processes (978 GWh in 2006)
- Sea water desalination (2 billion m^3 mostly in Japan in 2006) [1]

However, Nuclear share of procured heat for applications other than production of electricity is still fractional - 0.2% (2011).

Low temperature nuclear cogeneration was demonstrated and proven in several objects in Switzerland, Germany and Canada. Basing on experiences obtained from those objects it can be expected that HTR will be able to supply broader market than existing solutions. In particular supply high temperature process heat to industrial sectors allowing reduction of CO_2 emission regulated by EU.

Selected sectors of industry can be supplied by employing nuclear units to coupled production of process heat and electricity. The specificity of combined heat and power production for short-term application requires that heat producing unit - HTR would be located in direct vicinity of industrial site or cluster. This requirement can be removed applying a gas-to-gas Intermediate Heat Exchanger (IHX) in medium and long term horizon. There are a number of requirements which apply to sitting of nuclear facility especially near to areas which are inhabited. Those criteria will be discussed in chapter 2 and Annex 2. The concept of coupling nuclear unit with industrial site need to ensure very high reliability on availability, stable steam parameters, high level usage of existing infrastructure on industrial site as well as competitive economic factors.

1.1 Coupling between industrial site and HTR

In EUROPAIRS project, two timeframes of HTR deployment were specified. In the near-term horizon (within 5 – 10 years), HTR can be coupled with industrial facility via schemes which are based of mature technology. Near term horizon includes deployment of HTR for combined heat (at moderate temperatures up to 750°C) and power production for industrial sector. Medium and long term horizon (10–15 years) is the time needed for additional technology development for tighter coupling schemes, additional applications or higher temperature proof materials (over 900°C). Medium and long term horizons aim for achievement of higher temperatures in the HTR as well as development of additional applications like hydrogen production or synfuel. [2]

One of the important aspects from licensing perspective is exposure of plant workers and populations surrounding the plant for radiation from nuclear unit and impact of radioactive release during accident scenarios. Main potential threat during normal operating conditions is tritium contamination. For the purpose of first demonstrator, two barriers between primary loop and heat destination should be included even if after first barrier tritium share will be sufficiently low. It was proposed that heat exchanger in primary loop should be a steam generator reasoning this decision with maturity of the technology and affordable pricing.

Distance between the site and HTR unit should assure safe operation for both units and at the same time not cause extensive heat and/or pressure losses at long distances. It was established that 2 km [13] distance will be sufficient to prevent hazards from industrial site to affect HTR. Thus, minimum of 2 km up to distance of several km between HTR location and industrial site should be appropriate. Whereas from technical and economical point of view it was determined that distance from HTR to utilizing location should not exceed 5 km [1]. Of course it is possible to transport steam to larger distances (steam transportation or IHX Gas-to-gas) but it must be economically justified.

1.2 Operational parameters and technical limitations of HTR

High Temperature Gas-cooled Reactor concept evolved through years of research experience. Through span of years few designs with different core structure, operational parameters and primary circuit were developed to a different level of readiness with aim of future commercialization. However at the moment there is no nuclear technology vendor offering commercial design for an industrial use ready for deployment.

HTR's thermal power of the HTR unit depends on many parameters (e.g. core geometry) However, design requirements are flexible allowing large variation in target heat production, as shown in Table 1. HTR can provide outlet gas temperatures up to 1000°C, which exceeds current conventional operation temperature of the heat exchangers as steam generators. In order to minimize technology risk, the output temperature is foreseen to be at a maximum of 750°C. This limitation has direct influence on maximum steam temperature of 570°C and pressure of about 17 MPa. However, this range of parameters still covers majority of applications foreseen for HTR, creating market sufficiently large to justify need for development of HTR systems. The average operating parameters of HTR are listed in table 1.

Table 1 Anticipated HTR demonstrator main parameters

Parameter	Value
Nuclear thermal power	200 - 600 MW_{th} / unit
Core outlet temperature	750°C
Core inlet temperature	250°C – 450°C
Maximum steam temperature	570°C
Steam pressure	17 MPa

Since HTR is a modular designs upper limit of power demand for industrial site selection is not applicable in reasonable extent, however, it should be noted that majority of industrial sites consumes between 10 and 500 MWt, lower limit should be placed in this range considering economy of scale. The fraction of the heat not used in the industrial process may be converted to electricity and delivered to the grid.

1.3 Industrial sector selection

The nuclear steam supply unit needs to meet end-user requirements to be considered as a favorable solution for industrial applications and be deployed in next years as a demonstration facility. Technical limitations for short term deployment indicate temperature below 750°C at the HTR core outlet as noted in previous section. Basing on temperature restrictions all applications requiring steam temperature above 570°C can be eliminated for near term horizon deployment. Industrial processes temperature juxtaposed with power demand for is presented in Figure 2.

Many industrial sectors consume steam as process heat, ingredient of chemical reaction or working fluid for electricity production. Different processes and purposes require specific values of the steam parameters like temperature, pressure, mass flow and availability. Basing on study performed in project EUROPAIRS the majority of industrial sites located within EU demand power supply between 10 and 500 MWth worth of steam at various temperatures.

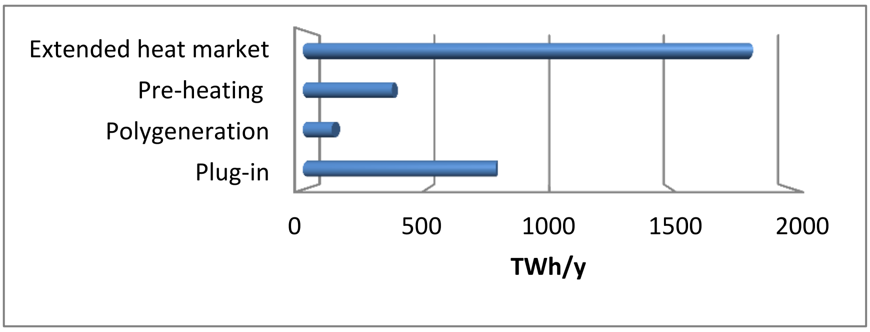


Figure 1 European heat market [3]

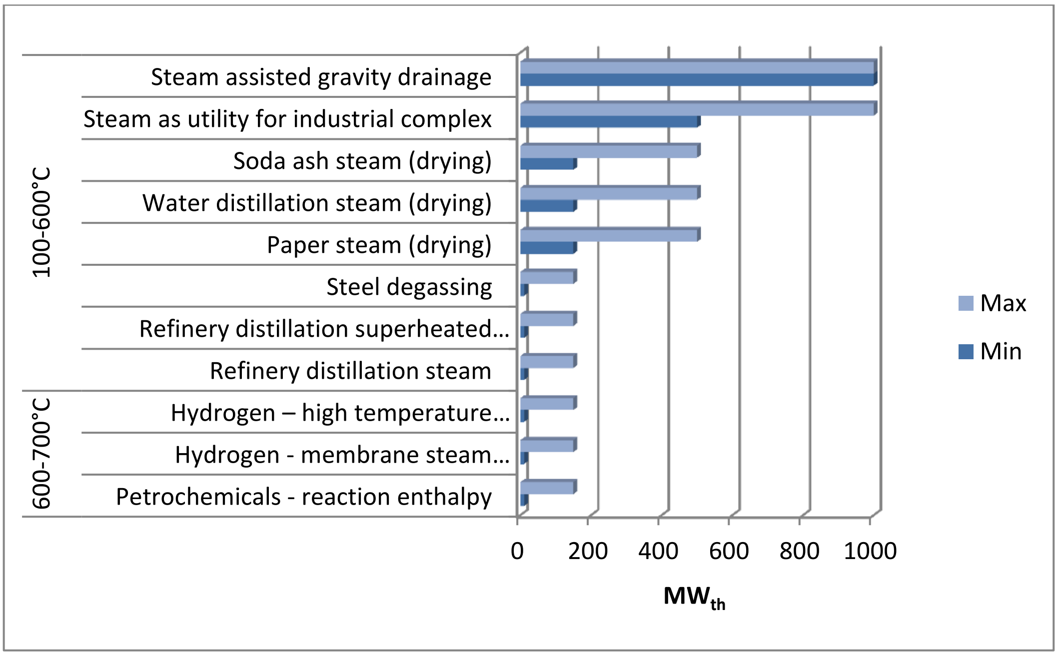


Figure 2 Power demand for various processes [2]

Industrial heat market can be divided into categories shown in the Figure 1. Potential short term market for nuclear cogeneration includes plug-in, polygeneration and pre-heating market. Plug-in market is limited to existing cogeneration facilities, all producing steam under 550°C, where majority of application are chemical industry and district heating. Sector of iron and steel making, is fuelled in majority with off-gases. The largest thermal capacity is utilized in oil refineries, chemical industry, iron, steel and cement production. In EUROPAIRS study it was determined that for those sites thermal capacity exceeds 500 MWth for 10 to 20 sites. Thus those sites have the highest potential for HTR deployment in near term. Building of those information following industries/processes can be considered as prospective to utilize nuclear cogeneration products:

- refinery distillation steam,
- refinery distillation superheated steam,
- petrochemicals - reaction enthalpy,
- steam as utility for industrial complex,
- paper steam (drying).

Sites listed above are the main interest for mapping effort carried out in this study.

1.3.1 Chemical sector

In EU chemical sector is formed in clusters at very high technical level and very high efficiency. Each installation has a lifetime of 30-40 years and after this time is replaced with new system. In EU there are over 90 individual chemical clusters which business infrastructure located mainly in Benelux, Germany, UK, France, Italy and Spain. For chemical clusters as other branches of industry price and availability of energy is fundamental aspect for profitability of the investment. Nuclear CHP unit could replace conventional CHP unit usually located at the cluster, or in its direct vicinity.

The beneficial factor for this kind of coupling is comparable demand for thermal energy and electricity. Operational conditions, availability and life time of HTR is compatible with chemical sites. Additionally existing infrastructure of steam supply unit on site can be adapted to peak power production and/or backup supply during HTR's maintenance periods. After necessary update the nuclear cogeneration unit can be probably connected to already existing pipelines thereby "plugging in" steam produced in HTR to process infrastructure at the site. This approach can reduce amount of required funding and simplify deployment of nuclear unit at the industrial site.

This approach can be threatened by lack of acceptance of local habitants. Coupling scheme must be designed in a manner which excludes possibility of radioactive contamination to process steam and final site product. The potential issues need to be resolved before commissioning of the first demonstration unit. Additional study on energy balance of chemical sites should be completed to asses need for backup/peak demand supply source.

1.3.2 Crude oil refineries

In 2012 in EU primary refining capacity of the mainstream refineries was over 700 million ton. Higher levels of refining and additional processing installations increase overall energy consumption in the refineries. To decrease CO_2 emissions nuclear unit can be deployed as steam/electricity supply unit.

According to [5] 94% of steam used in refineries is in temperature range 250-500°C and just 6% of heat is consumed in processes at temperature range 750-1000°C. Most of the processes in refineries are designed with parameters achievable for HTR, like temperature 550°C, pressure 3-4 MPa, thermal power of few hundred MW_{th} and process steam mass flow of 100 tons/h. In long term horizon production of hydrogen coupled with HTR unit may be another beneficial aspect for refineries which are one of the main hydrogen consumer.

It should be noted that crude oil refineries are designed for particular type of oil, which is available locally. Dependently from sulfur content and other factors, the installations are designed to process particular type of material. This can influence potential cogeneration coupling scheme, perhaps for every refinery it should be designed separately. [1]

At the moment part of energy demand of refineries is supplied by their own process gases (calorific off-gases). In case of applying external steam supply those gases would need to be disposed at other market. Since refineries are highly customized, depending on oil type supplied to the site, market study would be necessary to assess economic benefits. As for chemical industry, public acceptance of the nuclear energy source is required since environmental impact of refineries (and every other large industrial facility) is already sensitive subject among the stakeholders. [11]

2 Mapping criteria and methodology

2.1 Siting methodology

Industrial sites mapping for high temperature nuclear cogeneration demonstration is a multistage process refined after every stage, leading to selection of the most suitable site/sites from perspective of market restrictions, environmental aspects and business case. Industrial site selection is in one of the pillars determining success or failure of this project.

Methodology for mapping carried out in this study was based of two documents:

- European Utility Requirements for LWR Nuclear Power Plants [4], Rev D
- IAEA Safety standards series, Site Evaluation for Nuclear Installations, Safety Requirements No. NS-R-3, Vienna, November 2003 [5]

In IAEA document siting process was divided into five stages contained in two activities:

1. Site survey
    a. Site survey stage – identification of potential regions, potential sites, and candidate sites through screening and comparison
2. Site evaluation
    a. Site selection stage – evaluation aiming at selecting the final site through the ranking of the candidate sites
    b. Site assessment stage – confirmation of acceptability and complete site characterization; Derivation of site related design basis
    c. Pre-operational stage – Confirmatory and monitoring work
    d. Operational stage – confirmatory, monitoring and re-evaluation as per Periodic Safety Reviews

The priority of IAEA is security of people and protection of the environment therefore the methodology is written in general matter not dependent on reactor type. Thus it can be applied for gas reactor types as well.

The alternative document EUR, resolves siting process from opposite direction which is satisfying IAEA requirements per particular plant design, here LWR's of 3 and 3+ generation. This approach generates disproportions since the typical LWR is designed to electricity generation for electrical grid as a final product whereas HTR plant main function is to deliver process steam to industrial facilities. This affects location type, which for LWR would be outside of largely populated areas and far from external hazards (other facilities etc.). Because of potential product degradation in case of transferring steam via long distances the siting criteria need to allow locating HTR plant next to industrial facility. This can be performed due to inherent safety features of HTR, which prevent core meltdown and any significant radioactivity releases during accident scenarios.

2.2 Siting criteria

Siting criteria developed for demonstrator plant location in EU Member Country are listed in Annex 0. The criteria have been ranked accordingly to NC2I-R project background to accelerate the filtering process. Priority levels are: very high, high, medium and low. Additionally "exclusion criteria" have been introduced to the process. All of those criteria need to be answered positively to be considered as potential location for a demonstrator plant.

The list of criteria is a guideline to mapping task and cannot be considered as binding criteria for demonstrator site selection. Listed criteria need to be balanced accordingly with progress of the project. In first stage of mapping the most important criteria are thermal power demand and parameters of process steam produced/consumed on site. For purpose of this study it was assumed that 200 MWt and larger power demand will qualify site for further consideration. This level was selected as minimum due to anticipated thermal power of HTR reactors (e.g. Chinese HTR-PM) and the fact that priority deployment area is cogeneration of process heat and power. However, in some circumstances sites with lower usage will be considered on case by case basis. It should be noted that requirement of diversified energy supply to chemical sites limit the amount of energy that can be delivered from HTR unit. Since HTR unit is capable to produce (in steam cycle) steam at about 550°C and pressure up to 17 MPa, the preferred sites are with similar steam demand. The first selection of probable HTR cogeneration products end-user needs to fulfill aforementioned requirements.

3 European sites mapping

Mapping of industrial sites was divided into three subchapters, depending on area of expertise of task participants. Three following sections descript heat market and distinguish industrial sites located in Europe. Depending on availability of information sites were described in terms of power consumption, type of fuel, process steam parameters and other factors defined in Annex 1.

