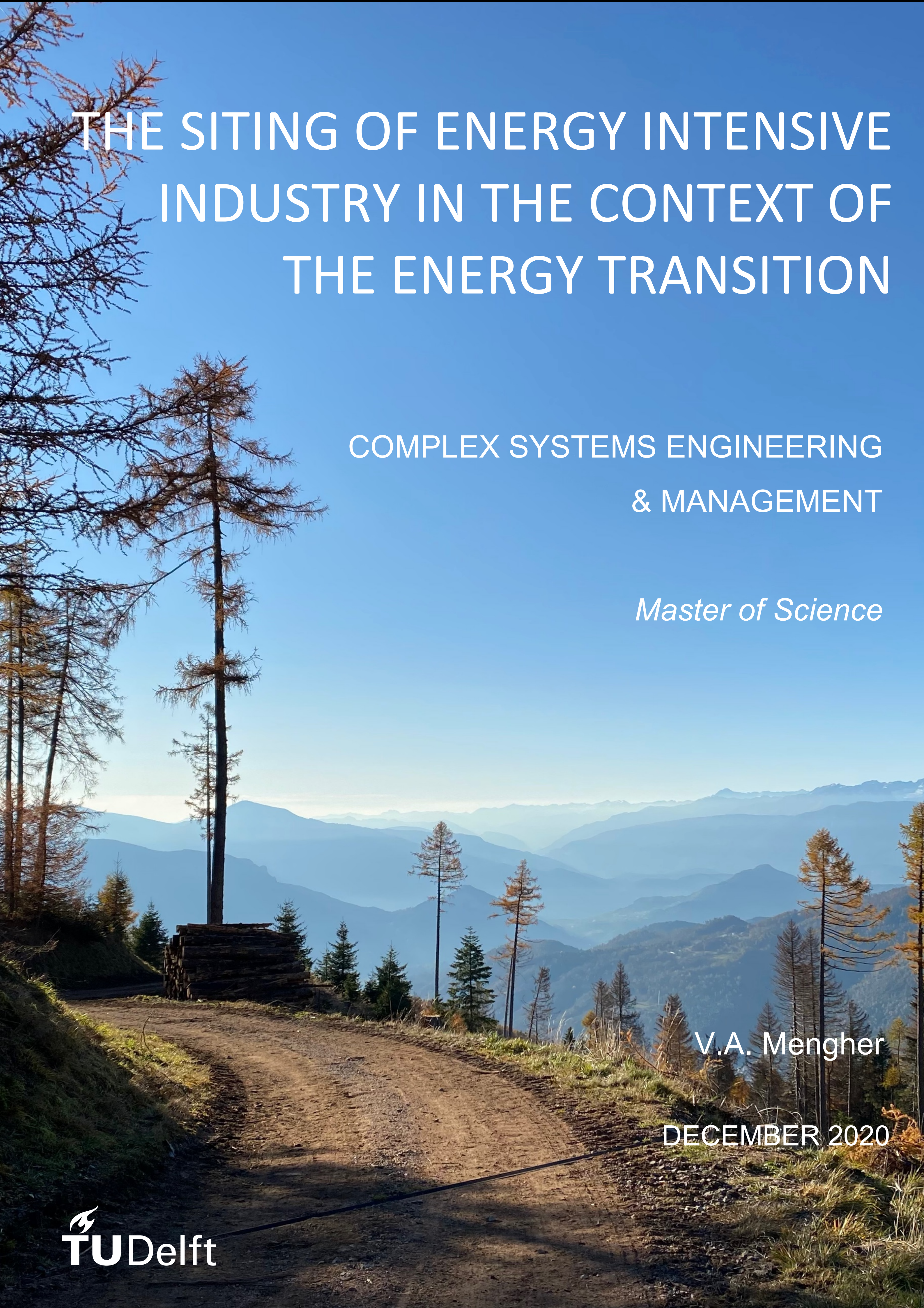

THE SITING OF ENERGY INTENSIVE INDUSTRY IN THE CONTEXT OF THE ENERGY TRANSITION

COMPLEX SYSTEMS ENGINEERING
& MANAGEMENT

Master of Science

V.A. Mengher

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Vlad Andrei Mengher

Student number: 4945913

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Graduation committee

Chairperson & Second Supervisor	:	Prof. dr. ir. Ivo Bouwmans	Energy and Industry
First Supervisor	:	Dr. Daniel Scholten	Economics of Technology and Innovation

Preface

What lies in front of you is the result of my graduate research in fulfilment of the master program Complex System Engineering and Management at the TU Delft. At the time that I am writing these words, the COVID-19 global pandemic and the so called ‘corona crisis’ are teaching us an important lesson. Disruptive system-level changes are more than real, and their effects change what we perceive as normal from one day to the next. I hope that society will be able to internalize this lesson and apply it to other domains that are harming life on earth. Although the pandemic influenced this graduation process in many unpleasant ways, I have enjoyed deepening my knowledge and understanding of the energy transition topic very much.

To start with, I would like to thank my first supervisor Daniel Scholten. You have been a point of reference through this uncertain time. Thank you for showing me that doing research is about fulfilling curiosities and thank you for your willingness to share your knowledge and your perspectives.

I would like to thank my second supervisor and chairperson Ivo Bouwmans. Since the day I enrolled at the TU Delft, you have been present and always willing to help. Thank you for all the precious suggestions and support.

Additionally, I would like to thank my family for their love and for always being by my side. Even if we have been separated by distance for a long time, I have never felt you closer to me than I do today.

Lastly, a special thank you goes to all my friends. Thank you for sharing amazing vibes and for always being there when I needed you most.

I want to dedicate this work to the Lagorai mountain range. The chain is depicted in the cover image of this thesis. It is very close to my heart because this is where I spent my childhood. A few years ago, strong wind events destroyed a large part of the forest located at the foot of the Lagorai chain. Scientists believe these strong winds are a response to changes in the climate caused by anthropogenic drivers. I hope that the insights that emerged from this work will take us one step closer to sustainable growth and help prevent the likelihood of such events in the future.

Enjoy reading!

V.A. Mengher
Delft, November 2020

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Executive Summary

Industrial location decisions are complex because they require the consideration of a wide range of factors. These factors are multidisciplinary, and often the criticality they pose on siting problems is not clear and agreed. They span in a spectrum of various disciplines, ranging from geography, history and social sciences to economics, physics and mathematics. As such, the literature results overpopulated of factors, and a common and agreed-upon definition is missing. The result is that scholars apply complex numerical methods for solving siting problems without a clear understanding of how factors influence specific location problems. To bridge this knowledge gap, the historical evolution of location theory is investigated. The intent is to shed light on the location determinants of a targeted location problem, the Energy-Intensive industry (EII) location problem. The result is a clear and documented classifications of location factors that are critical when making decisions regarding the siting of EIIs.

Driven by the intention of supporting location decision-making in the context of the present energy transition, the research investigates the effects of how shifting from traditional fossil fuels to renewable power capacities will influence the economic suitability of sites of clusters in the EU. To answer this question, two local industry clusters in Europe are identified, selected and used as test cases for analysis. These are the Northern Italy Po Delta cluster and Western Germany's Rhine-Ruhr cluster. Their internal structure is composed of specific industry sub-sectors, namely cement, steel and chemicals.

Since the energy transition motivates this research, the two clusters are projected on energy directions of change that enable cluster modernization. These directions of change are based on triangulation of findings emerging from the literature and interviewed experts. They are characterized by various transition technology options (TTOs) that are market-ready or close to market readiness. The projection of the clusters on the directions of change is seen as necessary because it enables to reason on industry changes triggered by energy transition drivers.

To offer an understanding of the suitability of European industry cluster locations to a changing energy medium, a method to conduct analysis is developed and applied. The necessity to develop the method is motivated by the lack of a methodology to serve as a commonly accepted framework for the analysis of industrial location problems in the context of energy transitions. The so-called cluster evaluation procedure evaluates the two clusters. The evaluation is conducted in three steps. The first step investigates the state-of-the-art of the cluster. The second step explores the future situation of the cluster (based on the previously mentioned energy directions of change). Finally, a comparison between state-of-the-art and expected future enables to reason on the suitability of the sites of the clusters to the expected future renewable environment.

The study focused extensively on the energy factor because it is the one undergoing transition. It was hypothesized to be the only variable of the location problem that is allowed to change. Interestingly, it was discovered that changes in the energy factor spill over and influence most of the remaining location factors. The findings emerging from the analysis can provide insight to investors and traders that are interested in siting and industry

modernization. The methodology developed to study EIIs could be extended to other sectors if one is committed to analysing the novel decision space and evaluating the factors at play on the novel location problem under investigation.
Two main findings emerged from performing the cluster evaluation procedure. Firstly, three possible options were highlighted when reasoning on the companies of both clusters as rational economic actors:

1. Invest in TTOs in this investment cycle and update business models accordingly;
2. Survive the shorth term and shut down existing production units at the end of their service lives (disrupting the local economy and integrated value chains);
3. Invest abroad and import commodities that are needed domestically (triggering further dependence on other nations).

Secondly, it was found that the present energy transition would have a severe impact on the suitability of sites of the investigated EII clusters in Europe. This happened because of the changes in the energy factor. This factor was hypothesized to be the only variable of the problem allowed to change. All other factors were seen as static variables. However, it was observed that spill overs emerging from changes in the energy factor significantly affect most of the remaining location factors. Specifically, changes in energy factor spill over to infrastructure that becomes essential. Examples of such infrastructure are the expansion of the national transmission and distribution networks, the expansion of existing interconnector capacity, the construction of energy storage systems, hydrogen production and transportation. Neglecting these requirements would imply to reason on an industry system that cannot function adequately in a transitioned world. Adding to this, further implications emerging from the spillovers of the energy factor concern the creation of added value carbon-neutral commodities that necessitate the existence of a market for successful commercialization. If the EU and the local governments fail in delivering dedicated and coordinated planning, investment support and appropriate policy, it becomes hard to expect that industry cluster in the EU will be able to face international competition. There is a strategic interest in ensuring that this happens. Current competition with China is unsustainable if the rules of the game do not change. However, the creation of added value commodities that internalize the cost of the transition and the design of a market for their commercialization changes the rules of the game and offer new business opportunities to the EII clusters that populate Europe. Future research efforts should internalize the dynamics that govern the location decision of EII clusters described in thesis and use them to better understand the effects of possible failures of intervention.