3.1 Poland

In 2011 final energy consumption of industrial sector in Poland was 16.2 Mtoe [6]. It is 3rd largest share in final energy consumption after households and transport which in 2011 consumed respectively 19 and 17.8 Mtoe. Apart of large electricity consumption, industrial sector need to be supplied in heat, mostly process steam which can be used directly or indirectly in various processes. Figure 3 shows heat generation in Poland in past two decades for all sectors. The Gross Heat Produced is defined as follows: "This is the total heat produced, including losses in the installations/network heatexchanges, as well as heat from chemical processes used as the primary energy form. Autoproducer heat used by the undertaking for its own processes is not included here. Only heat sold to third parties should be reported" [6]. Between 2001-2007 heat demand in Poland decreased about 26% due to thermo-modernization of buildings. After 2007 temporal increase in heat consumption can be noted, possibly because of growth of central heat distribution network in large agglomerations, connection of new clients and decreasing potential for further thermo-modernizations. According to prognosis of Polish Energy Market Agency (ARE) 15% growth is expected in district heating sector consumption. The largest consumption growth is expected in services and trade sector, however moderated growth is foreseen also for industry, agriculture and households. [19]

Size of industrial sector, profitability of existing and planned investments of new industrial objects depends in large part on prices and availability of energy and/or fuels. Prices for polish industrial consumers for recent years can be seen in Figure 5.

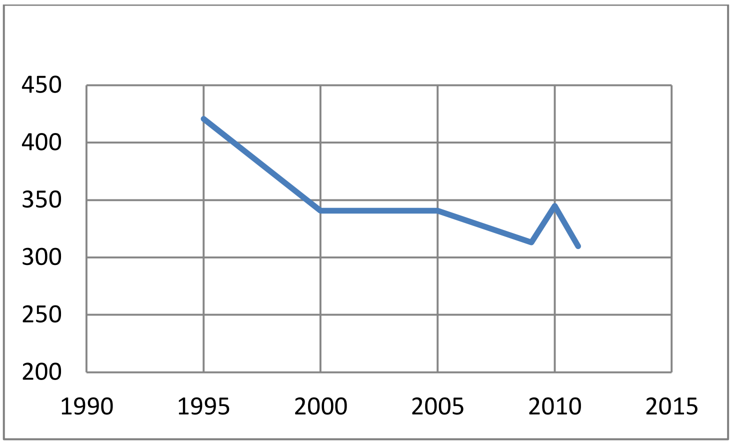


Figure 3 Total Gross Heat Generation (PJ) in Poland [6]

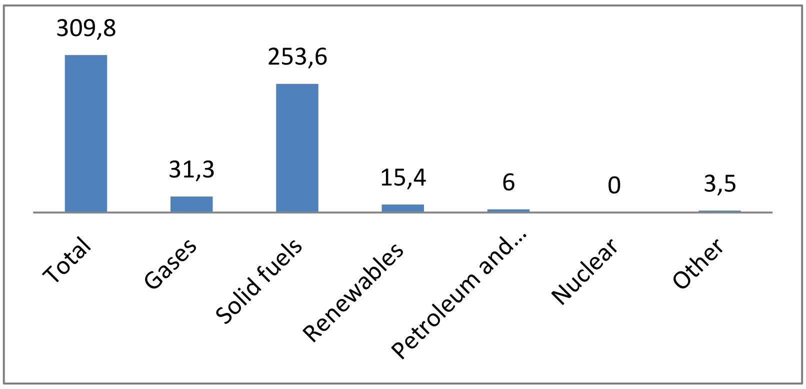


Figure 4 Gross Heat generation by fuel 2011 (PJ) [6]

It can be seen in Figure 4 the vast majority of heat is generated from combustion of solid fuels, which in 2011 amounted to over 80% of total heat generation. This result in energy price charged with CO_2 tax, thus deteriorated financial case for new and existing industrial facilities in Poland and all of EU Member States. Further progress of deindustrialization in Europe is anticipated unless more favorable environment will be created for industrial companies.

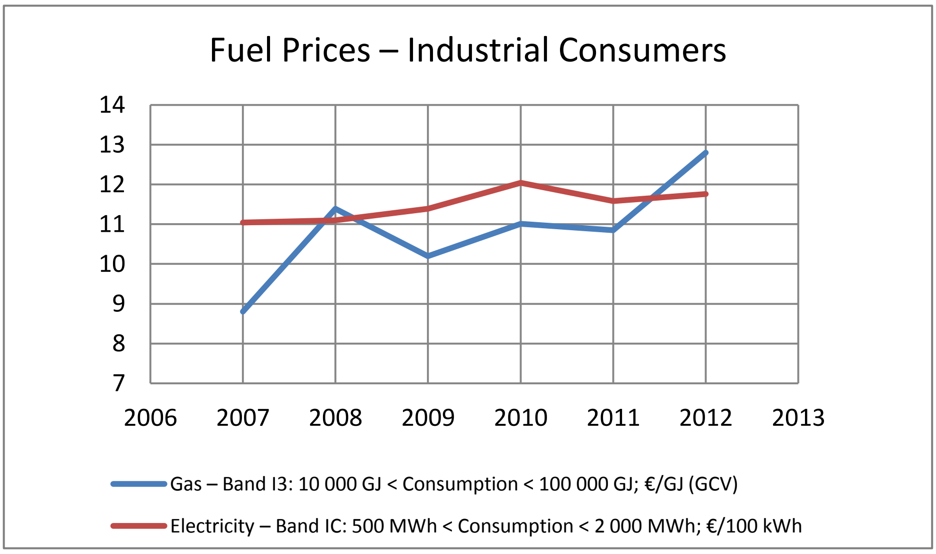


Figure 5 Fuel Prices – Industrial Consumers [6]

Nuclear cogeneration, CO_2-free can be considered as a potential solution to restrict CO_2 emissions and environmental impact of the industrial sector in Poland. The heat market of 309.8 PJ [6] can be at least in part supplied with steam produced at nuclear cogeneration units, especially segment of market defined as “plug-in” market, extended and polygeneration markets. At the moment the biggest competitors for nuclear cogeneration is gas cogeneration. However, it must be noted that trend of growing gas prices in recent years may indicate financial justification for deployment of new heat source to diversify current fuel assortment and stabilize the heat price as a product. Recent study of polish shale gas resources is not concluded yet on commercial shale gas reserves. The potential resources of polish shale formation were assessed by PGI-NRI Report of 2012, where total most probable recoverable gas resources were estimated at 0.35-0.77 Tcm. Recoverable shale gas resources in Poland have direct influence on gas and thus profitability of other cogeneration alternatives as HTR technology [20]

3.1.1 Mapping results

3.1.1.1 Sites location

Polish industry was screened for potential location of HTR demonstrator. Number of criteria was used in order to map industrial sites with most favorable characteristics. However criteria with the most significant impact were thermal power and temperature of produced fresh steam/consumed process steam. Basing on methodology described in chapter 2, input data sheet has been developed to collect the most relevant information from industrial sites. Input data sheet can be found in Annex 1. Several sites can be listed as potential location for HTR demonstration. All sites are either chemical plants or crude oil refineries with one exception of paper production plant. Sites are listed in Table 2 and shown at the map in Figure 6. Numbers assigned to sites in Table 2 are used in following sections to identify the results in figures.

#	Site name	Site type	City
1.	PKN Orlen	refinery	Płock
2.	Zakłady Azotowe Puławy S.A.	chemical plant	Puławy
3.	Anwil S.A. / ORLEN Group	chemical plant	Włocławek
4.	ZCh Police S.A.	chemical plant	Police
5.	Kwidzyn Sp z o.o. International Paper	paper	Kwidzyn
6.	Grupa LOTOS	refinery	Gdańsk
7.	Zakłady Azotowe w Tarnowie-Mościcach S.A.	chemical plant	Tarnów
8.	Zakłady Azotowe Kędzierzyn S.A.	chemical plant	Kędzierzyn-Koźle
9.	PCC Rokita	chemical plant	Brzeg Dolny
10.	Rafineria Trzebinia S.A.	rafinery	Trzebinia
11.	Lotos Czechowice S.A.- LOTOS GROUP	refinery	Czechowice-Dziedzice
12.	Lotos Jasło S.A. - LOTOS GROUP	refinery	Jasło
13.	Rafineria Nafty Jedlicze S.A. - Orlen Group	refinery	Jedlicze
14.	KGHM Polska Miedź S.A*.	energy production/ distribution	Lublin
15.	Tauron Polska Energia S.A.*	energy production/ distribution	Katowice

Table 2 Industrial sites in Poland

*quantities presented for group of facilities under one company name not particular site

Figure 6 Location of investigated industrial sites in Poland

3.1.1.2 Rated thermal power

The structure of power consumption of the sites which are in area of interest is different than for power plants, designated strictly for electricity production. Units considered in this project produce major share of thermal power and only low percentage of it is converted in steam turbine/generator cycle into electricity. Steam is not just an energy carrier but also a medium required for processes, sometimes a direct ingredient of the chemical reaction. Estimated rated thermal power production of objects from Table 2 is shown in Figure 7 This evaluation describes plug-in and extended market.

It can be seen that majority of the sites produce about 500 MW_{th} - seven sites. There is just one site which produces over 2000 MW_{th}. Five sites have been listed as facilities with thermal power production of around 100 MW_{th}. However possibly this market can be larger as mapping task was focused at sites with thermal capacity of over 200 MW_{th}.

The total polish industrial market exceeds 10000 MW_{th} [21] of installed capacity, however, in this study just part of this market was considered – over 6000 MW_{th} due to specific criteria that need to be fulfilled by demonstrator site.

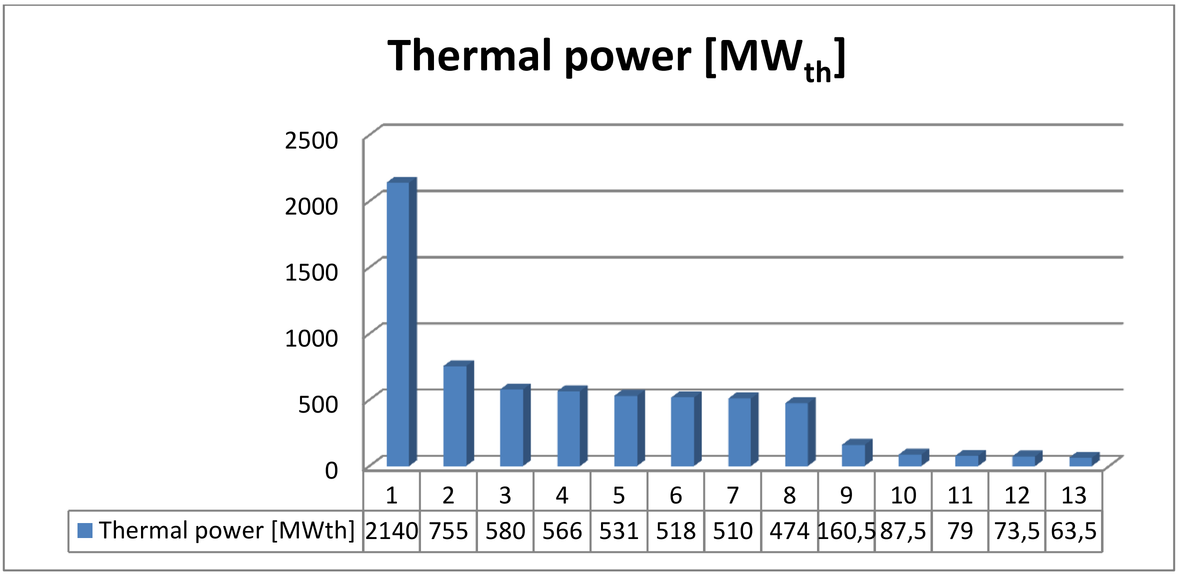


Figure 7 Thermal power of investigated sites

3.1.1.3 *Electric power production and usage*

As most of the steam produced in steam boilers is used as media or ingredient in processes, only small share of steam is used to produce electricity. Summary of electricity production on site, and winter/summer demand is shown in Figure 8. Not far all considered sites information on power demand was available, where not obtained space is left blank.

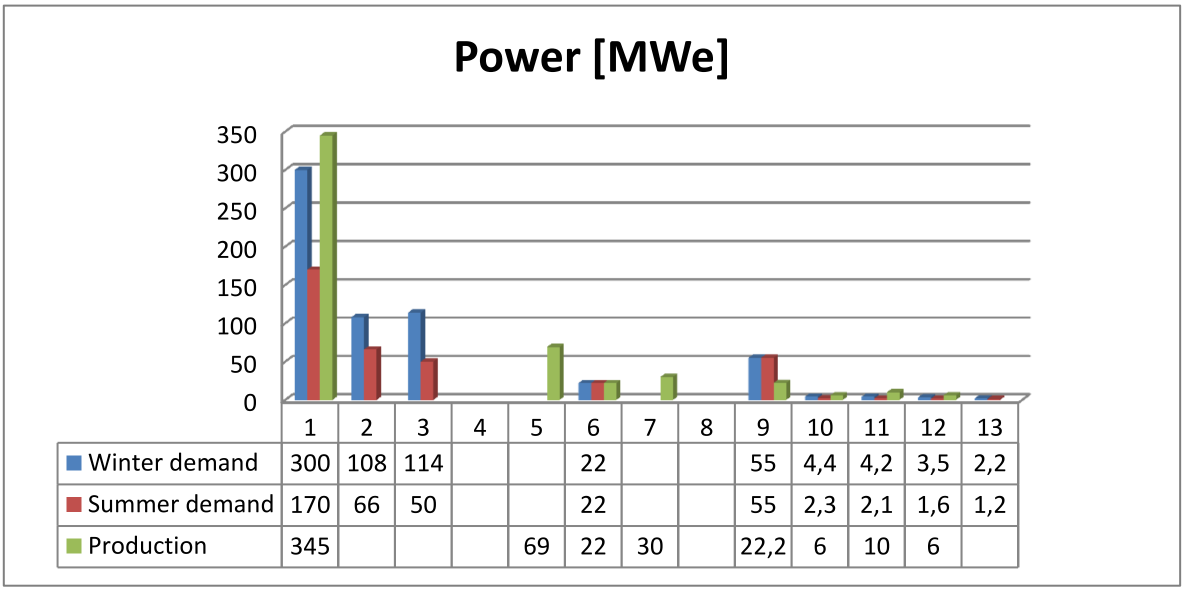


Figure 8 Electricity demand at investigated sites

3.1.1.4 *Fresh steam parameters*

All sites listed in Table 2 consume high temperature steam in various processes. Most of CHP units on site produce high or medium pressure steam (from 1.5 to 14 MPa) at high temperature of about 500°C which is then converted into medium of low pressure/temperature required for particular applications. Usually fresh steam is converted into 2-3 types of steam using infrastructure available onsite. As shown in Figure 9 and Figure 10 weighted (rated thermal power) average temperature and pressure of the fresh steam are respectively 510°C and 10 MPa. Thus conclusion can be drawn that HTR is capable of supplying all of those sites in steam at suitable parameters (temperature and pressure), however further analysis need to be performed to asses compatibility of HTR's steam production capacity against site thermal power consumption.

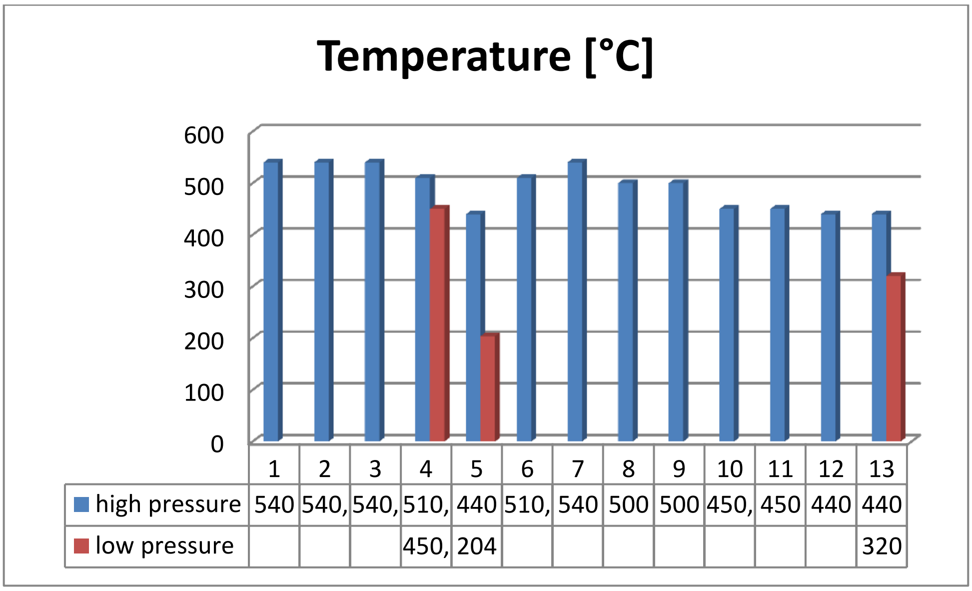


Figure 9 Fresh steam temperature

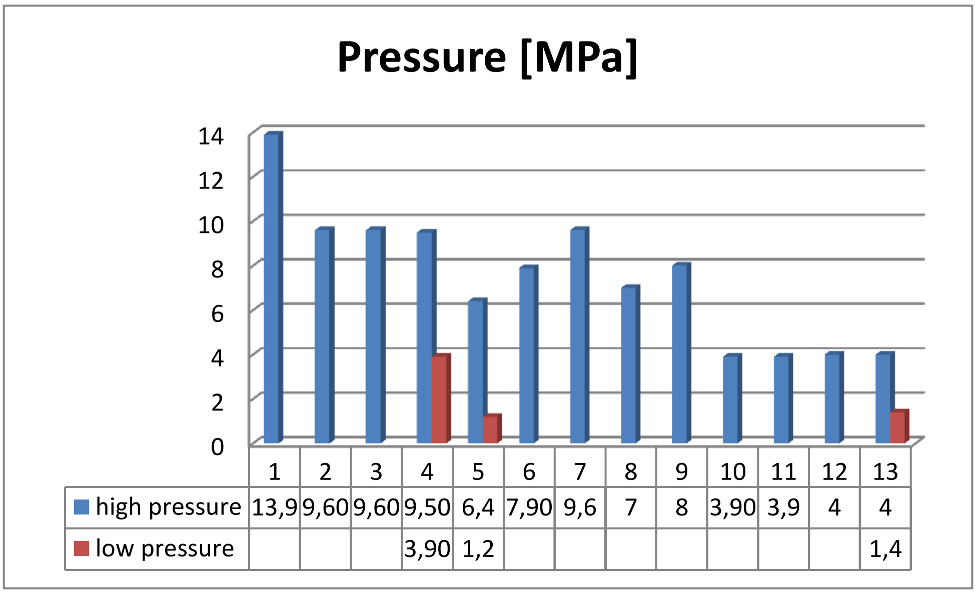
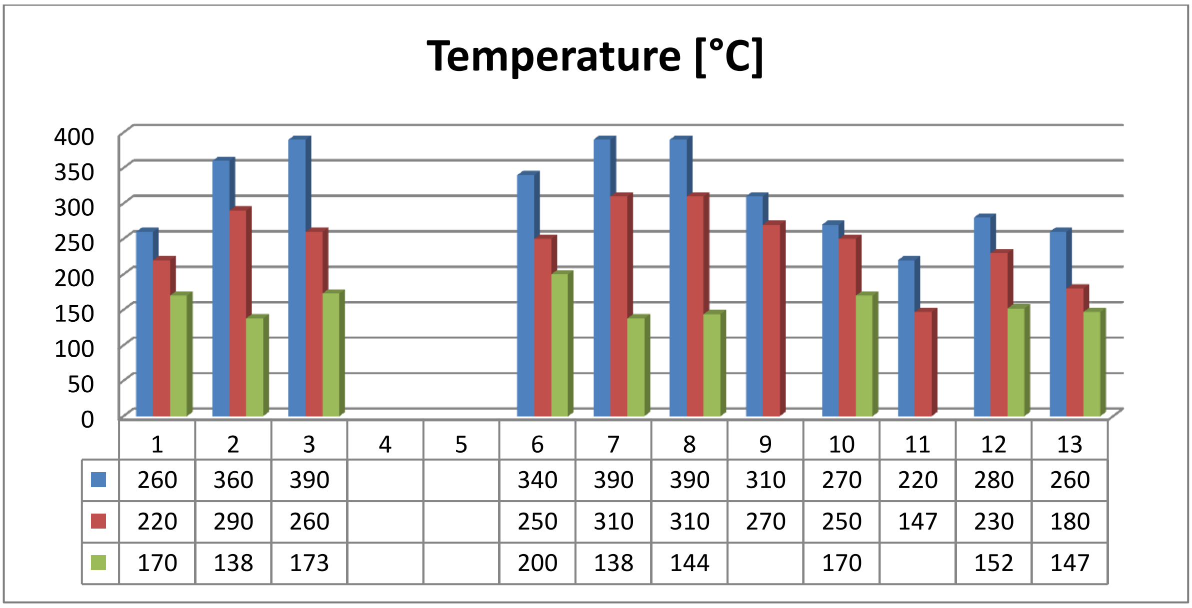


Figure 10 Fresh steam pressure

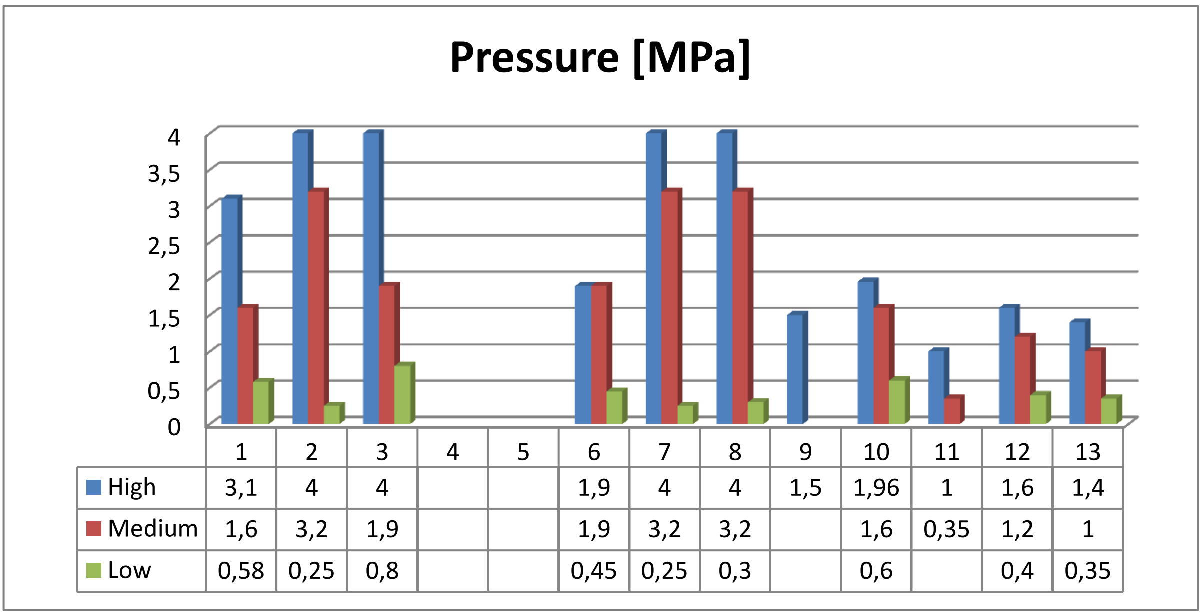
3.1.1.5 Process steam parameters

Fresh steam produced on site needs to be converted into medium which can be used for further production processes. Usually more than one type of steam is used onsite. Most common configuration among the industrial sites investigated is conversion of fresh steam into three different types of media. For convenience in this document they were defined as high, medium and low depending on values of temperature and pressure. Not for all sites this information was obtained, were cell left blank - no information was provided.



	1	2	3	4	5	6	7	8	9	10	11	12	13
■	260	360	390			340	390	390	310	270	220	280	260
■	220	290	260			250	310	310	270	250	147	230	180
■	170	138	173			200	138	144		170		152	147

Figure 11 Process steam temperature



	1	2	3	4	5	6	7	8	9	10	11	12	13
High	3,1	4	4			1,9	4	4	1,5	1,96	1	1,6	1,4
Medium	1,6	3,2	1,9			1,9	3,2	3,2		1,6	0,35	1,2	1
Low	0,58	0,25	0,8			0,45	0,25	0,3		0,6		0,4	0,35

Figure 12 Process steam pressure

3.1.1.6 Age of current steam production unit

All of the sites mapped in Poland use steam boilers to supply industrial facilities with steam at parameters discussed above. Majority of those units is fuelled with coal, smaller share uses heavy oil and other fuels which introduces third largest share of CO_2 emission in Poland – 10% in 2010.

In connection to applicable law, emissions form those boilers are regulated by EU Directive IED (Industrial Emission Directive) 2010/75/UE from 24th November 2010 and national regulation from Ministry of Environment from 22nd April 2011 (Dz. U. Nr 95/2011, poz. 558), however emission limits are more strict in IED, thus that is the limiting document. IED applies to LCP (Large Combustion Plants) with thermal power over 50 MWth and regulates emission of sulfur dioxide, nitrogen oxides and particulate matter. According to the directive, all units which are not fulfilling the recommended limits need to be decommissioned by 2016. IED allows for some LCPs in agreement with EC and local governments to extend deadline for compliance of those requirements by 2020 with additional restrictions.

This directive influence directly amount of steam boilers that will be decommissioned in following years creating market for other type of cogeneration or steam production unit like HTR. Planned modernizations and decommissioning of the stem boilers for selected sites is shown in Figure 13. Considering only selected sites, 25 boilers will need to be decommissioned by 2019. Some of those sites have already plans for new steam production units like PKN Orlen or Anwil S.A. For the rest of the sites new steam supply system issue remains not clarified. In total almost 2000 MW_{th} will be decommissioned before 2019 in nine sites considered in the study as presented in Figure 14.

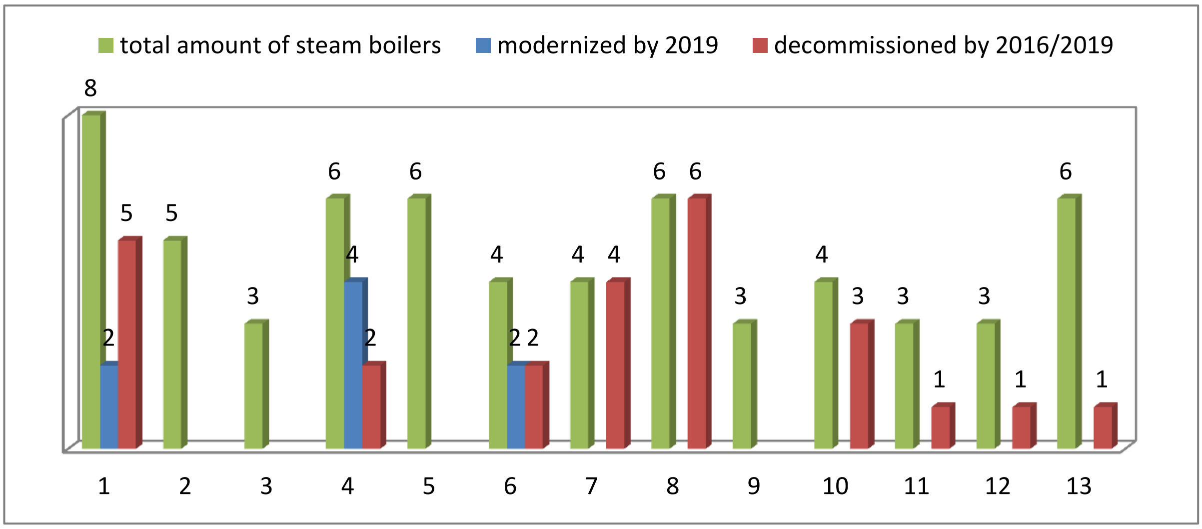


Figure 13 Future modernizations and decommissions of steam boilers

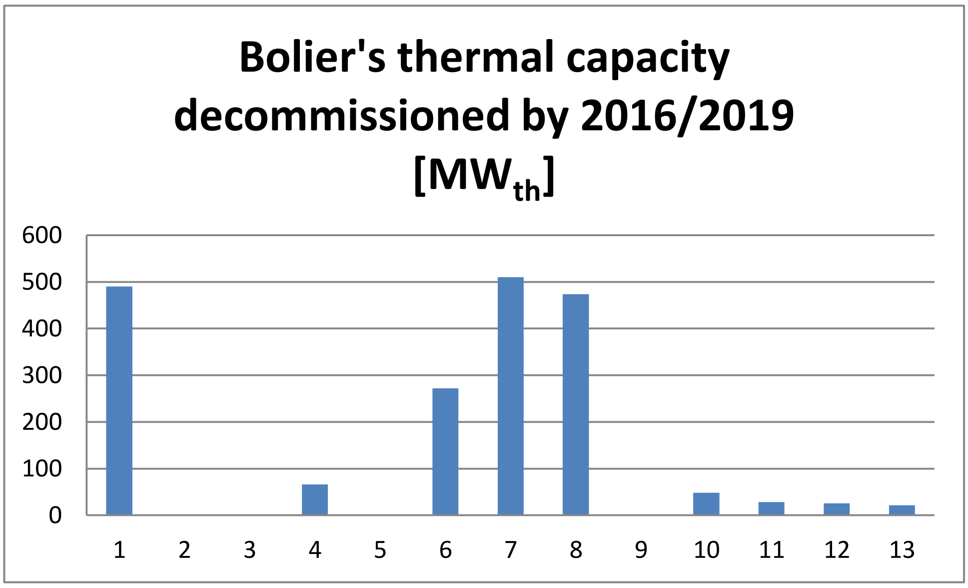


Figure 14 Bolier's thermal capacity decommissioned by 2016/2019

3.1.2 Regulatory framework

In Poland nuclear safety and radiological protection is regulated by President of the National Atomic Energy. Atomic law is described in Act of Parliament of 29th November 2000 and its secondary legislation. The latest version of this document (Dz. U. z 2012 r. Nr o, poz. 264) was created in order to adapt Polish law to the international law. [7][8]

Current law was created with the aim of deployment of large nuclear power plants. Thus the regulatory framework for medium and small reactors with inherent safety features is not established yet. In some part current state of law can be applied, however, to maximize economic advantages of this design some advancement need to be made, in specific re-definition of EPZ. This advancement is necessary to enable location on HTR unit in direct vicinity of the industrial site which is often located near to inhabited areas. [8]

At the moment Polish atomic law define three characteristic zones around nuclear facility:

- *Border of nuclear facility* – circular area with radius defined as distance from middle of the nuclear facility to the furthest point of the estate

- *Location of nuclear facility* – area in distance of 5 km along the border of nuclear facility (or more if justified to assure geological stability and safety of the object)
- *Region of nuclear facility* - area in distance of 30 km along the border of nuclear facility

Those definitions were developed in past basing on design basis accident scenarios, in specific on released radiation dose for design based accident scenarios for large LWR's.