1 Introduction

Over the past several decades, the scientific community acknowledged that anthropogenic change is real and directly triggers changes in the climate. In response to this finding, many international organizations developed pathways that are intended to support and guide the global energy transformation (International Renewable Energy Agency (IRENA), 2018). In the same report, the general director of IRENA, Adnan Amin, affirms that the most challenging sector of intervention is the industrial sector. He argues that “Heavy industry as a whole has advanced far in increasing its use of renewables in 2017 or in the immediately preceding years; but electrification and the development of innovative transition enabling technological solutions (for example, for primary steel making and cement production) continue apace” (IRENA, 2018). However, energy intensive industries (EIIs) remain accountable for the majority of CO2 emitted by the whole industry sector (NATO, 2016). Following Amin’s line of reasoning, it appears critical to re-think the high energy demands of certain EII’s, the high carbon content of certain products, and the high emissions of certain processes, in ways that suit the energy transition. It is important to realize that this is the moment in history when the re-thinking must happen. Moreover, it is also important to deviate from well-known and consolidated old trajectories and propose novel practices that are able to trigger effective change. The guiding principle is that the emergence of new energy carriers and energy sources can be used to our own advantage as they offer new and unique possibilities for intervention. Interestingly, rather than focusing on the technical re-design of carriers and processes, it appears valuable to re-think and re-formulate the way in which heavy industrial facilities are located in terms of energy requirements. By evaluating the implications of transitioning from the traditional fossil fuels and nuclear based energy mix to the envisioned generation portfolio dominated by renewables and clean energy sources, it will be possible to offer strategic guidance to industries that are prone to such transition.

In technical terminology, the concept of plant location refers to the selection of a specific site for establishment of the physical unit of production process (Stearns, Carter, Reynolds, & Williams, 1995). Nowadays, decisions concerning the siting of such units are of high strategic relevance for corporations (Phelps & Wood, 2018). The reason being that the chosen location has direct impact on competitiveness, energy efficiency, operational costs and emissions (Siemens, 2020). To respect the complexity of the industrial location problem, a set of very sophisticated skills, high level of knowledge and interdisciplinary expertise are required. In the domain of plant location selection, complexity is associated to the large population of factors that influence the location problem, and more specifically, to the knowledge required to interpret them. These factors span across various disciplines, from geography, history and social sciences to economics, physics and mathematics. Goiri, Le, Guitart et al. (2011) proposes proximity to population centers, proximity to powerplants, proximity to key network backbones, proximity to raw materials and social acceptance, as examples of factors that act as determinants in industrial location problems. Because of their importance and significance for the study at hand, chapter 2 investigates the factors and classifies them in groups of interest. Although these factors are found to be central in existing literature (see Table 1 in Section 2), the criticality they pose on siting problems generally does not find an agreed upon definition. Because of the multidisciplinary nature of location problems, it is important to identify the most salient factors to the specific case under investigation. For example, on the one hand, when focusing on heavy industries or data servers, it emerges that their location is closely related to where electric power is affordable and available (Goiri et al., 2011). On the other hand, when analyzing the textile industry, factors such as cheap labor cost and water availability dominate the decision space (Akinola, 1965). In the context of the 21st century, where rapid technological changes in various industry sectors can have extremely beneficial consequences on both society and climate, it is critical to re-think and re-design the way decisions regarding the siting of intensive energy users and large industrial pollutants are made.

Recent economic and geographic literature devote much emphasis on two closely correlated concepts, namely industry locations and industry clusters. Michael Porter, pioneer of cluster theory, bridges the two concepts by specifying that areas subject to agglomeration forces have the potential to become populated by clusters of agents (Porter, 1998). In addition, Brenner and Mühlig (2013) stress the correlation by showing that the success of a cluster lies in its self-reinforcement, which occurs only in the presence of positive local externalities. The authors also emphasize that the emergence of local clusters is possible only if relevant factors are present in a specific geographical area. Since location factors are by definition area specific, performing a cluster-based analysis makes it possible to bridge together locational consideration and their effects on specific clusters, thus on the areas where these clusters are located. As such, by analyzing Europe’s energy intensive users with a cluster-based mindset, it becomes possible to observe patterns of a larger population of industries and the areas they influence. This is valuable when considering that the energy transition is of a global character and does not make much sense to study it in isolation. By zooming into the various industry sub-sectors, it was found that cement, chemicals and steel manufacturing are accountable for the majority of carbon leakage and total power consumption among all other manufacturing industrial sub-sectors (NATO, 2016). As such, rather than focusing on the impact of the transition on specific industry facilities, it is of value to define an industry cluster composed of these large industrial pollutants and intensive energy users. The cluster takes the name of EII cluster or heavy industry cluster and is inspired to the commonly agreed European definition[1]. This observation enables to study the collective impact of all sub-sectors of interest on the energy transition. This is performed by investigating the cluster’s adaptability potential to energy transition requirements, which allows to formulate propositions that serve as practical recommendations for the relevant stakeholders. These recommendations reflect the impact that the changing nature of energy supply and the adoption of related novel transition technology options (TTOs) will have on the defined heavy industry cluster.

Reviewing the literature pointed to the existence of a gap in the context of industrial facilities siting and their energy interdependencies. It has emerged that modelers propose increasingly sophisticated tools for optimizing the placement of various energy facilities while unaware of the industrial needs that are closely linked to them (Fairley, 2017). As described, this is partly motivated by the absence of a commonly agreed definition of factors and the criticality they pose on siting problems. This research attempts to support contemporary location decisions by

[1] The Masterplan for a Competitive Transformation of EU Energy-Intensive Industries enabling a climate neutral, circular economy by 2050. The document is cited throughout the thesis as (EU Comission, 2019).

embedding in the location decision-making problem both industrial and energy requirements. This practice reduces the risk of wasting development resources as it considers cross-industry clusters of agents and the important linkages between them (Doeringer & Terkla, 1995). Location decision processes will result restructured in ways that enable practitioners to make choices that ensure productivity, effectiveness and efficiency for future operations while modernizing and reducing their footprint on the climate. To cope with the complexity evoked by the shift towards a complete electrification of loads, and the various technologies that are needed for adequate system functioning, a descriptive method for site and cluster evaluation is develop. As such, chapter 4 and 5 serve as test cases, which investigate the transition potential of two different heavy industry clusters in the EU. By reasoning logically on the steps taken and on the findings emerging from the two test cases, it is possible to develop a methodology to perform analysis on EII clusters in the transition context. Such methodology is proposed as a novel evaluation procedure that offers understanding on the suitability of EII clusters to a medium that is transitioning. From a practical perspective, the cluster evaluation procedure enables practitioners to understand whether an existing industry cluster is well positioned for a renewable future or not. Specifically, the developed procedure enables to identify changes that sites and clusters will undergo through time. As such, it becomes possible to a) reason on changes in economic activity of specific geographic areas; b) formulate targeted policy which can increase or decrease the attractiveness to invest in certain areas; c) reflect how renewable energy (RE) influences energy costs and therefore how it will impact the economic suitability of certain areas, d) identify the critical components that are essential for cleaner industry.

1.1 Research Objective & Emerging Research Questions

This work aims to identify how industry clusters are going to be influenced by an ever-changing energy medium. The added value lies in the ability to evaluate how the increasing share of RE will impact current industry site locations and the cluster of industries that populate these sites. This is performed by assessing how well selected industry clusters in Europe are suited to renewables vis-à-vis fossil fuels. In fact, it is logical to expect that the geographic distribution of certain industry clusters (i.e. EII cluster) may experience variations in response to an increased availability of RE capacities. This information is quantified by evaluating, for a specific cluster type, its transition potential. In other words, the changes that a cluster would experience if it chose to adopt novel transition technology options which enable to utilize at best the expected larger shares of RE capacities. To this end, an evaluation procedure that supports and guides organizations when facing locational choices is developed and applied. The evaluation procedure captures the methodology developed in the thesis and it could be applied in future locational decision-making analyses. It enables to predict the extent to which an industry cluster and the area it influences are suited for the present energy transition. This information can guide corporations when investigating future-proof siting choices. The rationale being that, by applying the proposed methodology, the firm will be able to secure its levels of production, efficiency and effectiveness subsequent to a location choice. From the research objective, the main research question is formulated:

“How will the energy transition influence the economic suitability of sites of selected industrial clusters in the EU?”

In order to answer the main research question, it is decomposed into several sub-questions.

1 "How do industries decide on siting and why is it so?

2 "What are the current Energy-Intensive industry clusters in Europe and how to modernize them?"

3 "How to analyse industry clusters that are facing contemporary transition siting choices?".

4 "What does the analysis show in respect to cluster changes and their locations?".

1.2 Research Scope

It was decided to narrow down the design space by investigating the heavy industry siting factors with a special interest in energy interdependencies. The rationale is multifaced. First, heavy industry is the sector that demands most of the globally generated energy (NATO, 2016). Second, the energy transition and the means to facilitate it motivates this research. Finally, it is hypothesized that dispatching heavy industrial facilities in terms of aspects that are not limited to economic return on investment (i.e. changes in energy carriers and novel energy sources) may be of great advantage for the industrial sector as a whole.

The first and second sub-questions aim to identify the features that bound the decision space. This, in itself, constitutes a scoping function. The idea is that different industry sub-sectors are subject to different constraints. Examples are rules and regulations regarding the geographical location or special security and design measures required at the site (Boholm, 2013). By an accurate definition of these constraints, it becomes possible to understand and properly set the boundaries of the problem.

A decision to scope the research by investigating the decision-making aspects of plant location is made. The reason is that current research is mainly oriented towards demonstrating how heat and electric power demand can be supplied by renewable energy sources (Taibi, Gielen, & Bazilianc, 2012). The present study recognizes that large shares of renewables are changing the existing energy mix. However, this information is internalized by means of analyzing how the relative attractiveness of current industrial locations is likely to change in relation to an increased penetration of renewables.

Finally, the design space becomes narrower when understanding that integrating industries and sectors, which may have been fragmented, creates useful multisectoral and multiregional interdependencies (Albala-Bertrand, 2018). It is important to consider demand and supply dependence, that many industries have on a particular industry (i.e. energy dependence). The rationale is that by identifying these interdependencies, it becomes possible to study clusters of industries that are strategically interlinked. An example of this is heavy industry, which is composed of different industry sub-sectors. In an official report of the European Union, Hollanders (2020) defines cement manufacturing, upstream chemical production and upstream metal manufacturing as the sub-sectors that constitute the energy Intensive Industry cluster. This classification is recognized as a standard by the EU. For this reason, it will be employed throughout the thesis for data gathering and analysis purposes. Interestingly, these sub-sectors are affected by the similar patterns, namely intensive energy demand and large volumes of GHG emission. The added value of utilizing a cluster-based mindset lies in enabling to understand the collective behavior of such sub-sectors. In conclusion, the study focuses on heavy industry clusters and their interdependencies with the energy sector. However, future research should be aware of the importance of incorporating all relevant industry sub-sectors and the interdependencies between them.