3.1.3 Example location site description - LOTOS GROUP S.A. (Poland)

LOTOS GROUP S.A. (marked as A in Figure 15) located at Baltic sea shore can be a preferential type of site for HTR demonstration. LOTOS Group is a prospering oil refinery modernized in 2000 and 2012 to enlarge production capacities. Characteristics of interest are described below:

▪ Number of steam boilers	4
▪ Number of operating steam boilers after 2019	2
▪ Primary steam parameters:	
o Pressure	7,9 MPa(g)
o Temperature	510 °C
▪ Nominal steam production	$61*10^4$ kg/h $29*10^4$ kg/h in 2019
▪ Nominal power of the steam boilers in total	518 MWt
▪	262 MWt in 2019
▪ Work performance	54,8 $*10^4$ kg/h
▪	$26,1*10^4$ ton/h in 2019
▪ Fuel	fuel oil, LPG, processed gases
▪ Steam nominal parameters for the industrial applications	
o - pressure	19 / 19 / 4,5 bar(g)
o - temperature	340 / 250 / 200 °C
▪ Number of operating steam turbines	2
▪ Nominal power of steam turbines	30 MWe
▪ Work performance of steam turbines	22 MWe

The refinery produces, for own consumption purposes, process steam in four steam boilers fueled with heavy oil, LPG and off-gasses. All boilers were built in 1974 and then modernized in 2000. In winter season all steam boilers are operated, in summer just three of them are producing 60t/h of steam less than during winter season. All boilers fulfill requirements of national emission law, however, they do not comply IED. Thus two boilers will be modernized by 2019 and two will be decommissioned by 2019. From above information it can be inferred that LOTOS Group is facing need for a construction of a new steam supply unit after 2020 to maintain stable steam supply after decommissioning two of their steam boilers by 2019. LOTOS Group is considering investment into new CHP unit of maximum 250 MW_e, however, final decision has not been made.

Refinery was going through major modernization finished in 2012 which increased their production capacity to 10.5 Mt/y. At the moment refinery is classified as complexity class 3, which means that refinery is able to perform following processes: thermal cracking, visbreaking, hydrocracking or/and catalytic cracking, vacuum distillation, atmospheric distillation, gasoline hydrotreating and production of bitumen.

This site could be classified as prospective location for HTR cogeneration unit. However further and more detailed analysis is required. Red circle in Figure 15 represents reasonable area in which HTR NSSS (nuclear steam supply system) should be localized so the steam pipeline is no longer than 4-5 km. In selected area we can distinguish tree kinds of terrain: 1st coast, 2nd city area and 3rd green area (agricultural or unused). The 3^{dr} category can be considered as prospective for HTR site. Additionally LOTOS Group S.A. is located in 30 km distance from Tczew, location considered for Polish Nuclear Power Plant. Preliminary safety evaluation for this region has been completed with a positive result. The site is located at the outer part of the city of almost 461 thousand inhabitants with population density of 1758 people/km^2.

Furthermore, landscaping plans for this location do not pose any additional limitations. Considered location is classified as agricultural land without restrictions from environmental preservation perspective. This terrain is already an industrialized area and all required infrastructure as power grid connection and water vicinity is available.

Hazards present onsite: explosive substances, flammable substances, toxic substances.
Environmental hazards: no seismic activity, possible flooding.

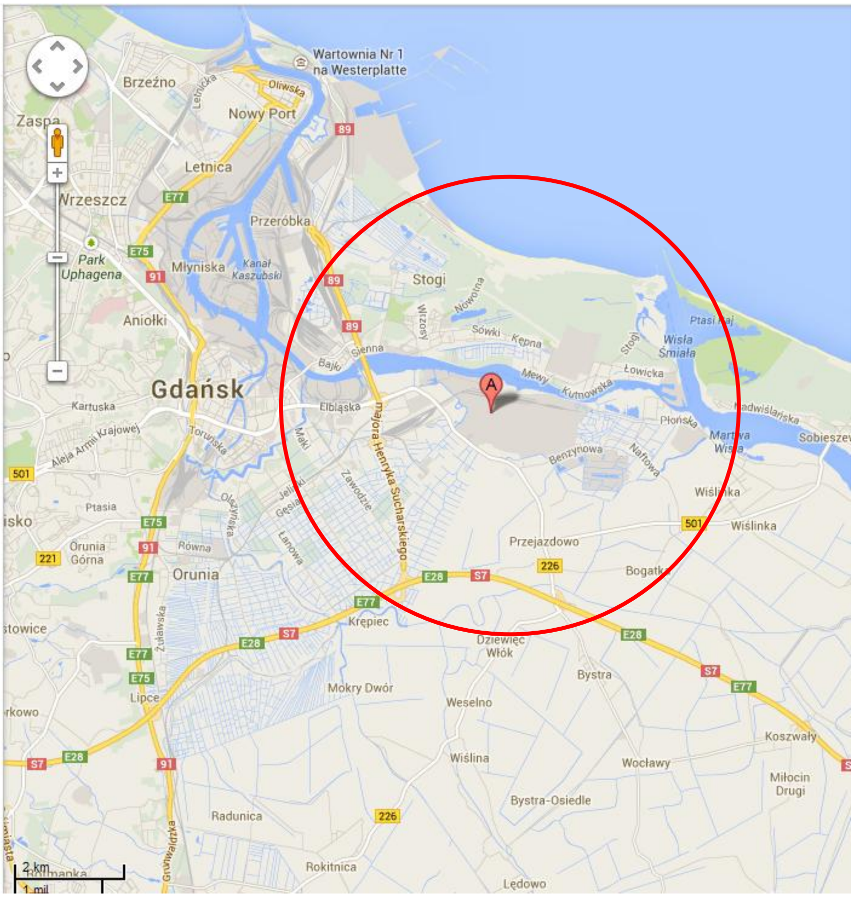


Figure 15 Location of LOTOS S.A. on the coast on Poland

3.2 Eastern Europe

Eastern Europe means here the following countries (see in Figure 16): Hungary (11 sites), Romania (4 sites), Croatia (3 sites), Ukraine (2 sites), Slovakia (2 sites), Serbia (2 sites) and Bulgaria (1 site). The order of appearance in the list indicates the number of successfully finished data collection processes at each country during the sites mapping.

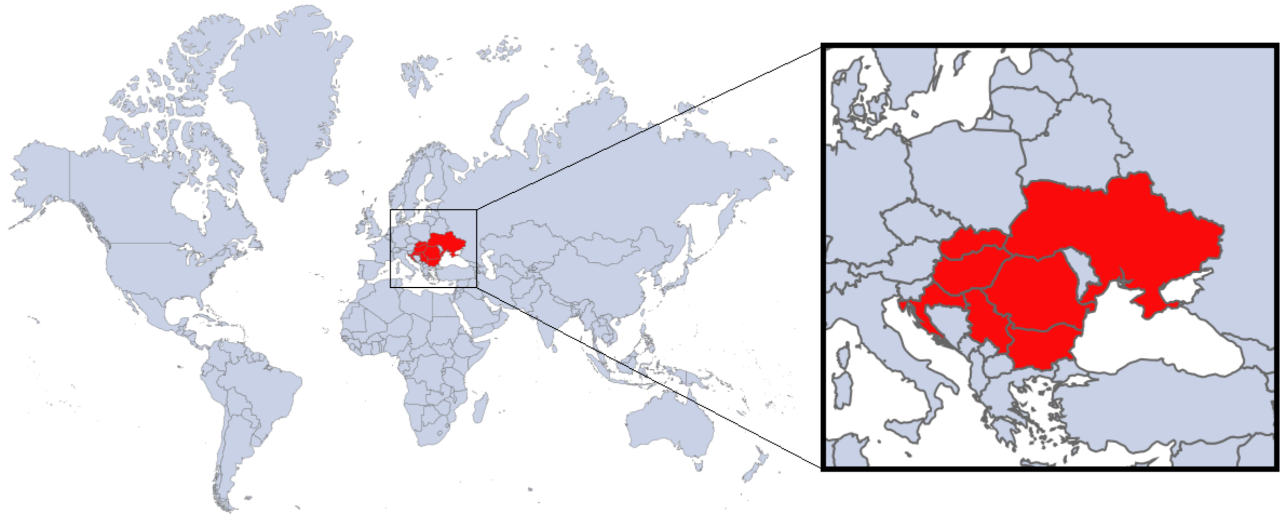


Figure 16 The investigated countries during the site mapping process in Eastern Europe

Figure 17 shows the final energy consumption in ktoe and percentage for each sector for the investigated countries (the total final energy consumption of a country can be seen below each cake diagram).

The final energy consumption of industrial sector is the largest share among the shares of all sectors in the Slovak Republic and Ukraine overtaking the shares of residential and transport sectors. It is the second largest share in Bulgaria, Romania and Serbia after the share of the transport or the residential sector while it is the third and fourth largest share in Croatia and Hungary respectively (see Figure 17). Similarly than in Poland apart of large electricity consumption industrial sector need to be supplied with heat, which is mostly process steam. It can be used directly or indirectly in the processes. Figure 18 and Figure 19 depicts the total heat production in the investigated countries in the past two decades for all sectors.

The total heat production of Ukraine is the largest among the others. Romania and Bulgaria have moderate total heat production while the others have relatively small values (see Figure 18 and Figure 19).

Figure 20 depicts the shear of the heat production by fuels. As it can be seen the fossil fuels (coal, oil and gas) dominates the heat production from the fuel viewpoint. The nuclear heat generation is very marginal or absent in the mix of heat production of the Eastern European countries. This result in energy price charged with CO_2 tax similarly than in case of Poland.

As a conclusion about the above cited data it can be stated that the nuclear cogeneration as a CO_2-free combined heat and power production technology can be considered as a potential solution to restrict CO_2 emissions and environmental impact of the industrial sector in Eastern Europe. The limiting factor is the relatively small heat market in most of the investigated countries. Only Ukraine has a suitably large heat market to host a possible HTR demonstration project.

The heat market of approximately 600 PJ in Ukraine could be at least in part supplied with steam produced at nuclear cogeneration units, especially parts of market defined as “plug-in” market, extended and polygeneration markets. At the moment the biggest competitors for nuclear cogeneration is gas cogeneration. However, it must be noted that trend of growing gas prices in recent years and the political tension between Ukraine and Russia may indicate financial and political justification for deployment of new heat source to diversify current fuel assortment and stabilize the heat price.

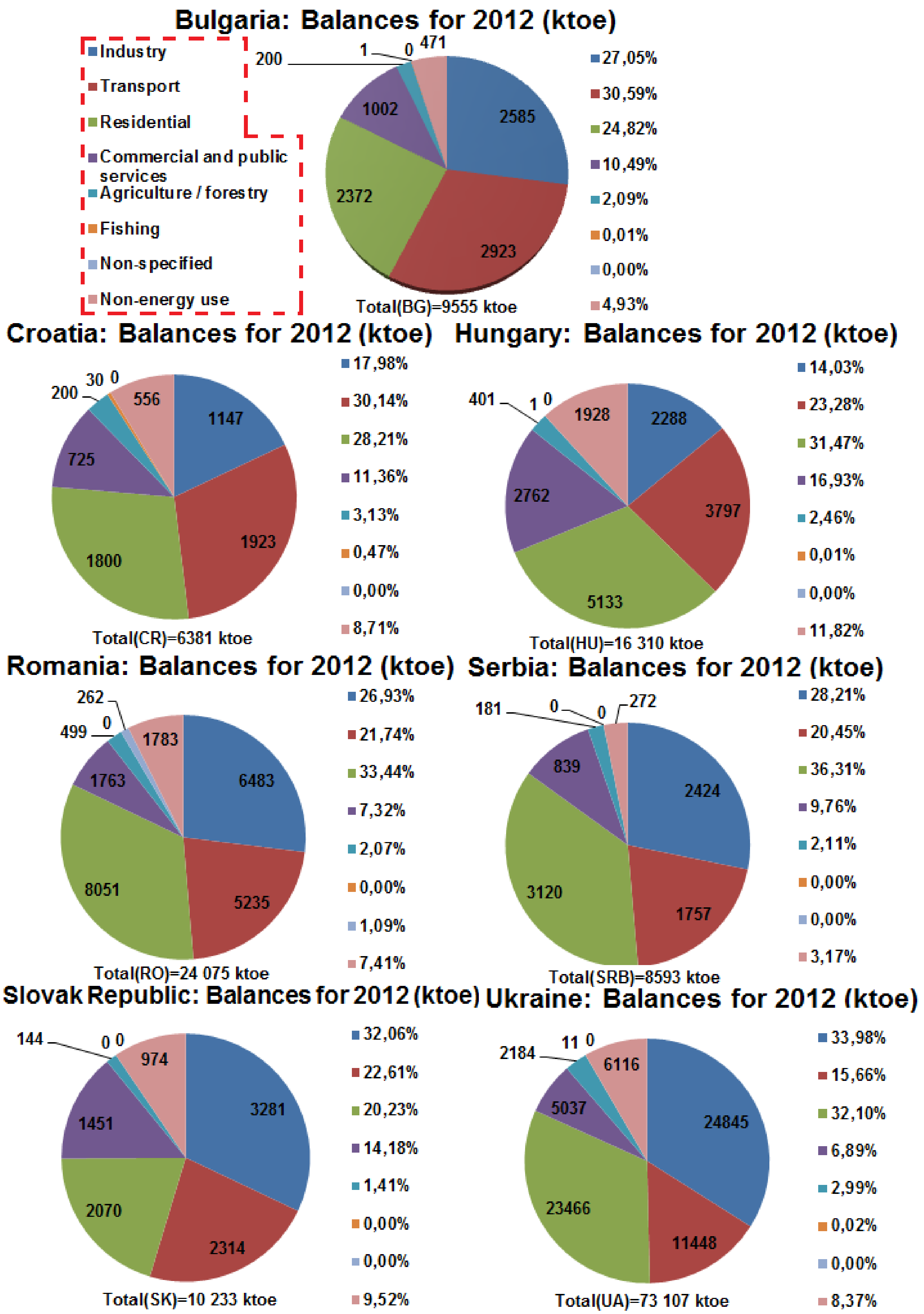


Figure 17 Final energy consumption in the investigated Eastern European countries [22]

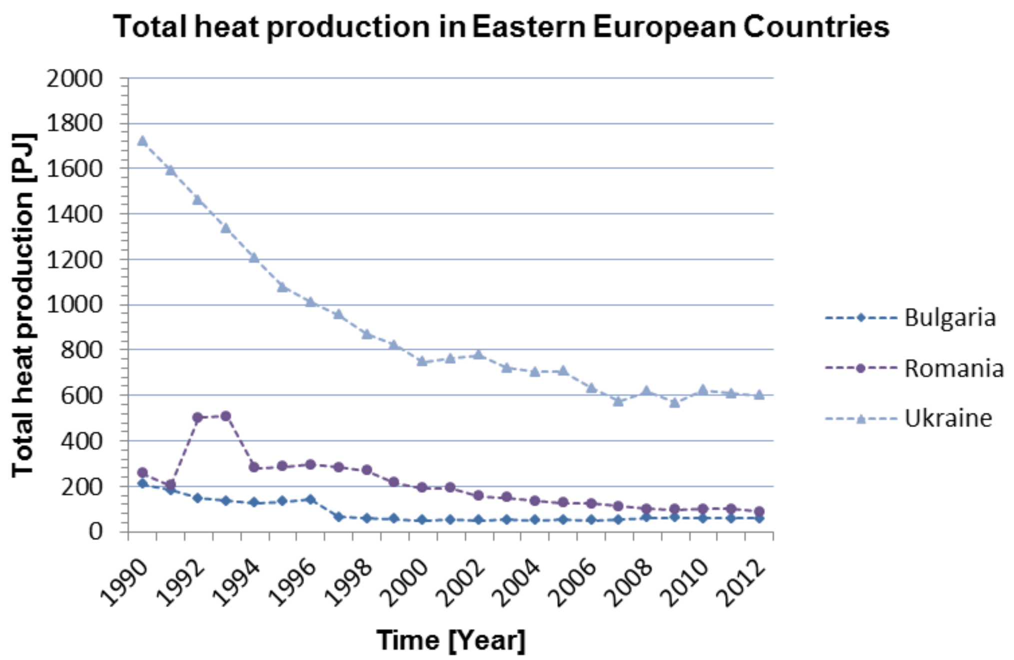


Figure 18 The total heat production in Bulgaria, Romania and Ukraine in the past two decades for all sectors [22]