1.3 Societal and academic relevance

The growing interest in location decisions is explained by the strategic implications deriving from this type of decisions. From an economic perspective, the implication relates to the new economic activity that an area will experience sub-sequent to location of industry. From a policy perspective, the implication lies in the ability to formulate targeted policies aimed at modifying (i.e. increasing or decreasing) the attractiveness to invest in these areas. In other words, by implementing the methodology proposed by this study, industrial policy development could rely on more structured information rather than on fragmented data while safeguarding the economic aspect of the problem.

Although research on location theory has gradually matured (Xu, Liu, Zhang, & Liu, 2018), this field of study remains affected by an elevated degree of data fragmentation. This situation is generated by the extreme diversity that characterizes different location problems. This is a gap that was found in the literature and is coped with by summarizing and categorizing locations factors. To offer unambiguous factors focus is on a specific location problem, the heavy industry location problem. The required information (i.e. location factors) are gathered by means of a literature review and are triangulated with the opinion of experts from interviews. This data gathering approach ensures validity of findings and enables to capture location factors that can be used for further analyses.

To offer understanding on the suitability of European industry cluster locations to a changing energy medium, a procedure to conduct analysis is developed and applied. The necessity to develop the analysis procedure is motivated by the lack of a methodology to serve as a commonly accepted framework for the analysis of industrial location problems in the context of energy transitions the analysis procedure is an academic contribution. In addition, the findings emerging when preforming the developed Cluster evaluation procedure offer insight to industrial practitioners as it enables them to envision the direction of change ahead of time. The practical implication is that long term investments will be safer, because affected by lower levels of risk and uncertainty. Other stakeholders, such as national governments, national TSO and the EU Commission are targets of the information emerging form the analysis.

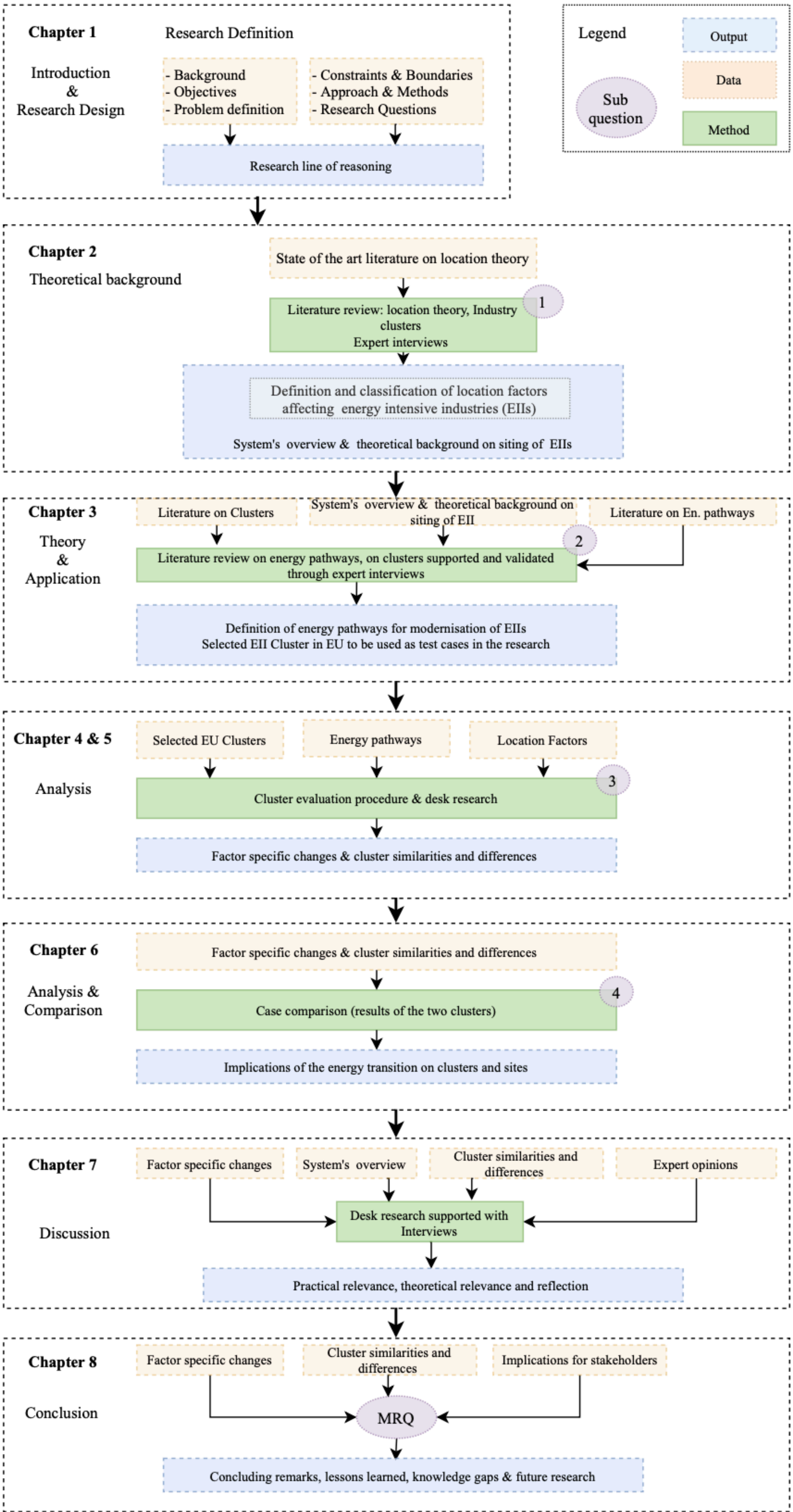
From a macro level perspective, the large share size of the system under study, the considerable number of actors involved, the variety of infrastructure involved and the interdependencies between them all, make it a suitable candidate to be analyzed from the unique perspective of CoSEM. To conclude, in line with the Master of Science on the complexity that affects the energy and technological innovation topics, the intent is to reduce the footprint that contemporary society has on Earth’s ecosystem while facilitating strategic decision-making in industrial siting processes. This is seen as an important milestone because it brings the literature one step closer to sustainable economic growth.

1.4 Research design

1.4.1 Research approach

The scientific method requires reproducibility of data in research (Dingham, 2010). Therefore it is important to present the lens through which the researcher views its work and makes decisions (Harrison, Birks, Franklin, & Mills, 2017). The ambition of this research approach is that of enabling a comparison between state-of-the-art and future of industry clusters in Europe. For this reason, a deductive research approach is applied. It consists of observing general information and phenomena and transform them into specific observations and conclusions that enable to build theory. (Hyde, 2000). In order to reason on possible future changes and to relate them to reality, the study is conducted as an exploratory study (Stebbins, 2011). The choice relates to the final research objective, that is to offer insight on how the energy transition could influence the competitiveness of targeted EII clusters located in the Europe Union. The research flow diagram depicted in Figure 1 shows the research activities that will be undertaken in order to successfully answer the research questions.

Figure 1 Research flow diagram



1.4.2 Theoretical framework

In order to conduct this study, a preliminary literature review aimed to set a theoretical background was a necessary step. To this end, a search methodology was developed. In order to gain a greater level of understanding and deeper knowledge on issues related to site selection, search for academic papers using strings of keywords and Boolean operators was conducted. The keywords used were: Facility; Industry; Cluster; Location; Energy; Factors; Siting; Problem; and Framework. Different combinations using the operators AND, OR with the keywords were performed. The strings that lead to identify most of the relevant articles were "Industrial facility" AND "siting", "Industrial location" AND "theory" OR "factors". From a total of 78 papers that treat the topic under study a selection process was initiated. This was based on the evaluation of each paper's abstract, which allowed to narrow the literature down to 44 relevant academic articles. A further sieving process was performed by carefully analysing the remaining articles. The result is a narrower literature space that enables a clear understanding of the evolution that characterized industrial facility siting practices throughout the past century. Table 1 presents an overview of the reviewed literature and its value.

Table 1 Preliminary reviewed literature and its value

Authors(s)	Title	Year	Value
Skibin, D.	Siting of Industrial zones near cities	1975	Theoretical treatment of industrial siting problem
Smith, A.	A Theoretical Framework for Geographical Studies of Industrial Location	2017	Simplifying the location problem to fundamentals
Crum, R.	Defining Key Siting Criteria Will Lead to a Perfect Location Match.	2020	Guidance for establishing key siting criteria; Information on critical factors
Terouhid, S. A., Ries, R., & Mirhadi Fard, M.	Towards Sustainable Facility Location: a literature review	2012	Sustainability requirements for location selection
McCann, P., & Sheppard, S.	The rise, fall and rise again of industrial location theory	2003	Need to restructure traditional location models
Owens, S.	Siting, sustainable development and social priorities	2004	Conflicts over siting: national need vs local interest
Maniezzo, V., Mendes, I., & Paruccini, M.	Decision support for siting problems	1998	Detailed information on decision support systems
Badri, M. A.	Dimensions of Industrial Location Factors: Review and Exploration	2007	Classification of factors
Gupta, A. K., Suresh, I., Misra, J., & Yunus, M.	Erratum: Environmental risk mapping approach	2002	Linkage between sustainable and eeconomic development
Briassoulis, H.	Environmental criteria in industrial facility siting decisions: An analysis	1995	Overview of factors
Rahmat, Z. G., Niri, M. V., Alavi, N.	Landfill site selection using GIS and AHP: a case study: Behbahan, Iran	2017	Possible method to determine suitable site
Ohri, A., Singh, P. K.	Landfill Site Selection Using Site Sensitivity Index A Case Study of Varanasi City in India	2009	Possible method to determine suitable site; Information on critical factors

Negi, P., & Jain, K.	Spatial multicriteria analysis for siting groundwater polluting industries	2008	Multicriteria method can be adapted to determine the criticality of factors
Ohri, A., & Singh, P. K.	Spatial Multi Criteria Analysis for Siting Industries	2010	Guidance for establishing key siting criteria; Information on critical factors
Rock, O., Nwankwo G. I., Abraham E.	Sustainability analysis and characterization for industrial siting	2018	Environmental factors
Feser, E. J., & Bergman, E. M.	National industry cluster templates: A framework for applied regional cluster analysis	2000	Linkages in demand of good and services among industries

Location of warehouses, manufacturing sites and distribution centers are classical examples of location decision-making problems (Skibin, 1975). These problems are generally approached by applying location theory concepts (Smith, 2017). This field of research emerged in 1909 when Alfred Weber published a book titled “Theory of the Location of Industries” (Terouhid, Ries, & Mirhadi Fard, 2012). This research set the foundation for both descriptive and normative location decision theories. Both branches of location decision theory are still in place today since they serve different objectives. Normative theories set up mathematical decision-making models (McCann & Sheppard, 2003) while descriptive theories focus on spatial socio-economic patterns that follow each placement (Owens, 2004).

Despite the differences, both methodologies serve the purpose of identifying specific locations for a given type of facility within a certain area. Generally, within the area of interest, there are many locations that can host the same type of facility. The desirability of a location relative to another appears to be governed by a multitude of diverse factors (Maniezzo, Mendes, & Paruccini, 1998). Throughout the reviewed literature only two academic articles that have recognized the importance of these factors were found. Badri (2007) develops a process that leads to the definition of 14 sets of critical factors in industrial siting problems. The critical factors are classified in two larger groups, namely general location factors and international location factors. The general location factors are: transportation; labour; raw materials; markets; industrial sites; utilities; government attitude; tax structure; climate and community. The international location factors are: policy situation of foreign country; global competition and survival; government regulation and economic factors. Terouhid et al., (2012) reviews critical factors in the attempt to understand if current research is aware of the importance of including sustainability requirements when performing a location decision problem. The study shows that location theory originally focused on factors that are of a purely economic nature and that it evolved by embedding social and environmental factors in location decision problems. The two reviews agree on the fact that current location decision-making models need to be restructured in order to enable sustainable economic growth. The reason is that sustainable development goes hand in hand with economic development (Gupta, Suresh, Misra, & Yunus, 2002), which can be linked to the effects (i.e. positive and negative) on society’s welfare deriving from the transition of EIIs.

Most of the reviewed articles are case studies that offer very specific solutions to specific location problems. Although all authors use the concept of critical factors when determining suitable locations, it appears unclear how these factors are determined and chosen (Briassoulis, 1995). A common pattern in processing the gathered data is the use of multi-criteria decision analysis (MCDA) and geographic information system (GIS) techniques to solve the location decision problem. Examples of this practice are performed by Rahmat et al., (2017), Ohri and Singh (2009) and Negi and Jain (2008). Ohri and Singh (2010) and Negi et al., (2008) argue that in order to respect the complexity of the location problem MCDA is a good candidate. The rationale is that it enables to express the importance of a factor relative to another factor by associating weights to each of the them and subsequently ranking them. This is important because it enables more effective estimations, thus, more accurate determination of suitable locations in terms of the criticality that factors play. Finally, GIS serves the function of storing data and representing them as thematic maps that facilitate interpretation of results (Onwe, 2018).

In a nutshell, although the reviewed literature agrees on the importance of identifying critical factors, a clear methodology for their definition and use is missing. It seems that current approaches employed in locational analyses, don't consider the grand scheme necessities imposed by the contemporary historic context. In other words, the implications and spill overs that the energy factor has on the overall location decision, on the other factors at play and on the Earth's climate system. As such, it can be argued that employing advanced methods, such as GIS and MCDA, won't necessarily allow to face this complex problem. The rationale being that, the increasing share of renewable energy capacities and the availability of transition technology options (TTOs) for their utilization, imply rethinking of how the energy factor influences siting decision making. In light of these considerations, it emerges that more structuredness and guidance are needed when defining and utilizing factors for specific siting problems. The reason being that every type of facility is subject to certain critical factors that dominate the overall location decision. Perfect matches, intended as means that enable the emergence of a future proof industrial ecosystem, are foreseen only when strategic combination of the requirements of the considered types industry sub-sectors is guaranteed. Surprisingly, the reviewed literature does not internalize the interdependencies between energy generating infrastructures and EII sites as critical factors of the siting problem. With the intent of enriching state-of-the-art literature, strategic clusters of industries (Feser & Bergman, 2000) are defined and used as test cases. The purpose is that of demonstrating that by blending traditional location theory approaches, it becomes possible to anticipate how renewables will influence existing site locations and the clusters of industries that populate them.

The proposed framework, which takes the form of a procedure to be applied when conducting locational analyses in transition contexts, is a necessary step for answering the main research question. It combines insights from the literature and from the real-life industrial medium. Its purpose is that of enabling to reason on changes that will affect the locations of the industry cluster under study. As such, critical factors are identified by means of a literature review and by interviewing experts in the field. The literature review serves as a first step for identifying the critical factors, which in a second phase are evaluated by experts. The experts are asked to quantify the role that factors play now and the role that factors will play in the future. For validation purposes experts are also asked to share their thoughts on other factors or aspects that they consider critical for the siting problem. Finally, a critical comparison between the two sets of results allows to reason on the changes that clusters, and sites will experience because of the transition.

1.4.3 Research Methods

1.4.3.1 Theoretical background methods (sub-questions 1 & 2)

Determining how RE will change the fortunes of existing heavy industry clusters requires knowledge on the state-of-the-art of such clusters, particularly on their geographical distribution and on the factors that most influence them. To set a common theoretical background, a theory sub-question is raised. This sub-question aims to explain the status of current European site locations and why they are there. As shown by economic (Clark, Wilson, & Bradley, 1969; Carod, 2005; Goiri et al., 2011), geographic (McCann & Sheppard, 2003; Smith, 2017) and location theory literature (Briassoulis, 1995; Maniezzo et al., 1998; Negi & Jain, 2008; Phelps & Wood, 2018), industrial location decision-making is not new, and in many instances, it is a proven practice for locating industrial facilities worldwide. Given that there is sufficient historical and research data in scientific literature to answer the proposed question, the better-suited method is to conduct a state-of-the-art literature review on the factors influencing the location problem. Reviewing the literature provides with context information. Besides, it serves the purpose of coping with factor ambiguity, a feature that affects current siting practices. This aspect is coped with by categorising the location factors that populate location theory literature and by noting the emphasis that authors place on specific factors. To ensure reproducibility of results and of factors, specific indicators are employed when performing cluster evaluation. Eventually, long response times to incorporate new findings into literature's main body of knowledge may occur. This limitation is coped with by interviewing experts from academia and from the industrial operational environment. Semi-structured interviews are conducted for data gathering and validation purposes. Refer to section 1.4.3.3 for a detailed description of the expert interview process and its value.

The contemporary energy transition motivates the emergence of the main research question. For this reason, the intent is to know about industrial siting but with a particular focus on energy interdependencies. To explore these interdependencies, sub-question 2 suggests collecting and elaborate on critical research data. To answer this research, question a series of activities are initiated. In the first place, a literature review sheds light on the transition technology options (TTOs) that could decarbonize and electrify existing fossil fuel dependent manufacturing processes. Secondly, information on the state-of-the-art of industry clusters in Europe is collected through desk research and a further literature review. Finally, the two sets of information are merged together. This is done by projecting the sub-sectors of the identified EII clusters onto the TTOs. Because of the novelty of this research practice the opinion of experts was essential. Refer to section 1.4.3.3 for a detailed description of the expert interview process and its value.

1.4.3.2 Method to evaluate EII clusters in an energy transition context (sub-questions 3 & 4)

So far, the focus was on answering specific theory sub-questions aimed at generating the context, tools and purpose of the intervention. Since the intent of this study is to explore how the energy transition will impact selected industry clusters and respective sites, it is decided to shift from the mainstream usage of MCDA and GIS methods, and develop a method based on the functioning of the investigated system. This method is referred to as 'cluster evaluation procedure' and is a deduction-based method. In short, it consists of a series of steps that serve the purpose of assessing and evaluating the EII clusters. Compared to state-of-the-art methods, it is a valuable alternative because it allows pushing the limits of what can be said on the changing preferences regarding the siting of EIIs. As a matter of fact, current research is much devoted towards demonstrating how to transition or how to stimulate the transition (Hollanders, 2020). On the contrary, by applying the developed cluster evaluation procedure, it becomes possible to investigate the changes and effects of the transition on the industry clusters. Moreover, applying deductive and logical reasoning enables us to cope with the often-unstructured way that characterizes many of the reviewed locational analyses.

In order to evaluate the future of clusters and respective sites, the extent to which the transition will impact them must be evaluated. To do so, the findings on critical factors, TTOs, clusters typology and cluster location are merged. Practically, in accordance with the opinion of experts, each cluster type is projected on logical directions of change. In other words, clusters are associated with the TTOs that apply to them. This allows to reason on the system-level changes that EII clusters would experience when opting to transition. The subsequent step consists of applying the developed cluster evaluation procedure. The procedure focuses on changes in the energy factor[2] and its spill overs on the remaining location factors. The elegancy is that all factors are kept constant except one, the energy factor. This makes things manageable and enables us to identify and reason on energy transition implications. The output consists of a critical comparison between the present and future situation of the clusters in terms of the location factors. As such, it enables to appreciate how the energy transition will change the importance of location factors, thus influence the suitability of clusters and sites to a more renewable future. The cluster evaluation procedure is supported by observations that emerge from expert interviews. Refer to section 1.4.3.3 for a detailed description of the expert interview process and its value.

Validating the time dimension of the problem poses limitations. It is very complicated to cope with the uncertainty which relates to the future developments that this study explores. To cope with this uncertainty, one must realize that it is not actually possible to prove with certainty what will happen in 2050. In order to demonstrate the resilient nature of the proposed methodology, it is important to realize that if factors and input variables are correct, then reasoning logically will lead to logical results. By doing so, based on the expected degree of change, it is possible to push the limits on what can be said on the future of industry sites. Cases are analysed with the intent of identifying how the changing nature of energy supply will influence current heavy industry sites. The method consists in a critical comparison between the current relative attractiveness of a site and its future (i.e. increased or decreased) relative attractiveness.

1.4.3.3 The role of expert interviews in the research

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[2] The initial idea was to apply MCDA methods in order to evaluate the relative importance of the energy factor. However, conducting interviews, pointed to the fact that the increasing importance of the energy factor is already being internalized in the industrial operational environment. Therefore, it was decided to leave the application of the MCDA to for further research. The expectation is that it is possible to empirically demonstrate the relative importance of the energy factor when compared to the remaining traditional siting factors.

Because of the novelty of the proposed research, expert interviews play a critical and enabling role in this study. Semi-structured interviews are conducted for data gathering, projection and validation purposes. In a formal phone call or video meeting, experts are walked through the state-of-the-art and the future envisioned situation. The population of interviewees is composed of experts from academia with knowledge on energy transitions, energy systems and industry issues. The second category of experts is composed of industrial practitioners that hold highly ranked positions in cement, steel and chemical companies. Finally, because of the necessity of technological developments, transmission and distribution systems, electricity price issues and RE technology integration, the Italian TSO is interviewed. Table 2 offers information on the interviewees, their role in the organization and the topics that have been discussed. The transcripts of the interviews are reported in the appendix according to the interview ID. To ensure a win-win situation and to avoid misinterpretation, the transcripts have been checked by the interviewees before integration in the research. The audio recording are saved on the personal computer of the researcher and will be deleted after the defence of this thesis.