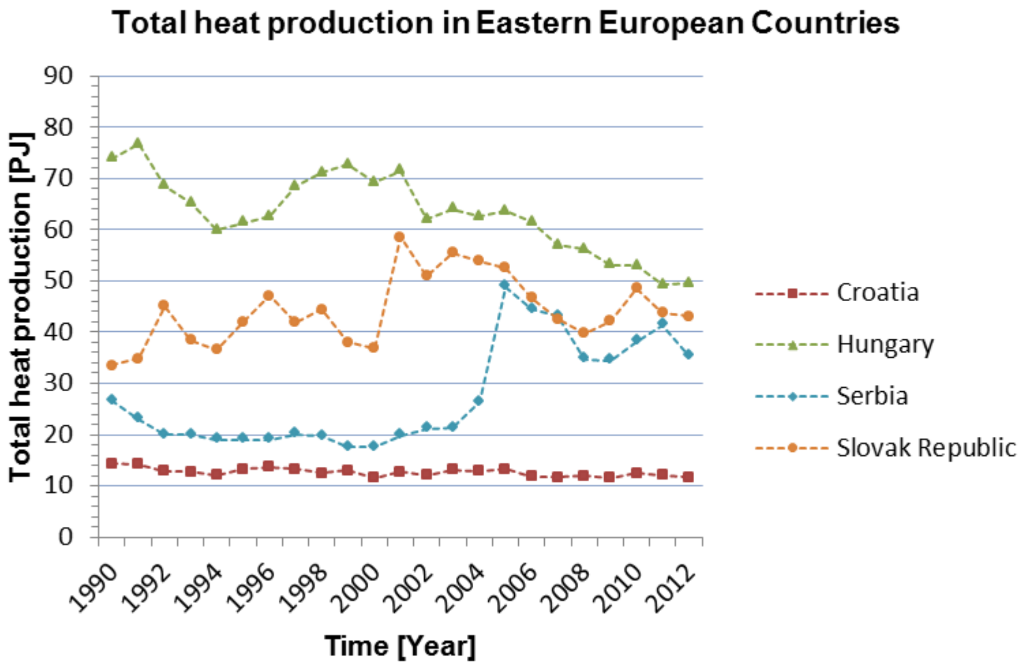


Figure 19 The total heat production in Croatia, Hungary, Serbia and Slovak Republic in the past two decades for all sectors [22]

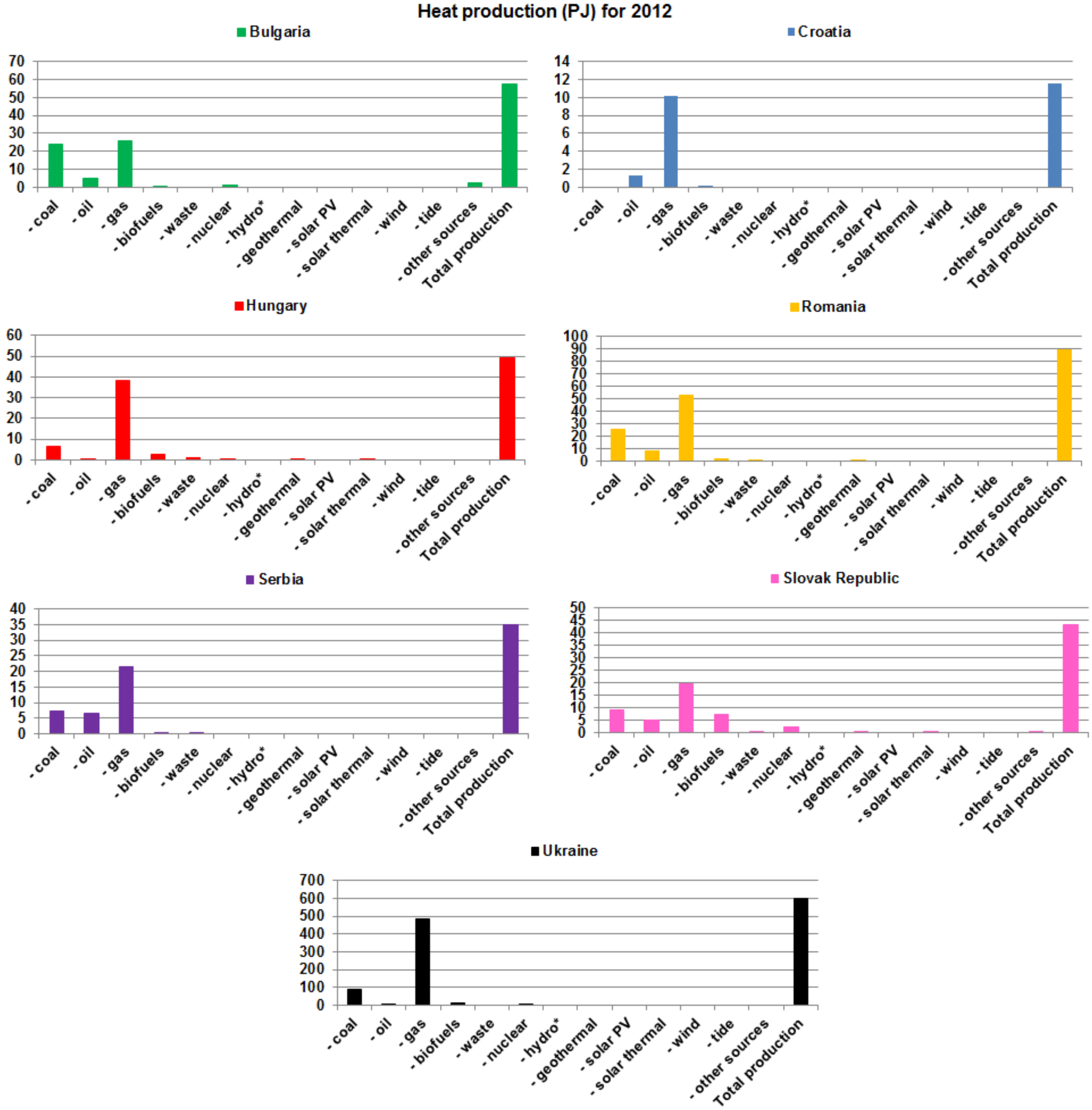


Figure 20 The shear of the heat production (PJ) by fuels in the investigated countries [22]

3.2.1 Mapping results

The sites location, rated thermal power, electric power production and usage, process steam parameters are presented in this sub-chapter.

3.2.1.1 Sites location

The Eastern European industry was screened for potential location of HTR demonstrator project as well. Number of criteria was used in order to map industrial sites with most favorable characteristics, however the most influential criteria were thermal power and temperature of consumed process steam. Basing on methodology described in section 2.1 , input data sheet has been developed to collect the most relevant information from industrial sites. Input data sheet can be found in Annex 1.Several sites can be listed as potential location for HTR demonstration project. All sites are pharmaceutical factories, crude oil refineries, and metal foundry or petrochemical, chemical or steel processing factory. Sites are listed in Table 3

Table 3 List of the investigated sites

#	Site name	Site type	Country	City
1	Richter Gedeon Nyrt.	pharmaceutical company	Hungary	Budapest
2	Sanofi-Aventis	pharmaceutical company	Hungary	Budapest
3	MOL Százhalombatta Dunai refinery	oil refinery	Hungary	Százhalombatta
4	Busch-Hungária Kft.	steel foundry company	Hungary	Győr
5	FÉMALK ZRT.	aluminium foundry company	Hungary	Budapest
6	Wescast Hungary Autóipari ZRt.	steel foundry	Hungary	Oroszlány
7	Euro Metall Kft.	steel foundry company	Hungary	Budapest
8	NEMAK Győr Alumíniumöntöde Kft	aluminium foundry company	Hungary	Győr
9	ISD Dunaferr Zrt. & ISD Power Kft.	steel foundry company & own power plant	Hungary	Dunaújváros
10	TVK & TVK CCGT CHP Power Plant	petrochemical company & own power plant	Hungary	Tiszaújváros
11	Borsod-CHEM & BC (Borsodchem) CHP Power Plant	chemical company & own power plant	Hungary	Kazincbarcika
12	Oltchim S.A.	chemical company	Romania	Ramnicu Valcea
13	Chimcomplex SA Borzesti	chemical company	Romania	Onesti
14	SC Laminorul SA Braila	steel processing company	Romania	Bralia
15	S.C. MECHEL TARGOVISTE S.A.	steel processing company	Romania	Targoviste
16	Azot (Cherkasy)	chemical company	Ukraine	Cherkassy
17	Avdiivka Coke and Chemical Plant	chemical company	Ukraine	Avdiivka
18	Duslo, a.s.	chemical company	Slovakia	Šaľa
19	MOL Slovnaft Bratislava refinery	oil refinery	Slovakia	Bratislava
20	PLIVA HRVATSKA d.o.o.	pharmaceutical company	Croatia	Zagreb
21	INA d.d. Rijeka refinery	oil refinery	Croatia	Rijeka
22	INA d.d. Sisak refinery	oil refinery	Croatia	Sisak
23	Naftna Industrija Srbije Pančevo refinery	oil refinery	Serbia	Pančevo
24	Naftna Industrija Srbije Novi Sad refinery	oil refinery	Serbia	Novi Sad
25	LUKOIL Neftochim Burgas	petrochemical company	Bulgaria	Burgas

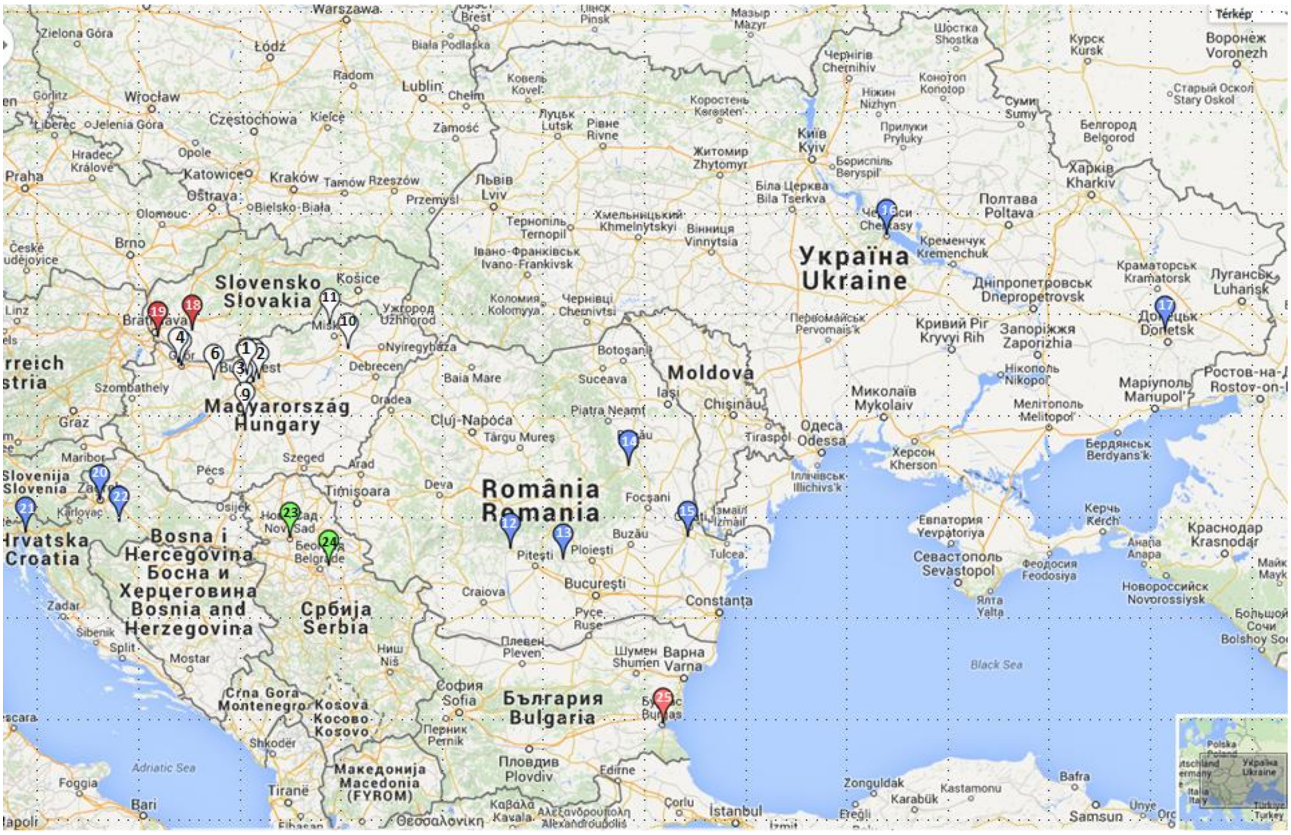


Figure 21 Depicts the location of investigated sites (see the marked numbers in Table 3)

3.2.1.2 Rated thermal power

The estimated thermal power usage of investigated sites can be seen in Table 4 and in Figure 22.

Table 4 Thermal power usage at each investigated site

#	1	2	3	4	5	6	7	8	9	10
P_{th} [MWth]	80	22	630	1	3	80	40	120	200	70
#	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
P_{th} [MWth]	150	60	60	10	15	720	25	55	460	80
#	**21**	**22**	**23**	**24**	**25**					
P_{th} [MWth]	380	180	375	200	65					

It can be seen in Table 4 that almost half of the investigated sites use more than 100 MWth - ten sites. There are just two sites which use over 500 MWth. The remaining 15 sites use less than 100 MWth.

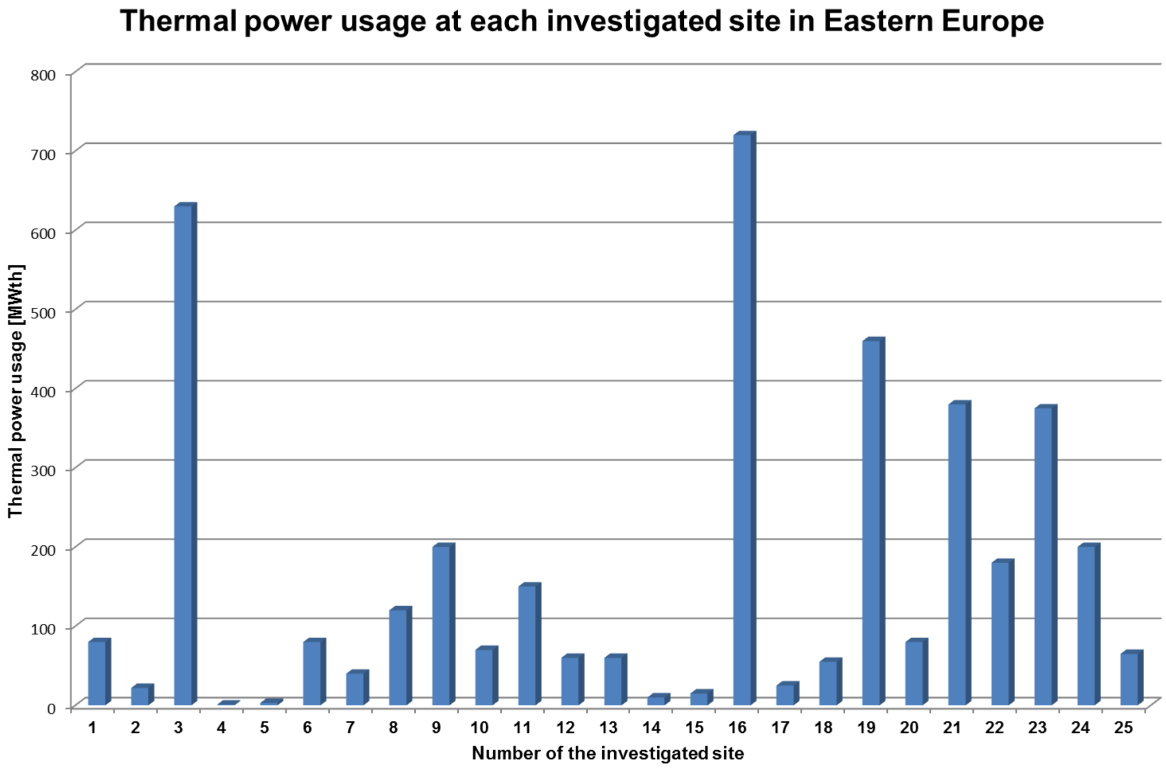


Figure 22 The thermal power usage at each investigated site

3.2.1.3 Electric power production and usage

A summary of electricity usage on site is shown in Figure 23 and Table 5. Not far all considered sites information on power demand was available, where not obtained space is left blank.

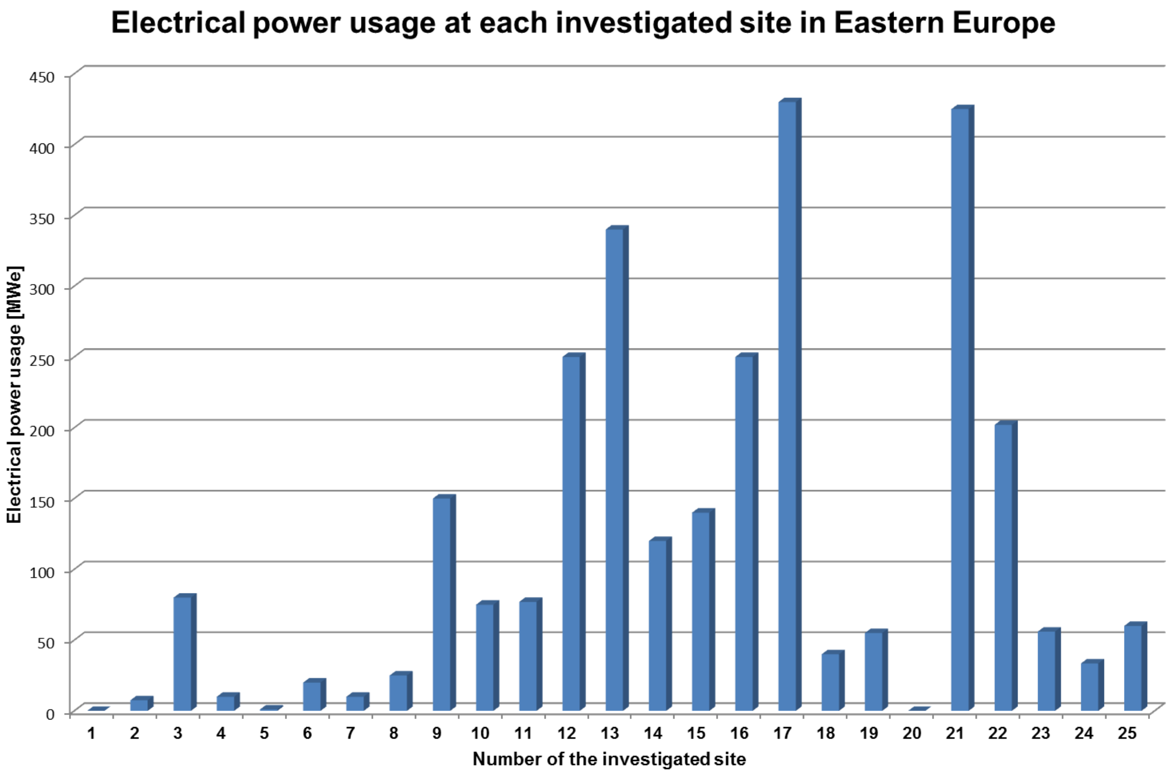


Figure 23 The electrical power production and usage at the investigated sites

Table 5 Electrical power usage at each investigated site

#	1	2	3	4	5	6	7	8	9	10
P_e [MWe]		7,5	80	10		20	10	25	150	75
#	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
P_e [MWe]	77	250	340	120	140	250	430	40	55	
#	**21**	**22**	**23**	**24**	**25**					
P_e [MWe]	425	202	56	33,5	60					

3.2.1.4 Process steam parameters

All sites listed in Table 5, consume various temperature and pressure steam in different processes (see in Table 6 and Table 7). Most of CHP units on site produce medium or high pressure steam (from 1.5 to 14 MPa) at high temperature of about 500°C which is then converted into medium or low pressure/temperature required for particular applications. Usually fresh steam is converted into 2-3 different parameter media using infrastructure available onsite. Not far all considered sites information on process steam parameters was available, where not obtained space is left blank.

Table 6 Process steam temperature at each investigated site

#	1	2	3	4	5	6	7	8	9	10
T_s [°C]	100-400	max. 300	various		700	max. 1600	max. 1600	700	450	80/240/380
#	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
T_s [°C]	various	saturation	various	110	110	various			various	100-400
#	**21**	**22**	**23**	**24**	**25**					
T_s [°C]	various	various	various	various	85/240/360					

Table 7 Process steam pressure at each investigated site

#	1	2	3	4	5	6	7	8	9	10
p [bar]		0,35/0,7/2,5	0,2/1/4						0,6/0,9/ 1,8/3,7	0,1/1,5/4
#	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
p [bar]	0,2/1,5/4	35/13/6		0,2	0,2	various			0,2/1/4	
#	**21**	**22**	**23**	**24**	**25**					
p [bar]	0,2/1/4	0,2/1/4	0,2/1/4	0,2/1/4	0,1/1,5/4,5					

3.3 Rest of Europe

3.3.1 Introduction on heat and industries

The European heat demand has never been quantified for the chemical industry [3]. However, the final energy use (not only for heat purpose) in the European chemical industry was estimated at around 3,000PJ in 2010 (CEFIC, ECOFYS, 2013). The particularity of the chemical industry is that energy vectors such as oil and natural gas, are used to provide energy but are also used as feedstock.

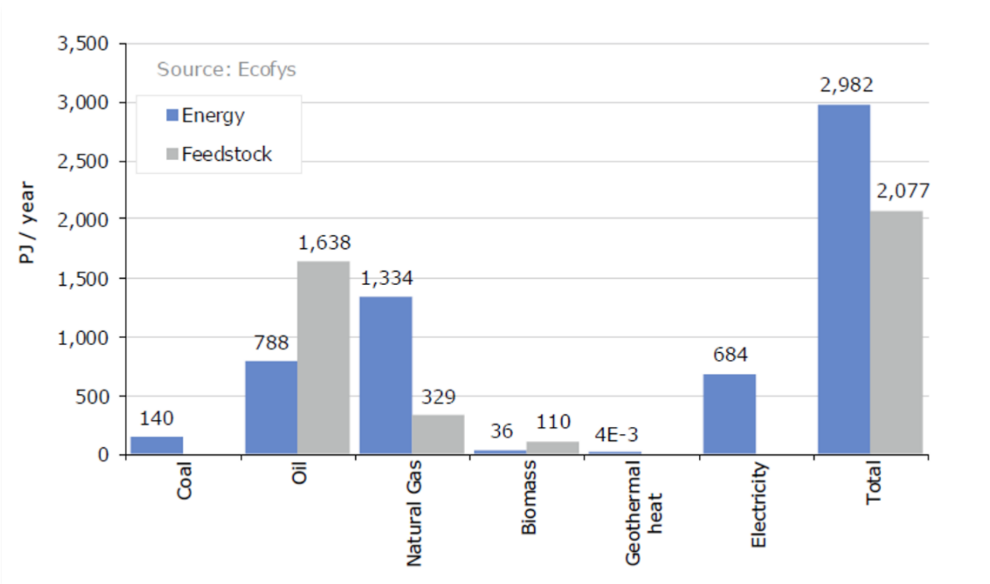


Figure 24 Feedstock and energy use by the European chemical industry in 2010, (Ecofys 2012)

Figure 24 shows that the main energy vectors used today in the chemical industry are natural gas and oil. Indeed, natural gas presents several major advantages:

- High operational flexibility and availability
- Relatively low price in Europe for countries which do not have natural resources
- Relatively low carbon footprint

In the chemical industry, the heat sources are mainly internal boilers and cogeneration. Within an installation, exothermic reactions can also be used to provide heat to endothermic reactions. CHP is already widely applied (CEFIC, ECOFYS, 2013). It mainly concerns large clusters or high-demanding chemical processes so that the capacity of the CHP plant corresponds to the heat and energy demand of the site.

3.3.2 Methodology

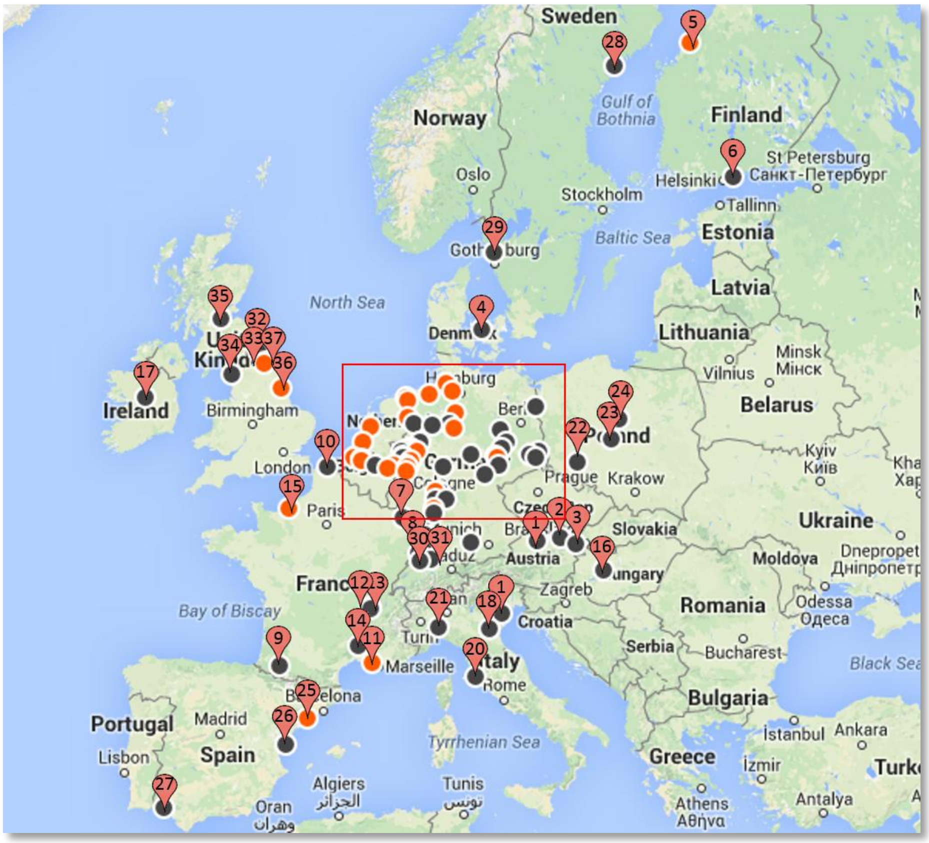
The mapping of the chemical parks in Europe was established using different sources of information. First, the organization *ECSPP – European Chemical Site Promotion Platform*, provided the basis of the mapping. [19]

Other European and National Chemical organizations were also contacted to identify other parks and confirm the information provided by the ECSPP. However, these organizations were difficult to contact and only few relevant information was collected.

Finally, to get more technical information on the clusters concerning their energy consumption, the parks for which contact information was found, were contacted. The list of contact points is given in Annex 3.

3.3.3 Mapping results

As it is shown on Figure 25, more than 90 chemical parks were identified in Europe. Most of the European chemical parks are located in a triangle formed by the countries: Germany, Belgium and the Netherlands. France and the UK are also important actors.



a

b

Figure 25 a. Chemical parks in Europe, b. Focus on the chemical parks in Germany, Belgium and The Netherlands, source: ECSPP

Table 8 List of chemical parks in Europe

Number	Name	City	Country
1	Chemiepark Linz	Linz	Austria
2	Dynea Austria GmbH	Krems	Austria
3	Schwechat		Austria

4	Novo Nordisk Kalundborg	Kalundborg	Denmark
5	Kokkola Industrial Park	Kokkola	Finland
6	Porvoo		Finland
7	Carling, Lorraine	Carling	France
8	Chalampé		France
9	Lacq-Mourenx	Pau	France
10	Dunkerque	Dunkerque	France
11	Fos-Lavera-Berre	Fos sur Mer	France
12	Lyon-Feyzin	Feyzin	France
13	Pierre-Bénite	Lyon	France
14	Salindres	Salindres (gard)	France
15	Seine Valley: Le Havre - Port Jérôme - Gravenchon - Rouen	Le Have, Port-Jérôme, Rouen	France
16	Pétfürdö	Pétfürdö	Hungary
17	Monksland	Monksland	Ireland
18	Ferrara	Ferrara	Italy
19	Porto Marghera		Italy
20	Scarlino	Scarlino	Italy
21	Spinetta Marengo		Italy
22	Środa Śląska	Środa	Poland
23	Turek	Turek	Poland
24	Włocławek	Włocławek	Poland
25	AEQT - Tarragona Chemical Cluster	Tarragona	Spain
26	BP Oil Refinería de Castellón, S.A.U.	Castellon	Spain
27	Huelva	Huelva	Spain
28	Processum Technology Park	Örnsköldsvik	Sweden
29	Stenungsund		Sweden
30	Infrapark Baselland	Muttenz	Switzerland
31	Solvay Ind.park	Bad Zurzach	Switzerland
32	AkzoNobel R&D center Felling UK	Felling	United Kingdom
33	Billingham	Billingham	United Kingdom
34	GlaxoSmithKline Ulverston	Ulverston	United Kingdom
35	Grangemouth	Grangemouth	United Kingdom
36	Saltend Chemicals Park	Hull	United Kingdom
37	Wilton Power Station	Teesside	United Kingdom
38	Industripark Kleefse Ward	Kleefse	The Netherlands
39	Port Of Antwerp	Antwerp	Belgium
40	Tessenderloo	Tessenderloo	Belgium
41	Agro-Chemie Park Piesteritz	Piesteritz	Germany
42	Allessa Chemie GmbH	Frankfurt-Fechenheim	Germany
43	BASF Coatings GmbH, Münster	Münster	Germany
44	BASF Schwarzheide GmbH	Schwarzheide	Germany
45	BASF SE, Ludwigshafen	Ludwigshafen	Germany
46	Bomlitz/ Walsrode	Bomlitz	Germany
47	Castrop-Rauxel	Castrop-Rauxel	Germany
48	ChemCoast Park Brunsbüttel	Brunsbüttel	Germany
49	Chemie-Industrie- Park Bleicherode	Bleicherode	Germany