Table 2 List of interviews and focal points of discussion

ID	Organization	Role of expert	Focal points of discussion
Germany 1	Heidelberg Cement	Director EU public affairs & investor relations	Location factors, energy changes (mainly for cement), projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Germany 2	Wuppertal Institute for Climate, Environment and Energy	PhD research fellow Division Future Energy and Industry Systems	Location factors, energy changes (chemicals, cement and steel), projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Germany 3	Technische Universität Braunschweig	PhD research fellow on grid stability and Pumped Hydro Energy Utilization and Storage	Location factors, energy changes (chemicals, cement and steel), projection of factors, TTOs potential, spillovers, costs, storage, future RE capacity
Italy 1	Università degli Studi di Trento	University professor of Electric energy systems	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Italy 2	Università di Padova	University professor of technique & management of industry systems	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Italy 3	TERNA (Italian TSO)	Real time dispatch & development of energy pathways for the Ministry of Economic Development	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity

Italy 4	Zintek S.r.l. Porto Marghera, Venezia	CEO	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Italy 5	Eurocoperture S.r.l. Metalwork in Italy	CEO	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Italy 6	AssoEnergia and Confindustria	Technical specialist	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity
Italy 7	Eureka energy efficiency in industry S.r.l.	Director general	Location factors, energy changes, projection of factors, TTOs potential, spillovers, costs, government responsibilities, future RE capacity

In chapter 2, the location determinants of EIIs are investigated through a literature review. Besides, factors are associated with indicators that enable unambiguous quantitative measurements. To ensure the validity of the selected factors and of the indicators, experts from the academia and the industrial operational environment are consulted. In the first place, they are asked whether they recognize the selected factors and indicators as critical for the siting of EIIs. Besides, they are also asked to share their thoughts on other factors and indicators which may have not been included in the selection process by the author. Finally, experts are asked to quantify the relative importance of the various factors at play on the location problem under study. This proved to be valuable because it enabled to work on data that was not yet incorporated into literature's main body of knowledge.

Chapter 3 explores existing EII clusters in Europe and projects them on logical energy directions of change. The projection is performed by associating the clusters to transition technology options (TTOs) which enable for cluster modernization. Because of the novelty of this research field, the opinion of experts is essential. At this stage experts are introduced to various TTOs and are asked whether they consider these technologies to have the potential to be adopted by industry in the real world. The results are analysed to find recurring themes, capture key takeaways and to create credible, logical directions of change.

Chapter 4 and 5 use the information gathered in the previous two chapters to evaluate two specific EII clusters. To this end, a method to conduct analysis is developed and applied. Generally, tools that are not internationally recognized as standards may be affected by limitations. To cope with such limitations and to ensure the validity of the findings, experts are consulted. The methodology to conduct the interviews starts by introducing the state-of-the-art of the clusters. It continues by foretelling the expectations that arise when considering a certain projection (i.e. cluster with associated TTOs from chapter 3) and verifying whether the interviewees confirm, deny or have a different perspective. Specifically, the experts share considerations of factor projections into the future, the implication for the future of cluster, the implication for the future of industry sites and the spillovers emerging because of changes in the projected energy factor. In summary, experts are walked through the state-of-the-art and through the future envisioned situation. The result is a credible and validated storyline that shows how changes in the nature of energy supply will influence the economic suitability of sites of clusters of EIIs in Europe. Finally, in the remaining chapters, the opinion of experts is used for alignment purposes and to verify expectations and findings.

2 The location determinants of energy intensive industry

The present chapter investigates the considerations that industrial practitioners face when choosing sites for future industrial activities. By investigating the historical evolution of location theory, it is possible to demonstrate that location choices are based on specific siting factors. These factors are largely influenced by the historical context that motivated scholars to conduct locational analyses. As such, early location theories focused on agriculture, later they experienced a shift to industry, and now they are broadening their spectrum of application to specific industry sub-sectors. This is seen as a driver, that transformed a situation governed by the presence of few factors into a novel decision space governed by a multitude of diverse factors. In order to offer a clear and structured overview, the various factors are subdivided into specific groups of interest. In response to the first sub-question, these considerations enable us to understand how industries decide on siting and what are the practices that shaped these decision processes. Moreover, the final section offers arguments that these industries should integrate when evaluating siting choices in the context of a more renewable future.

2.1 Historic evolution of location theory and traditional siting factors

The 19th century's methodology of economic analysis consisted in investigating the nature and characteristics of various production processes. This practice shaped the classical questions that practitioners ask themselves when facing siting efforts. At the time, scholars were investigating the ways in which input variables were transformed into physical commodities. As such, understanding of the determining features of the transformation process was the priority. To study the transformation process, early location works attempted to investigate the interdependencies between production and geography. At the time, geography was conceptualized in terms of land and land use. As a result, analyses were based on practices aimed at investigating the function that land as an input variable plays in determining the characteristics of the transformation process (McCann & Sheppard, 2003).

The general approaches, employed in classical analyses, largely depended on the historical context in which they were developed. Although the interest on spatial concentration does not change much through time, the areas of interest do change remarkably. Johann Heinrich von Thünen, a pioneer of location theory, described agricultural location and its implications (see The Isolated State, 1826). In short, his analysis showed that accessibility to the market (i.e. village) has the potential to create a system of agricultural land use. Thünen envisioned a single market surrounded by homogeneous farm areas where farmers grow their crops. The critical factor in this location problem is set by transportation costs. When transportation cost is low, the location rent is high, and vice versa. Two interesting concepts emerge from this work. First, a continuum rent gradient along which the further the distance from the market, the lower the location rent becomes. Second, the gradient is influenced by the type of crop. This is addressed by analyzing the differences between the locations of extensive and intensive agriculture in relation to the same market. When compared to extensive agriculture, intensive agriculture presents steeper gradients and will locate closer to the market. In other words, crops that are perishable (i.e. vegetables) must be close to the market, thus they will have a steep gradient. Crops that are durable (i.e. grain) can be located further away from the market, thus they will have a less steep gradient. Even though these considerations may seem straightforward, it must be realized that they date back two hundred years and their formulation required in depth analysis. Despite the attention given to the agricultural topic by ancient civilizations as well as the Greeks and the Romans, Thünen is the first who starts thinking in terms of demand, supply and their implications.

Due to the historic relevance of agriculture, almost one hundred years had to pass before scholars shifted the area of interest. The industrial revolution transformed economies that had been based on agriculture into novel economies based on large-scale industry, mechanized manufacturing and the manufacturing system (Augustyn, Bauer, & Duignan, 2019). Novel power sources, novel machineries and innovative ways of organizing work made industries more productive and efficient. In the beginning of the 20th century, the German location economist Alfred Weber writes a book in which he formulates a theory of industrial location (see Theory of the Location of Industries, 1909). The core assumption is that firms will choose a location in view of minimizing their total costs. Weber treats the location problem as a triangulation problem. The optimal location for the production of commodities emerges by constructing a triangle that integrates the geographic and economic aspects of the problem. The vertices of the triangle refer to the location of the market and to that of raw material sources. The kernel objective of the theory is to determine the least-cost production location within the triangle. This is done by analyzing the total transportation costs of raw materials to the production site, and from there to the market. Even though a century has passed from the emergence of Thünen's theory, the critical factors in Weber's location problem remain very much related to transportation costs and its determinants. An interesting difference between the two is that, once a least-transport-cost location is determined, Weber shifts the focus of attention to the understanding of labor cost and the role of agglomeration economies. In a nutshell, his theory implies an optimal consideration of cost factors but with a particular interest in transportation. The rationale being that transportation is the building block of the model and other factors play minor adjustments effects.

2.2 Implications for intensive energy users

Thünen and Weber's theorization is very useful for understanding the location trends of heavy industries, particularly from the industrial revolution until the mid-twentieth century. Insights from their work allows to understand that activities with intensive use of raw materials are inclined to locate near supply sources. For instance, while steel manufacturing factories will locate near energy sources (i.e. electricity and heat) or port sites, activities depending on easily retrievable raw materials, such as water, will locate closer to markets. This is again expressed by means of a gradient that quantifies the information. The weight of input products is divided by the weight of the respective output product. This value takes the name of material index and indicates whether the location should be toward the market or closer to material sources. When the index is greater than one, the location tends to be closer to the material source. When the index is smaller than one, the location will be closer to the market. The principles deriving from Thünen's and Weber's early theories result applicable on contemporary industries that deal with very high material indexes. Yet, recent developments in manufacturing, globalized supply chains, novel economic sectors and the reduction of transportation costs have largely influenced locational behaviour practices.

2.3 From transportation cost to a broader range of siting factors

To internalize the issues triggered by the emergence of a more complex and interdependent industrial reality, Alfred Marshall analyzes the phenomenon of industrial concentration and its persistence (see Principles of Economics, 1920). His work provides insight on the underlying features that enable industry concentration. The first point made is that industries will choose areas that offer critical resources for the firm's activity. From this perspective, localization is governed by the presence of physical factors in a specific area. The second point relates to the social forces acting on industry concertation. In this view, the availability of skilled workman is critical for industrial development. Marshall's concludes by stressing the importance of firm's cooperation in fulfilling the production process. This work set the foundations for understanding the effects of agglomeration economies. In other words, the changes in industrial organization that lead to the formation of industrial districts. Contemporary research refers to such agglomerated districts as industry clusters (Porter, 1990, 1998), which are geographical areas that hold concentration of specific types of industry firms. Yet, industry concentration in regions remains dominated by the critical factors (i.e. resources and competences) which act as determinants in the context of infrastructure siting.

These three early manuscripts have been introduced because they have largely contributed to structuring contemporary thinking on location theory. It is interesting to observe the path dependent trajectory that location theory experienced from its emergence until the present moment, in other words, through its evolution. Despite minor features, the three research efforts build one on another. Thünen is the first who understands that the presence of a market has to potential to create different systems that will supply that market. In his context, a system of agricultural land use that is mainly influenced by aspects related to transportation. Weber builds on his predecessor's work and shifts the focus to the industrial sector. He stresses that firms will decide on where to locate based on cost minimization routines. By reasoning on industrial locations, their proximity to raw material sources and to the market, the conclusion that transportation costs dominate the location problem results confirmed. It is Marshall that broadens the scope of location analysis by introducing a much larger set of factors that influence location choices. He builds on previous work by confirming the importance of raw materials availability and by highlighting the relevance that availability of skilled workman and the degree of cooperation between firms play on location problems. Furthermore, it can be noted that the three classical scholars identify critical factors that dominate location problems. The first factor to be noted was the cost of transportation. Subsequently, availability of raw materials and proximity to market highlighted the significance played by transportation costs. Finally, work force and firm's interdependencies have been intergraded into location analyses.