50	ChemiePark Bitterfeld Wolfen	Bitterfeld Wolfen	Germany
51	Chemiepark Knapsack	Hurth	Germany
52	Chemiepark Köln-Merkenich	Koln-Merkenich	Germany
53	Chemiepark Rudolstadt/ Schwarza	Rudolstadt	Germany
54	Chemie- und Industriepark Zeitz	Zeitz	Germany
55	Chempark Dormagen	Dormagen	Germany
56	Chempark Krefeld-Uerdingen	Krefeld-Uerdingen	Germany
57	Chempark Leverkusen Currenta	Leverkusen	Germany
58	CoastSite Wilhelmshaven	Wilhelmshaven	Germany
59	Deutsche Gasrußwerke, Dortmund	Dortmund	Germany
60	Gelsenkirchen-Scholven	Gelsenkirchen	Germany
61	Honeywell Seelze Industrial Park	Seelze	Germany
62	Industrial Park Dorsten-Marl	Dorsten	Germany
63	Industrial Park Werk GENDORF	Gendorf	Germany
64	Industriepark Gersthofen Servicegesellschaft	Gersthoven	Germany
65	Industriepark Griesheim	Griesheim	Germany
66	Industriepark Guben	Guben	Germany
67	IndustriePark Lingen	Lingen	Germany
68	Industriepark Premnitz	Potsdam	Germany
69	Industriepark Schwarze Pumpe	Spremberg	Germany
70	Industriepark Solvay Rheinberg	Rheinberg	Germany
71	industriepark walsrode	Walsrode	Germany
72	Industriepark Weinheim	Weinheim	Germany
73	Industry Centre Obernburg	Obernburg	Germany
74	InfraLeuna GmbH	Leuna	Germany
75	Infraserv GmbH & Co. Höchst KG	Frankfurt-Höchst	Germany
76	Krefeld-Uerdingen Currenta	Krefeld-Uerdingen	Germany
77	Lemförde	Lemförde	Germany
78	Marl Chemical Park	Marl	Germany
79	NUON Industriepark Oberbruch	Oberbruch	Germany
80	Pharma- und Chemiepark Wuppertal	Wuppertal	Germany
81	Rhodia-Industriepark Freiburg	Freiburg im Breisgau	Germany
82	Schkopau	Schkopau	Germany
83	Schwedt/Oder PCK Raffinerie GmbH	Schwedt	Germany
84	Stade	Stade	Germany
85	Willstätt industrial park.	Willstätt	Germany
86	Chemelot	Geleen	The Netherlands
87	Chemical Cluster Delfzijl	Delfzijl	The Netherlands
88	Eemshaven	Eemsmond	The Netherlands
89	EMMTEC Industry & Business Park	Emmen	The Netherlands
90	Port of Amsterdam	Amsterdam	The Netherlands
91	Port of Rotterdam	Rotterdam	The Netherlands
92	Valuepark Terneuzen	Terneuzen	The Netherlands

The number of chemical sites in Europe is very large. However, it was difficult to access all these sites to know more about technical information concerning their energy consumption/production. In the simple cases, the chemical park was managed as one entity with one name, one website and, in several cases, with one energy management company. The energy management company deals with the demand of the industries and find solutions to power the industries; it handles the contracts and the technical issues. However, in many cases, the park does not appear as one entity with one regular name, and in these conditions, it was very difficult to know and contact the appropriate person to discuss the energy issues of the park. In addition, parks may not have centralized energy solution, and each industry/company takes care of its own energy demand.

Overall, technical information for 19 parks has been described.

#	Site	Country
1	AEQT - Tarragona Chemical cluster	Spain
2	Wilton Power Station - Teesside	UK
3	Roches-Roussillon	France
4	Saltend Chemicals Park	UK
5	Lacq-Mourenx	France
6	Chemelot	The Netherlands
7	EMMTEC Industry and Business Park	The Netherlands
8	Industry Park Niederau	Germany
9	Industry Park Kleefse Ward	The Netherlands
10	Nuon Industrypark Oberbruch	Germany
11	Chempark Leverkusen Currenta	Germany
12	Chempark Dormagen	Germany
13	Chempark Krefeld-Uerdingen	Germany
14	Novo Nordisk Kalundborg	Danemark
15	Marl Chemical Park	Germany
16	Infraleuna	Germany
17	Leuna Werke	Germany
18	Port of Antwerp	Belgium
19	Port of Rotterdam	The Netherlands

Table 9: European parks for which information was collected

3.3.3.1 Thermal power

The thermal power of different sites is represented below:

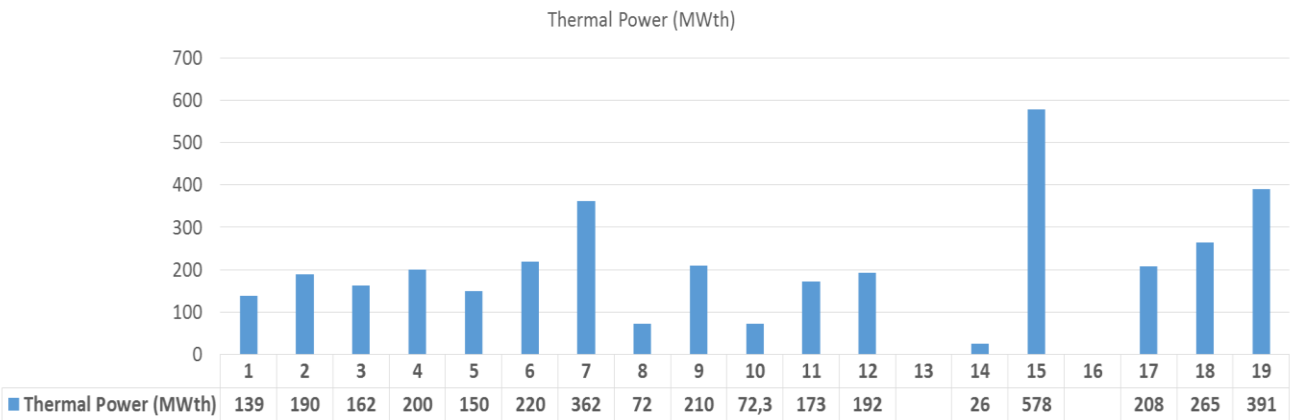


Figure 26: Thermal power of some of European chemical parks

As it can be seen in the figure, most of the sites have a thermal capacity between 100 and 200 MW_{th}. Several small parks have a thermal capacity below 100 MW_{th} and a minority of important parks has a thermal power higher than 300 MW_{th}. These results are consistent with the ones in Eastern Europe. The thermal power of the Polish sites seems higher, it might be explained by the high number of refineries that require large amounts of steam.

3.3.3.2 Electrical power

The electrical power usage of the different sites is represented in figure 26. The electrical power usage for the site of Rotterdam was not represented since the electrical power usage was too important (5,388 MW_e).

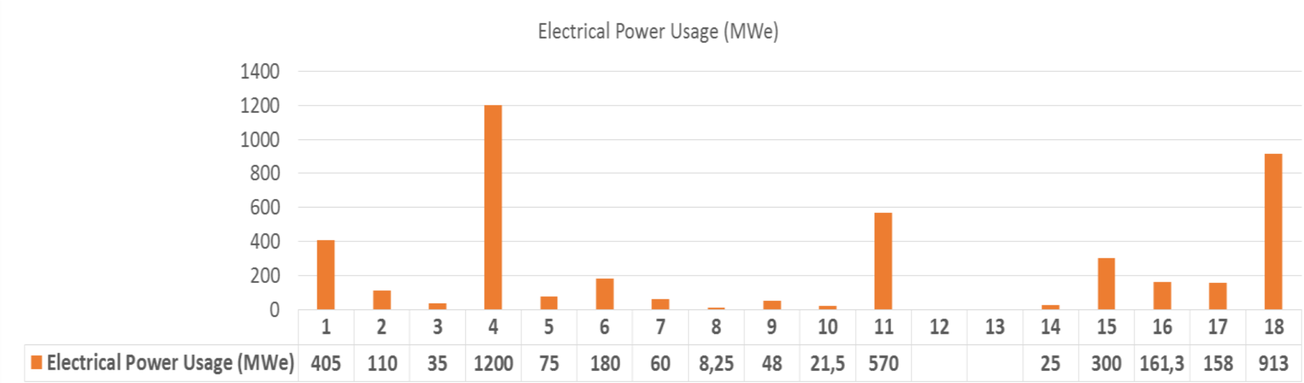


Figure 27: Electrical Power Usage of European chemical parks

There is a large discrepancy in the electrical power usage. Indeed, a majority of the sites use less than 200 MW_e but larger sites can have an electrical power usage from 400 MW_e to more than 5,000 MW_e. These figures are consistent with the Poland situation since in most cases only a small share of steam is used to produce electricity.

3.3.3.3 Electrical/Thermal power ratio

The ratio of electrical power to thermal power might be interesting for the project since it is an important parameter in the nuclear cogeneration demonstrator. This ratio was calculated for the different sites and represented in the figure below:

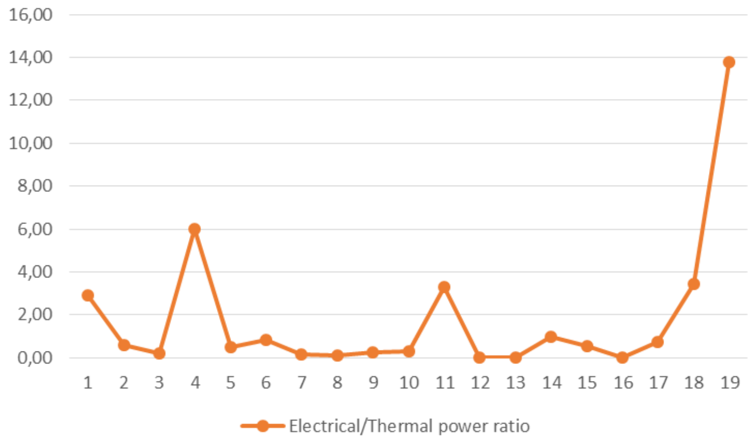


Figure 28: Electrical/Thermal power ratio for European sites

As it is shown in the figure, the ratio varies widely depending on the site. Indeed, the ratio depends on the requirements of the industries and so is directly linked with the application/use of the steam.

3.3.3.4 Process steam parameters

All the sites described in this section have different steam networks to match the requirements of various processes. Most of time, they have 3 networks:

- Low pressure (LP): a few bars
- Intermediate pressure: usually between 10 and 20 bars
- High pressure (HP): higher than 30 bars

Number	Steam Pressure (b)
1	2 networks: 1 medium pressure (45b), 1 high pressure (110b)
2	4 networks: High Pressure (HP), Intermediate High Pressure (IHP), Intermediate Pressure (IP), Low Pressure (LP)
3	2 networks: 6b-32b
4	2 networks: 4-17b
5	6 networks: 4 to 100b
6	Different networks: a low pressure, a medium pressure and other high pressures (80-110b)
7	up to 30b
8	various
9	various
10	various
11	low and high pressure (6 - 31b)
12	3 pressures : 6 -16 - 31b
13	3 pressures : 6 -16 - 110b
14	low and medium pressure
15	various
16	various
17	4 networks: 2 high pressures (40b and 20b), 1 intermediate pressure (13b), 1 Low Pressure (2b)
18	various
19	various

Table 10: Steam pressure for European parks

The temperature of the process steam was more difficult to obtain. Like for the pressure, the temperature varies with the different steam pressure networks but is not higher than 600°C and is usually between 200 and 500°C.

Number	Steam Temperature (°C)
1	560°C
2	
3	Around 500°C
4	
5	Not higher than 380°C
6	highest steam network: 500°C
7	Not higher than 480°C
8	various
9	various
10	
11	
12	Around 450°C
13	Around 450°C
14	
15	various
16	various
17	highest steam network: 320°C
18	various
19	various

Table 11: Steam temperature for European parks

4 Conclusion

The subject of this task was to localize and characterize chemical and petrochemical sites within Europe which can be a potential market for deployment of the HTR's. It was established that benefits of nuclear cogeneration can be utilized by industrial consumer of process steam at high and intermediate parameters, industrial consumer with on-site CHP unit or need for one and sites with aging steam boilers. The main processes compatible with HTR capabilities are:

- refinery distillation steam,
- refinery distillation superheated steam,
- petrochemicals - reaction enthalpy,
- steam as utility for industrial complex,
- paper steam (drying)

Mapping of industrial sites was conducted in a manner allowing describing the heat market and distinguishing industrial sites located in Europe. Depending on availability of information sites were described in terms of:

- Rated thermal power
- Electric power production and usage
- Fresh steam parameters (temperature, pressure, mass flow)
- Process steam parameters (temperature, pressure, mass flow)
- Current power production unit characteristics (size, age, fuel)
- And others (e.g. environmental factors, regulatory framework etc.)

In total 132 sites were located within Europe. The sites located within central and eastern Europe were summarized in figures 29, 30 and 31. The figure 29 shows percent share of industries in the mapped pool. The chemical and petrochemical industries are dominant in this figure and represent respectively 30% and 35% of the mapped sites. Remaining sites are metal processing plants and pharmaceutical plants.

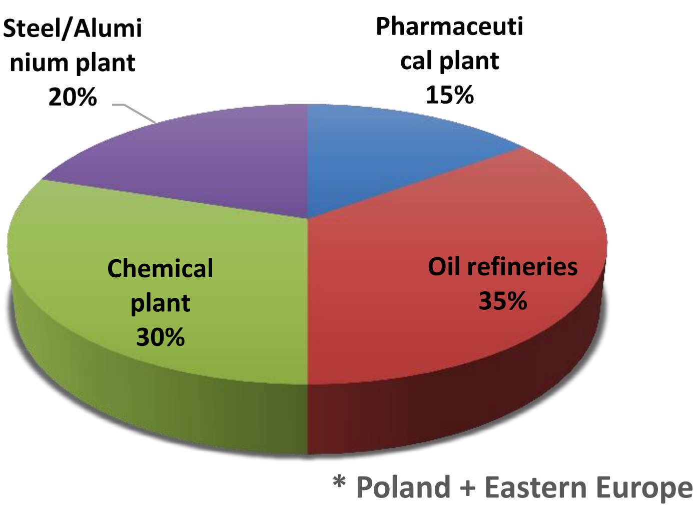


Figure 29 Percent share of different industries mapped

The figure 30 represents division of localized sites to thermal power demand categories. Majority of sites use less than 100 MWth – 20 sites. In the category of more than 100 MWth, 8 sites were located. The last significant category was about 500 MWth, in this category include 9 sites.

The electrical power demand is distributed somewhat in more uniform manner. The smallest demand – up to 50 MWe was reported by 20 sites. Each of next categories, respectively 51-100 MWe, 101-200 MWe and 201-400 MWe, reported between 4 and 6 sites.