An extensive number of neoclassical publications followed these early findings. The methodology applied by neoclassical scholars diverges from the classical one, but at the same time is rooted into it[3]. Throughout the late 20th century, the emergence of complex and interdepend supply chains, resulted in a renewed interest in identifying the factors that influence location choices. Just as in the early works, contemporary practices for location selection are seeking to establish what are the critical factors that influence location problems.

In the meantime, a broader set of industrial sectors entered the locational debate. These considerations set the foundations for a much broader investigation of the factors that are important when facing siting choices. As a fact, contemporary literature provides an enormous number of studies that aim to identify factors that are important for very specific siting problems. In addition, these studies are performed on the basis of different concepts and assumptions. Thus, it becomes challenging to grasp a clear picture of what factors influence what problems and how. On the basis of the previous findings, it appears that this research pathway has transformed a situation governed by the presence of very few factors (i.e. transportation, workforce and degree of firm cooperation) into a novel decision space governed by a multitude of factors that are extremely diverse in nature. As such, contemporary literature is populated by a considerable number of factors that are industry and problem specific. Concomitantly, this research pathway left several gaps with respect to the criticality that different factors play on different siting problems, and on how contemporary scholars, choose factors for performing locational analyses. To cope with these issues, it appears valuable to review contemporary literature on location theory and categorize factors into specific group of interest. This enables a clear and structured definition of groups of factors that act as determinants for location determination, for industrial concentration, thus for the emergence of industry clusters.

2.4 Contemporary siting factors

The chapter continues by reviewing the late 20th century literature on industrial location theory. The purpose is that of offering an overview of the various factors that are taken in account by contemporary scholars in their location problem formulations. Since this research aims to determine how the increasing share of renewable energy (RE) will impact current industrial site locations, a choice on what industrial sectors and what factors to consider was made. The choice internalizes that industrial sectors with intensive use of energy capacities are going to be the most affected by the transition in the energy system. As such, the factors that are captured in the review concern the sub-sectors that compose the heavy industry cluster. Examples of these sub-sectors are steel and iron manufacturing, chemical refineries, cement production and hydroelectric power generation (Duignan, 2020; Hollanders, 2020; Hollanders & Merkelbach, 2019). It will be shown that, despite the fact that the presence of more factors is increasing the complexity of siting problems, it is possible to cope with it by narrowing the factors down

[3] The methodological approach utilized in classical location theory diverges significantly when compared to the neoclassical principles of economics. The rationale is that novel economic concepts such as factor substitution or marginal productivity conditions, were themselves just being investigated within late nineteenth century economics (Blaug & Teneur, 1968). Consequently, classical location theory assumes a neoclassical character only during the second half of the twentieth century. It is the combined effort of Alonso (1964), Muth (1969), Mills (1970) and Evans (1975) that enriches the state of the art of economic theory by integrating the notion of mutual factor substitutability.

into specific groups of interest. A judgmental process led to define two major groups of interest, namely factors affecting spatial distribution and factors affecting industrial concentration. In addition, it was found that the factors affecting industrial concentration are also critical for the emergence of industry clusters. To conclude, the end objective is that of offering a more structured definition of siting factors and the indicators that are used for their definition. This information aims to ensure clearly documented decisions and will be utilized in the novel cluster evaluation procedure offered in chapters 4 and 5.

2.4.1 Search Methodology

Contemporary literature provides various considerations on the mechanisms that led to the selection of industrial locations. As introduced, the role played by location factors in such literature is dominant. When necessary and supportive factors are present in a certain area, the phenomena of agglomeration may manifest, thus leading to the emergence of local industrial clusters (Marshal, 1920; Brenner, 2004). Furthermore, the close relation between site selection routines and the conditions for industry clusters to emerge, allow to expect that the emergence of industry clusters will occur only if relevant location factors are sufficiently present in the area of interest (Brenner & Mühlig, 2013). As the intent is to be as general and insightful as possible, various bodies of literature are explored with the intent of capturing all potential location factors. These include economic literature, geographic literature, location theory literature, locational decision-making literature and the new economic geographic literature on agglomeration and clusters.

To identify potentially relevant papers among peer-reviewed articles, multiple online databases such as Google Scholar and Scopus were utilized. Various groups of papers belonging to the previously cited bodies of literature were retrieved using a search methodology.

The first group of papers was retrieved using the keywords: “industrial location” and “decision- making” resulting in 150 academic articles. Then the keyword “factor” scoped the papers down to 51 relevant articles.

The second group of papers was retrieved using the keywords: “location theory” and “industrial location” and “factor”. This pointed to 37 valuable documents.

A first analysis of the two groups of literature led to an additional search of keywords such as “agglomeration” and “industry cluster”. These topics belong to the new economic and geographic body of literature, which focuses on various patterns that led to the emergence of industry clusters. This body of literature is populated by an enormous number of specific analytical case studies that investigate the clustering phenomena via econometric approaches. To remain in line with the purpose of the present study, emphasis is given to the patterns of factors that enable agglomeration, thus creating the conditions for the clustering of industries.

Finally, by back-referencing citations in the gathered articles, the search results are improved. The retrieved documents are processed utilizing judgement. Since not all retrieved papers were reporting critical factors, it was decided to focus only on the papers that do. The objective is that of revealing the influential factors to consider when facing decisions concerning the location of energy intensive industrial facilities. This observation enabled to reduce the number articles from 103 to 31. After gathering detailed factors from each of the papers, it was found that they could be classified into distinct categories. Together, these categories define the critical factors of the industrial location problem.

The review includes Djwa (1960), Clark et al., (1969), Skibin (1975), Murray et al., (1980), Czamanski (1981), Blackley et al., (1986), Stafford (1985), Hansen (1986), Newman (1988), Badri et al., 1995), Briassoulis (1995), Stearns et al., (1995), McCann et al., (2003), Carod (2004), Badri (2007), Backhaus et al., (1988), Brenner et al., (2013), Chakravorty (2003), Ellison et al., (2010), Goiri, etal., (2011), Terouhid et al., (2012), An et al., (2014), Jirásková (2014), Gilbert (2016), Smith (2017), Takano et al., (2018), Missiaia (2019), Xu et al., (2018), Snieska et al., (2019), Musolino et al., (2020), Adler et al., (2020).

In conclusion, the search methodology pointed to the location literature that includes aspects related to location factors, decision-making, agglomeration and industry clusters.

2.4.2 Factors affecting spatial distribution

The availability of certain primary factors is seen as necessary condition for manufacturing industries to take place. These factors are transportation and raw materials, climate, the market, energy sources and the cost of knowledge. The factor capital cost (CAPEX) is also mentioned by various researchers but, because of its mobility, it won't be explicitly treated as a location determinant. The rationale being that modern industries are capital intensive and require huge investments, which generally take place in large metropolitan areas. Moreover, the presence of economies of scale in these metropolitan areas should enable fast returns of capital expenses. Assuming that a certain capital is available, is not an appropriate proxy to be used when advising where to locate an industry. It appears more valuable to internalize the fact that a certain capital is available and use this knowledge to make choices that enable large and secure returns. As a guiding point, this is where the other location factors come into play. For instance, Thünen would say "invest the capital where transport costs are minimized"; Weber would largely agree with Thünen; Marshall would say "Invest the capital in agglomerated districts". What this research says is to "Invest the capital in areas where there is foreseeable potential for energy transition initiatives". The remaining factors, when available, serve a screening function for the selection of geographic areas. The following is a brief description of the nature of these location factors. Most information and definitions are provided by the US Army engineering district on industrial location analysis (Ben-zvi, 1981). Through the description, italic characters refer to the indicators that serve for measuring factors.

MARKETS

The *presence of markets* and the *access* to them is seen as primary condition for manufacturing to take place (Djwa, 1960; Murray Jr. & Seneker II, 1980; McCann & Sheppard, 2003). Despite the absence of a unique definition of markets, the concentration of population, the availability of distribution systems and the concentration of industries in metropolitan areas, allow to refer to these *metropolitan areas* as market centers. To quantify and express the relative importance of the market factor when performing analysis, a proxy for market size is necessary. Sales volume is a good metric to express the market factor[4]. It is quantified by taking the number of units sold and multiplying by the profit per unit (i.e. EURO).

RAW MATERIALS & TRANSPORTATION

The *geographical distribution of raw mater*ials explains the spatial distribution of various industries. As pointed out by Thünen and Weber, industries that rely on raw material that lose weight in the process of production or materials that are perishable, will be located in the proximity of the raw materials sources. Moreover, *transportation of input* raw materials as well as well *transportation of produced commodities* is key for the success of manufacturing industries. For instance, evidence from practice shows that almost all transportation centers in the US are also hubs of manufacturing (Ben-zvi, 1981). To express the relative importance of the raw materials and transportation factor a cost proxy is defined (i.e. euro/tone of raw material & euro/km). The choice of these units is motivated by the opinion of experts. They argue that the availability of raw material in the present era is dictated by physical commodities traders and brokers. In addition, they confirm that transportation should always be expressed as a cost factor.

ENERGY SOURCES

In their various forms, energy sources vary in the degree of importance as a localization factor from industry to industry (Ben-zvi, 1981). Generally, most industries do not consider energy sources as a critical factor (Djwa, 1960). However, the sub-sectors that compose the heavy industry cluster tend to locate where an *abundant, secure and affordable supply of energy sources* is granted. An observation regarding energy sources as location factor emerges. This factor changes rapidly as the *cost of fuels* is influenced by a multitude of external parameters. In the context of the present energy transition, where traditional fossil fuels (i.e. coal, natural gas and oil) will be substituted by renewable energy sources, it is relevant to evaluate changes in the economic suitability of heavy industry clusters in the context of the envisioned transition. Chapters 3, 4 and 5 investigate this factor and its impact on the location decision of EII clusters.

COST OF KNOWLEDGE (LABOR WAGES)

Cost of knowledge as location factor refers to the *availability, productivity and cost of the needed workforce* (Hansen, 1986; Brenner & Mühlig, 2013). The basic considerations that define this factor lie in population size, age distribution and degree of mobility (Jirásková, 2014). Knowledge, intended as *skills possessed by the workforce*, is a function of the quality of education and the presence of technical training programs. To express this factor a suitable metric should measure the net cash flow (i.e. salary to employee) required to attract and maintain a competent workforce (i.e. Euro/month).