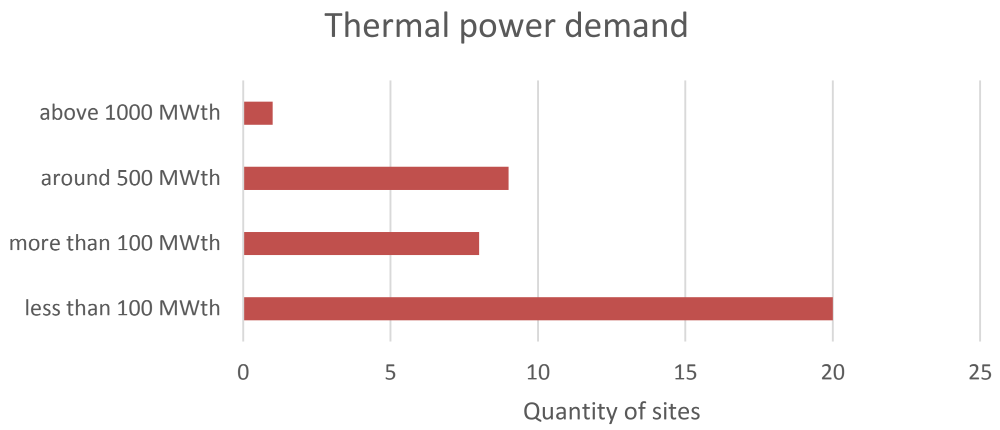


Figure 30 Sites categorized by thermal power demand

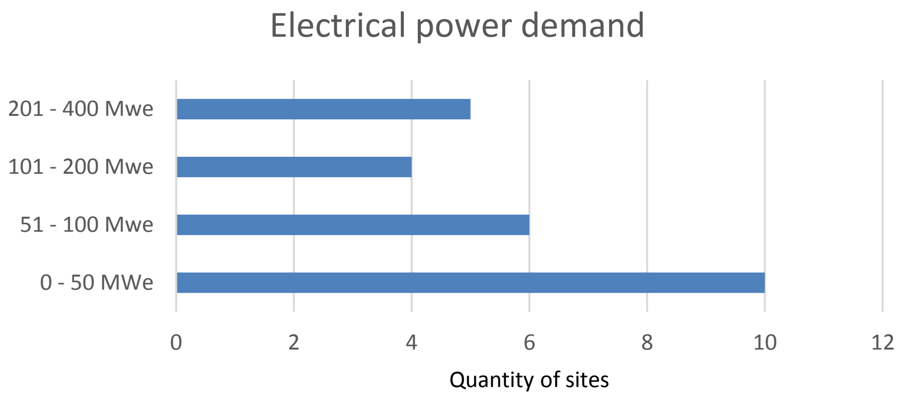


Figure 31 Sites categorized by electrical power demand

4.1 Poland

As a result of industrial objects mapping in Poland 15 sites were listed:

- 6 chemical sites
- 6 refineries
- 1 paper factory
- 2 power production/distribution units

It was determined that majority of the sites produce about 500 MW_{th} - seven sites. There is just one site which produces over 2000 MW_{th}. Five sites have been listed as facilities with thermal power production of around 100 MW_{th}. However possibly this market can be larger as mapping task was focused at sites with thermal capacity of over 200 MW_{th}. As most of the steam produced in steam boilers is used as media or ingredient in processes, only small share of steam is used to produce electricity.

Most of CHP units produce high or medium pressure steam (from 1.5 to 14 MPa) at high temperature of about 500°C which is then converted into medium of low pressure/temperature required for particular applications. Usually fresh steam is converted into 2-3 types of steam using infrastructure available onsite. Weighted (rated thermal power) average temperature and pressure of the fresh steam are respectively 510°C and 10 MPa. Investigated industrial sites usually convert fresh steam into three types of process steam of high, medium and low parameters available in section 1.6.1.5

IED influence directly amount of steam boilers that will be decommissioned in following years creating market for other type of cogeneration or steam production unit like HTR. Planned modernizations and decommissioning of the stem boilers for selected sites is shown in Figure 13. Considering only selected sites, 25 boilers will need to be decommissioned by 2019. Some of those sites have already plans for new steam production units like PKN Orlen or Anwil S.A. For the rest of the sites new steam supply system issue remains not clarified.

The regulatory framework for medium and small reactors with inherent safety features in Poland is not established yet. In some part current state of law can be applied, however, to maximize economic advantages of this design some advancement need to be made, in specific re-definition of EPZ.

4.2 Eastern Europe

Seven Eastern European countries have been investigated in the framework of this investigation: Hungary (11 sites), Romania (4 sites), Croatia (3 sites), Ukraine (2 sites), Slovakia (2 sites), Serbia (2 sites) and Bulgaria (1 site). So, as a result of industrial objects mapping in Eastern Europe 25 sites were listed:8 steel, aluminum foundry or steel processing factory

- 8 oil refinery or petrochemical processing factory
- 6 chemical sites
- 3 pharmaceutical factory

It was determined that two fifth of the investigated sites use more than 100 MW_{th} - ten sites. There are just two sites which use over 500 MW_{th}. The remaining 15 sites use less than 100 MW_{th}. However possibly this market can be larger because mapping task was focused at sites with thermal capacity of over 200 MW_{th}. Nine sites use more than 100 MW_e the rest uses less electricity.

Most of the investigated CHP units in Eastern Europe produce medium or low pressure steam (from 0.2 to 3.5 MPa) at from low to high temperature of about 100-1600°C which is then converted into medium or low pressure/temperature required for particular applications. Usually fresh steam is converted into 3-4 types of steam using infrastructure available onsite. Investigated industrial sites usually convert fresh steam into three types of process steam of high, medium and low parameters available in section 1.7.1.4.

Unfortunately, there is no information available about the planed decommissioning of currently operating steam boilers.

The regulatory framework for medium and small reactors with inherent safety features in Eastern Europe is not assessed in the framework of this research due to the high number and inhomogeneity of investigated countries.

4.3 Rest of Europe

In the rest of Europe, 92 chemical parks were mapped. These parks are located mainly in the triangle Belgium-The Netherlands-Germany. Germany, which could be seen as a serious host country for the demonstrator a few years ago because of its large chemical industry and its experience in nuclear, is no longer an option since its withdrawal from nuclear energy decided by the Government in 2011. Once the clusters were identified, several European associations as well as the clusters themselves were contacted to get technical information on energy production/consumption. However, European associations do not have such information. It was also difficult to get in touch with the clusters and reach the person dealing with the cluster's energy management. As a result, and because of time and resources limitations, quantitative information was available only for 19 sites.

The thermal capacity of the majority of the site is between 100 MW_{th} and 200 MW_{th}. The thermal consumption of several small parks is below 100 MW_{th} and a minority of important parks has a thermal power higher than 300 MW_{th}. The electrical capacity is much more discrete since a majority of sites use less than 100 MW_e but larger sites have an electrical power usage from several hundreds of MW_e to more than 5,000 MW_e. Therefore, it was not possible to determine a "usual" or a range of Electrical to Thermal power ratio as it highly depends on the process used in the chemical industry located in the park.

In most of the clusters, several steam networks are available at different pressures: a low pressure (a few bars), an intermediate pressure (between 10 and 20 bars) and a high pressure (over 30 bars). The process steam temperature of the steam networks fluctuates but is not higher than 600°C.

5 Acronyms and definitions

Acronym	Definition
CHP	Combined Heat and Power
EC DG RTD	European Commission – Directorate General for Research and Technological Development
ECSPP	European Chemical Site Promotion Platform
HTR	High Temperature Reactor

GHG	Green House Gasses
SET-plan	Strategic Energy Technology Plan
LWR	Light Water Reactor
IAEA	International Atomic Energy Agency
IED	Industrial Emission Directive
LCP	Large Combustion Plants
EPZ	Emergency Planning Zones
ECSPP	European Chemical Site Promotion Platform

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7 Annexes

Annex 1 Input Data Sheet

Site characterizing sheet contains sequence of fields describing basic information to verify its utility for NC2I-R project. Information (when possible) need to be requested directly from site and implemented into the sheet according to instruction below.

Table 12 Input data sheet

General information	site name	
	site type	
	location	*country*
		city
		address
		contact information
Site characteristics	expected site life time	
	economic background	
	expansion plan	
Power production - on site	electric power production	*[MWe]*
		total amount of steam boilers
	unit type	
	fuel type	
	thermal power (rated)	*[MWt]*
		pressure [MPa]
	steam parameters	*Temperature [^{0}C]*
		mass flow [kg s^{-1}]
	installation year/ modernized in	*[year]*
	next planned (boiler) modernization	*modernized by 2019*
		decommissioned by 2016/2019
External power supply	electric power	*[MWe]*
	thermal power	*[MWt]*
	steam parameters	*pressure [MPa]*
		temperature [^{0}C]
		mass flow [kg s^{-1}]
		[MWe] Winter/summer
Power usage	electric power consumption	
	thermal power usage	*[MWt]*
	process steam parameters (if more than one type separate by /)	*pressure [MPa]*
		temperature [^{0}C]

		mass flow [kg s^{-1}]
Security	hazards on site	*(dangerous, explosive chemicals?)*
	environmental hazards	*(seismic activity, flooding, etc?)*
Location aspects	site expansion possibility (less than 5 km radius from site)	*in site*
		off site
	political aspects	*regulatory framework*
	social aspects	*population density around site*
		public acceptance for nuclear
	Infrastructure around site	*water supply*
		power grids
		transport/ roads/rail
	other environmental restrictions	

Information need to be requested directly from site and implemented into the sheet according to this instruction.

Following sections are included: **<u>* required filed</u>**

1. General information* - data identifying the site
   a. site name
   b. site type
   c. location
      i. country
      ii. city
      iii. address
      iv. contact information – *Please include email/phone number of contacted person*
2. Site characteristics
   a. expected site life time*
   b. economic background – site economical viability
   c. expansion plan – *is there site expansion planned in short (up to 5 years) and medium (up to 10 years) term?*
3. Power production - on site *– *Power generated on site for industrial applications*
   a. electric power production – *total amount of produced electricity [MWe]*
   b. unit type – *type of power generating unit*
   c. fuel type
   d. operating thermal power – *usual thermal power generation [MWt]*
   e. steam parameters – *steam parameters at the exit from the generating unit (boiler)*
      i. pressure [MPa]
      ii. temperature [^{0}C]
      iii. mass flow [kg s^{-1}]
   f. installation year – *how old is the steam supply unit?*
   g. next planned modernization – *indicate a date of next planned modernization or dismantling of the unit*
4. External power supply *
   a. electric power – *how much electricity is purchased from energy suppliers [MWe]*
   b. thermal power – *how much steam is purchased from external supplier [MWt]*
   c. steam parameters – *parameters of purchased steam*
      i. pressure [MPa]
      ii. temperature [^{0}C]
      iii. mass flow [kg s^{-1}]
5. Power usage*
   a. electric power consumption – *cumulative electricity consumed on site [MWe]*
   b. thermal power usage – *cumulative steam consumption for electricity production and for industrial applications [MWt]*

   c. process steam parameters – *parameters of steam for particular industrial applications (if more than one type separate by /)*
      i. pressure [MPa]
      ii. temperature [^{0}C]
      iii. mass flow [kg s^{-1}]
6. Security
   a. hazards on site – *What conditions/substances on site can be potentially dangerous for HTR installation?*
   b. environmental hazards – *What aspects of environment can be dangerous for HTR installation (ex. Seismic activity, flooding etc.)?*
7. Location aspects
   a. site expansion possibility* - in less than 5km radius form site
      i. in site – A*rea which already belongs to the site.*
      ii. off site – A*rea located outside of the site.*
   b. political aspects* - *regulatory framework for nuclear objects in the country of interest*
   c. social aspects
      i. population density around the site* – *any cities, towns, villages in vicinity of the site (ex. town in distance of 4 km , population 15 000)*
      ii. public acceptance for nuclear
   d. Infrastructure around site – *for convenient construction and operation of HTR installation*
      i. water supply* – *rivers, sea sides in vicinity of the site*
      ii. power grids *– *voltage of available grid*
      iii. transport/ roads/rail
   e. other environmental restrictions
8. Other comments

Annex 2 Siting Criteria

7.1.1 Socio-political and socio-economic situation

No.	*Criterion*	*Level*	*Observation*
01	General relation on nuclear energy - social acceptance of nuclear industry - general atmosphere relating big scale industrial projects	Very high / pre-requisite	Some countries can be excluded at the time being (e.g. Germany)
02	Reliability of the regulatory environment - speed and consistency of the licencing process - stability and reliability of licensing process - Framework for change procedures in issued permits (e.g. compensations)	very high	At least a 20-years-time horizon should be secured
11	Liability and general insurance aspects - limitation of liability in case of an highly unlikely event with potential consequences on plant neighbourhood	high	Risks have to be covered for participation of private investors
10	Sustainability in financial terms - price guarantee - subsidies - other methods of project development	high	F.O.A.K.-projects are not viable without public support
21	Availability of nuclear skills	Medium	Desirable, but developable on long

	- image of professions in nuclear business - educational situation		term
16	Structure of land-ownership in vicinity to planned facility - risk of long lasting real estate conflicts	High	Can influence / slow down licensing process

7.1.2 Inter-industrial partnership/ customer relations

No.	*Criterion*	*Level*	*Observation*
04	Demand for high energetic steam - alternatives - price level for alternative sources - requirements on availability (penalties) - Expected site life time / planning horizon for steam consuming plants - Plans for site expansion or major refurbishments	Very high	Driving force for project development from technical point of view, Power demand about 200-600 MW_{th} in main focus
41	Demand for low energetic steam - demand for district heating - price level for alternative sources - requirements on availability (penalties)	Low	
22	Demand for electrical power - price for electrical power - requirements for supply to grid	Medium	Site specific (emergency) scenarios have to be considered
05	Risk-sharing by cross-ownership - stakeholder structure of the project - long term contracts	Very high	Main criterion for sustainability of the project

7.1.3 Social and regional aspects

No.	*Criterion*	*Level*	*Observation*
13	Population distribution - distance to next municipality - areas of high traffic	High	Non-technical consequences have to be anticipated
23	Distance to areas with protected status - environmental protected areas - FFH-protected areas - Areas of archaeological interest - areas with high recreational value	Medium	Risks can be minimized by careful site investigation
24	Social requirements - visual impact - Restrictions due to historical events	Medium	Compensation strategies should be developed in advance

12	Distance to sensitive facilities without project relation - military bases - airports - areas of high user's frequency (stadiums, railway stations etc.)	High	Early collection of stakeholder interests necessary

7.1.4 Geological situation and external hazards

No.	*Criterion*	*Level*	*Observation*
06	Seismic activities - expected PGA level - seismic faults	Very high	Site exclusion criterion
14	Man-Made underground activities and influences - drilling and mining - landfill - soil contamination	High	Incompleteness of database at old industrial sites likely (e.g. accidents during and after war times)
25	External flooding risk - river flooding - tsunamis - upstream dam collapses	Medium	Risks can be minimized be careful site investigation
26	Metrological events - extreme temperatures - high wind speed (hurricanes etc.)	Medium	Typically technical solutions available, influence of regulatory environment
27	Influence / hazards by other nearby industrial facilities	Medium	Site-specific studies necessary
28	Consequences of groundwater pollution (in both directions)	Medium	Extensive proof of irrelevance could become necessary

7.1.5 Technical infrastructure

No.	*Criterion*	*Level*	*Observation*
15	Max. distance for high energetic steam supply	High	5 km should be considered as current maximum
29	Grid connections - No. of independent grid connections - Voltage level of grid connection - alternative nearby power sources	Medium	Grid extension could be long lasting procedure, interfaces have to be clarified at early stage of project.
30	Cooling water availability - intake water quality and quantity - effluent water quality	Medium	Should be considered in relation with requirements on visual impact of cooling towers

	(e.g. max temperature)		
31	Traffic infrastructure - road - railway - ship	Medium	

7.1.6 Aspects for plant erection

No.	*Criterion*	*Level*	*Observation*
32	Available site area - distance to potential HTR-plant site	Medium	Design dependent, 40ha per unit should be considered as lower limit, to allow ease construction work.
33	Groundwater level	Medium	Only relevant for erection phase
34	Soil quality - requirements for deep foundation	Medium	Experiences on existing industrial sites
35	Requirements by neighborhood - compensation activities	Medium	Early recognition necessary

Annex 3 Filled data sheets

Attached as separate files.