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[4] MIT Sloan Management Review – Market metrics retrieved at: https://sloanreview.mit.edu/article/should-you-use-market-share-as-a-metric/

CLIMATE

The wind and precipitation aspects of climate, but also the relative humidity, average temperatures of an area are important determinants of location selection. German economist Eriedrich List argues that climate may be the principal factor governing the location of industries. His theory states that the most significant effect of climate on industrial location is perhaps the fact that it has accounted for the present population distribution (Djwa, 1960). In the context of the energy transition, the *ways manufacturing industries influence the climate* as a whole is central. As such, the climate factor is expressed in terms of avoided GHG emissions (i.e. avoided tones of CO2 per year).

2.4.3 Factors affecting industrial concentration and cluster emergence

The forces that act on the location of industry are not constrained to the factors that have been just been introduced. When considering the concentration of industries in certain areas and the slow but steady shift of industry from an area to another, it is important to grasp the essence of what drives these mechanisms. To this end, Badri, (2007), Brenner & Mühlig (2013) and Gilbert (2016) offer considerations that are worth mentioning.

POLICY ENVIRONMENT

Government activity has become an important localization factor (Badri, 2007; Brenner & Mühlig, 2013; Gilbert, 2016). These activities should be conceptualized as the *actions taken by government agencies, at state or local level*, to promote regional or local industrial development factor (Badri, 2007; Brenner & Mühlig, 2013). Generally, they explain the initial move of an industry to various parts of the country (Djwa, 1960). In a nutshell, they guide the planning of future distribution of industries in ways that can reduce regional disparities and environmental pollution. In practical terms, these are *policies* that include *tax incentives, grants and RD&D and training programs*. Nowadays, there is an increasing policy interest in setting up various types of industries in a bound geographic area. The rationale being that synergies between industries are seen as able to guarantee common advantages. Moreover, this aspect is internalized as important by contemporary literature and critical for future industrial policy development (EU Comission, 2019).

GEOGRAPHICAL CONDITIONS

All factors that attract industries in an area because of its geographical location are grouped under this heading. This includes the presence of the previously discussed *natural resources* but goes one step further. Geographical specificities such as *topography of land, accessibility of land and space for future expansion* (McCann & Sheppard, 2003; Ellison et al., 2010) are seen as kernel conditions for the emergence of local industry clusters.

INDUSTRIAL CONDITIONS

Geographic concentration of industries is triggered by the presence of a *combination of factors* that attracts one or a group of industries in a certain area. For instance, the availability of a favourable climate and the presence of raw materials in an area, attracts specific industries to that area. *Agglomeration forces* will then attract other industries that are forwardly on backwardly linked to the first group of industries (Badri, 2007; Brenner & Mühlig, 2013; Gilbert, 2016). Ben-zvi (1981) offers an example of the geographic shift experienced by manufacturing industry. The argument is that the shift of manufacturing to specific US regions is prompted by the availability of energy sources and labor, which lead to the formation of new geographic concentrations of manufacturing.

KEY INFRASTRUCTURE

The attractiveness to invest in a region is strongly dictated by the existing infrastructure (Badri, 2007; Xu et al., 2018). This is especially true for industries that require intensive transportation of commodities (i.e. manufacturing industry). The availability of *transportation facilities, alternative modes and freight rates* are regarded as major determinants in the location of manufacturing. Furthermore, the *existing and future expected infrastructure* in a region has a strong impact on the future potential developments in that region (Brenner & Mühlig, 2013).

2.4.4 Brief summary and factor classification

The various documents that have been explored for identifying critical factors are reported in Table 3. The table shows two broad groups of factors, namely factors affecting spatial distribution and factors affecting industrial concentration and cluster emergence. Within these two broad categories, the factors that act as determinants of heavy industry location problems are defined. The factors are validated by means of interviewing experts from the industrial operational environment. The structure of the table enables to grasp which of the critical factors each of the authors discussed in his paper. Information about the journal and year of publication are also included in the table. This offers understanding relative to when specific factors were taken on board for locational analyses. As such, it appears that factors such as the market, raw materials and transportation have always been considered for location determination purposes. Factors such as energy sources, and the broader category of factors affecting industry concentration and cluster emergence have only recently been integrated into locational analyses. An observation that is worth mentioning relates to the energy sources factor. If mankind desires to continue its existence, it is a must to eliminate its reliance on fossil fuels and switch to renewable energy sources. To this end, it appears valuable to investigate the implications of how, shifting from fossil fuels to renewable energy capacities such as biomass, wind and solar will influence the location behaviour of industries that heavily rely on intensive energy capacities. These industries are also largely contributing to environmental pollution because in most case their power needs are supplied by fossil fuel related energy.

2.5 Concluding remarks: industry modernization as enabler of the Energy Transition

The factors that act as determinants of heavy industry location problems have been identified by means of the previous literature review. Moreover, interviewing experts enabled to validate the importance of the identified factors. All experts agree on the role played by such factors and on the indicators that are used for expressing them. Overall, it can be noted that the majority of these factors are taken into consideration for safeguarding the economic interest of corporations. Although economic interest remains central in the present era, a wide variety of factors can be expected to become less critical for location determination purposes, while others can be expected to gain much relevance. For example, while the cost of raw material and transportation are losing importance because of economies of scale and global supply chains (Goiri et al., 2011), the affordability and availability of RE capacities is becoming central. As it was demonstrated, these considerations rise because of the path dependent trajectory experienced by location theory. The historic context prompted Thünen to focus on agriculture, and later it motivated Weber and Marshall to shift attention to industry. Moreover, a careful analysis of these early theories enables to understand that each scholar placed particular attention on specific history dependent location determinants. Thünen's and Weber's theories are rooted on cost factors but with a particular interest in transportation. Marshall's and subsequent location economists' theories are also rooted on cost factors, but they are not constrained to transportation. The rationale being that, as times change and go by, so do the factors that are taken into consideration for performing locational analyses. However, in the context of the 21st century, where much attention is devoted to changes in the climate caused by forces of an anthropogenic nature, it appears that the location determinants that are currently being employed in locational analyses need to be revised. Although energy transitions have historically been driven by innovation, in the present era it is driven by policy agendas aimed at mitigating the destructive consequences of fossil fuel combustion (Bromley, 2016). As such, current priorities seem to gravitate towards industrial siting but with a special interest in energy interdependencies. Although the economic aspects remain central in the contemporary era, if mankind desires to continue its existence, a number of grand scheme system changes need to be initiated.

To enable these grand scheme system changes, the Paris Agreement pointed to the necessity of a transition in the energy sector. In response, the European Union (EU), embedded these considerations through the Energy Union Strategy, which is already influencing the industrial landscape in Europe (Elkerbout, 2017). In practical terms, the EU Commission is demanding Energy-Intensive Industries (EII's) to consider renewable energy options not only as an integral part of their new build capacity, but also as a part of their existing capacity (IRENA, 2014). Although the energy transition demands transformational, not incremental changes in numerous EIIs, this study focuses on the industry sub-sectors that constitute a targeted industry cluster. The European Observatory of Clusters and Industrial Change (EOCIC) offers information on various industry sub-sectors and industry cluster types (Hollanders, 2020). As such, this information is used to define a cluster of industries whose modernization is expected to safeguard its future economic competitiveness. To add specificity, various internationally recognized energy transition reports and academic articles agree on the fact that within the industrial sector, chemicals, steel and cement production are the largest emitters because they employ energy intensive and high temperature processes (Singer & Peterson, 2016; IRENA, 2019). The key takeaway is that few fossil fuel dependent manufacturing processes are accountable for the majority of GHG emissions deriving from the whole industrial sector (Elkerbout, 2017) . As such, it is reasonable to intervene by transforming these large industrial pollutants. In a second phase, spillover effects should enable the employment of successful technologies to other industry sectors and other geographic areas.

Table 3 Factors affecting the location decision of Energy-Intensive Industries

Article information			Factors affecting spatial distribution						Factors affecting industrial concentration and cluster emergence			
Author	Journal	Year	Energy sources	Cost of Knowledge	Construction cost CAPEX	Raw materials & Transportation	Climate	The market	Policy environment	Geographical conditions	Industrial conditions (agglomeration)	Key infrastructure
Peter Djing Kioe Djwa	University of British Columbia	1960	x	x	x	x	x	x		x		x
C. Clark et al	Regional studies	1969			x	x		x		x		x
D. Skibin	Atmospheric Environment	1974			x	x		x		x		x
Willam G. Murray et al.,	Hastings Law Journal	1980				x		x	x	x		x
Daniel Z. Czamanski	European Journal of Operational Research	1981		x	x	x		x	x	x		x
Paul Blackley et al	Urban Studies	1985		x				x			x	x
Howard A. Stafford	Association of American Geographers	1985		x		x		x	x	x		x
Eric R. Hansen	Regional Science and Urban Economics	1986	x	x	x				x	x	x	
Robert J. Newman et al	Journal of Urban Economics	1988							x			
Jürgen G.	International Journal of Social Economics	1988					x		x			

Masood A. Badri et al.,	Journal of Operations & Production Management	1995		x		x		x		x		x
Helen Briassoulis	Environmental Management	1995					x			x		
Timothy M. Stearns et al.,	Journal of Business Venturing	1995								x		x
Sanjoy Chakravorty	The Journal of Development Studies	2003		x					x		x	
Philip Mccann et al.,	Regional Studies	2003	x		x	x		x		x		x
Josep Maria Carod	Regional Science	2004				x		x	x	x	x	x
Masood A. Badri	Businnes and public affairs	2007	x	x	x	x	x	x	x	x	x	x
Glenn Ellison et al.,	American Economic Review	2010		x						x	x	x
´Inigo Goiri et al.,	IEEE computer science	2011	x		x		x			x		x
Seyyed Amin Terouhid et al.,	Journal of Sustainable Development	2012				x	x		x	x		
Thomas Brenner et al.,	Papers on Economics & Evolution	2013	x	x	x	x			x	x	x	x
Youngsoo An et al.,	International Journal of Urban Sciences	2014		x	x	x		x			x	x
Eliška Jirásková	Ekonomika a management	2015		x	x	x		x		x		x
Brett Anitra Gilbert	Foundations and trends in entrepreneurship	2016	x	x	x	x	x	x	x	x	x	x
D. M. Smith	Economic geography	2017	x		x	x		x		x		
Keisuke Takano et al.,	Urban & regional development studies	2018									x	x
Wei Xu et al	Complexity	2018	x	x	x	x			x	x	x	x
Anna Missiaia	Cliometrica	2019	x		x						x	

Vytautas Snieska et al.,	Economic Research	2019				x	x		x	x		
Dario Musolino et al.,	The Annals of Regional Science	2020	x	x	x	x		x	x	x	x	
Patrick Adler	Regional studies	2020		x			x		x		x	x

Table 3 Factors affecting the location decision of energy intensive industry

3 Energy Intensive Industry Clusters in Europe

This chapter identifies Europe's EII clusters; it explores their internal structure (i.e. industry sub-sectors that constitute the clusters). It relates the internal structure to transition technology options (TTOs) that allow for the modernization of the cluster. To do so, the traditional concept of a cluster is introduced and related to the location factors identified in chapter 2. Subsequently, to enable detailed cluster evaluation, a systemic view is applied. This makes it possible to anticipate likely responses of industry clusters to energy transition drivers (i.e. changes in the energy medium). In order to explore these responses, the Northern Italy Po Delta Cluster and Western Germany's Rhine-Ruhr cluster are selected as test cases. The selection is based on the density of industrial sites across Europe, their relative size, their industrial production volumes, their spatial proximity, and characteristic of the areas they occupy. Once selected, the two clusters are investigated to understand the sub-sectors that constitute them. At this stage, interest shifts to the definition of logical directions of change that safeguard the future competitiveness of the clusters. The intent is to find effective ways that can be used as a means for enabling the modernization and value creation of the clusters in the vision of a more renewable word. To define these directions of change, internationally recognized energy transition pathways and trajectories are reviewed. For validation purposes, the findings emerging from the literature review are triangulated with the opinion of experts. Triangulating expert opinions with literature findings confirms various transition technology options (TTOs) as market-ready or close to market readiness. These technologies share the characteristics of functioning on renewable power and of enabling decarbonization and energy efficiency increases in the industry. The chapter finishes associating the selected heavy industry clusters to the defined logical directions of changes. Practically, this is done by linking the various sub-sectors that constitute each cluster (i.e. the internal structure of the cluster) to the TTOs that hold high adoption potential. This step is seen as necessary because it enables to reason on the changes triggered by the envisioned transition process of the clusters.

3.1 Industry cluster: definition, relation to location factors and systemic view

The emergence of industry concentration in the form of industrial districts, evoked by the agglomeration phenomenon, is a widely investigated topic within recent economic and geographic literature. Marshall is considered to be the father of such concept. In his early works, he argued that firms can benefit from their co-location, because it creates common labor pools, profit from knowledge exchanges and cooperation, and information from new services (Brenner, 2004). As shown in chapter one, these considerations set the foundations for understanding agglomeration economies and their effects. Porter (1990) and Porter (1998) internalize these effects and reason in terms of changes in industrial organization as result of agglomeration forces. Although industrial districts were not new, Porter was able to extend the purely spatial definition associated such concept. He understands that competition and cooperation in spatially bound districts results facilitated, not only because of the geographic concentration of interconnected firms, but because of the presence of specialized suppliers, service providers and associated institutions (Porter, 1998). As such, the concept of local cluster was introduced in contemporary literature. Currently it is understood as a collection of related industries which together create products or economic services (Schmitz, 1995). As discussed in chapter one, the relations between site selection routines and the conditions for industry clusters to emerge are narrow. In both cases, the role played by location factors is central. When necessary and supportive factors are present in a certain area, the phenomena of agglomeration may manifest, thus leading to the emergence of local industry clusters (Brenner, 2004). Moreover, the close relation between site selection routines and the conditions for industry clusters to emerge, allow to expect that the emergence of industry clusters will occur when relevant location factors are sufficiently present in the area of interest (Brenner & Mühlig, 2013). To investigate agglomeration forces and cluster formation, a specific group of factors was defined, namely factors affecting industrial concentration and cluster emergence (see Table 1, Chapter 2).

A practical example of the interdependencies between industry clusters and availability of location factions emerges when observing Map 1. A careful eye observes that the industrial distribution pattern presented in the map (i.e. geographic spatial closeness), reflects the finding on locations factors from Chapter 2. For instance, the Western Europe cluster (Mid-Rhine, Antwerp-Rotterdam-Amsterdam) is there because of the presence of a combination of critical factors that enabled the uptake of specific industry sub-sectors (particularly chemicals and steel manufacturing). As it is the case in that area, when focusing on industry concerned with the production of metal products, their location is governed by proximity to primary raw materials and access to energy sources (Ben-zvi, 1981). When shifting the focus to chemical industries, access to energy sources and to key infrastructure were found to be kernel location determinants (Badri, 2007). Finally, by comparing the characteristic of the Western Europe cluster to the availability of location factors, it does not surprise that there is concentration of similar industries in that area. The availability of specific location factors in that bound geographic space has attracted certain industries which on a different level of organization have attracted other related industries, leading to the emergence of a local industry cluster. The same line of reasoning holds for all geographic areas that host agglomeration of heavy industries.

This study applies a systemic view to the concept of industry cluster. The rationale lies in understanding how the energy transition will influence the ongoing industrial transformation and the possible reshaping of industry competitiveness. According to Porter (1998), clusters are cross-sectoral by definition, as they refer to a concentration of related industries and institutions, and thus, they become platforms for innovation and industrial change. The idea is that industry clusters transform and reinvent themselves in response to changes that come from both the external environment as well as from within the cluster itself (Izsak, Markianidou, & Rosemberg, 2015). In a nutshell, it is the endogenous transformation of industry clusters, brought about and in response to patterns that fluctuate between different levels of organization, that enables to treat them as complex adaptive systems (CAS). For instance, by defining heavy industry, as a cluster composed of certain energy-intensive industries (EIIs) systemic considerations can be offered. As such, in its medium, the heavy industry cluster is experiencing pressures from the external environment (i.e. carbon abetment policy, compliance with sustainability standards etc.) and from within the cluster itself (i.e. competitiveness requirements). A practical example concerns the Port of Rotterdam, which is currently working on cluster programs aimed at coping with the elevated CAPEX for adoption of CCS technology[5]. In this context, the external driver of change (i.e. climate change), stimulated non-linear spatial and temporal interactions between various heterogeneous system components (individual firms and stakeholders, the Dutch government, international associations etc.). On a different level of organization, one can appreciate the effects of this by noting the emergence of specific social artifacts (i.e. negotiation and contracts between firms) as responses to the main driver of change. On a further level of organization, these interactions are leading to the emergence of complex behaviours that respond to the environmental-level changes (i.e. interest in carbon abatement technology by industry practitioners) who themselves will trigger variations on other levels of organization (i.e. increased competitiveness advantage). The variation that this study is most interested in, concerns responses by the heavy industry cluster (cement, chemicals and steel sub-sectors) to specific energy transition drivers. The intent is to investigate the extent to which, embarking particular energy trajectories across Europe, will impact the selected heavy industry cluster.

3.2 Identifying energy intensive industry clusters

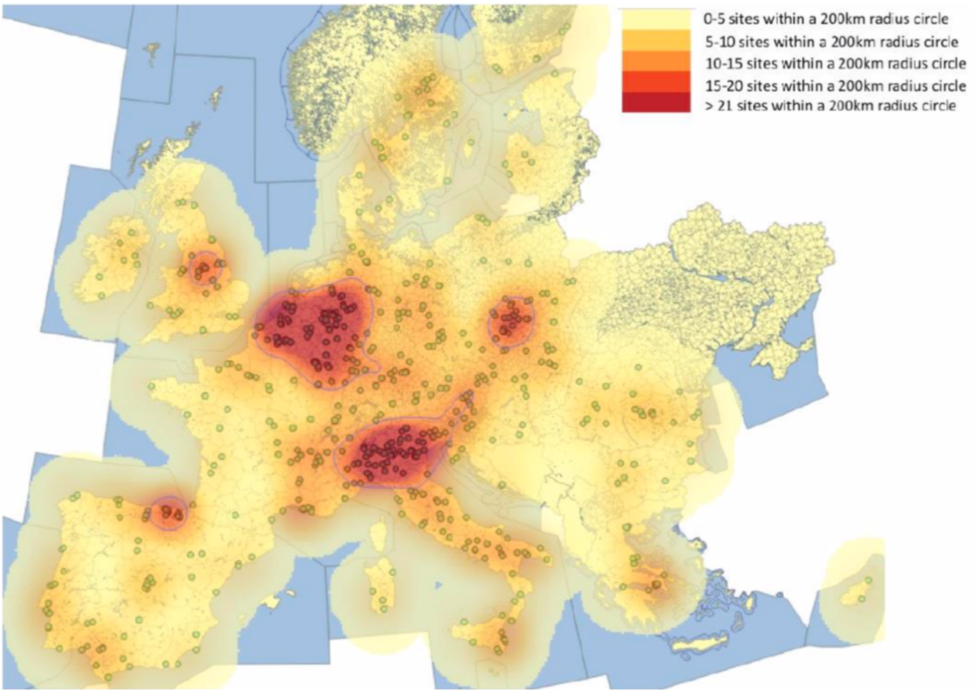
The concepts treated by Porter (1998) and Brenner and Mühlig (2013), on the close relation between industry clusters, their local geographical distribution and the critical factors that and area must possess in order to accommodate these clusters, serve as starting conditions for identifying interesting areas to study. To this end, information from the European Observatory for Clusters and Industrial Change[6], depicts the state of the art of specific industry clusters. The Methodology report for the European Panorama of Clusters and Industrial Change provides the full definitions for the narrowly defined 51 traded sectorial industries (Hollanders, 2020). As anticipated, focus is oriented on the heavy industry clusters composed of cement, steel and chemical facilities.

At this stage specific agents should be identified and used as test cases for analysis. To do so, the distribution of EU member states industrial production by industrial sector is determined. Determining such distribution requires availability of sensitive data (i.e. industry specific production volumes, relative industry size etc.). Although it is generally possible to retrieve such information from Eurostat, national statistics and industry association reports, severe limitations were experienced. The extremely sensitive nature of such data made it not possible to access and consult it. In addition, since the elaboration of such data goes beyond the scope of this study, it was decided to borrow considerations emerging from other studies. To this end, it was found that only two reports have investigated the spatial distribution of European heavy industry. STRANE innovation lead a techno-economic market study of all the European industrial sites that can be associated to the heavy industry cluster. The result of STRANE's work is a thematic map that shows the geographic dimension of all European industrial sites that belong to cement, steel and chemicals (see Map 1). Five main hotspots are identified. The largest covers Northern France, Belgium, the Netherlands, Luxembourg and

[5] https://www.portofrotterdam.com/en/news-and-press-releases/port-of-rotterdam-aims-to-take-the-lead-in-the-energy-transition
[6] Cluster Programmes - Regional ecosystem scoreboard (https://interactivetool.eu/EASME/RES/RES_2.html#)

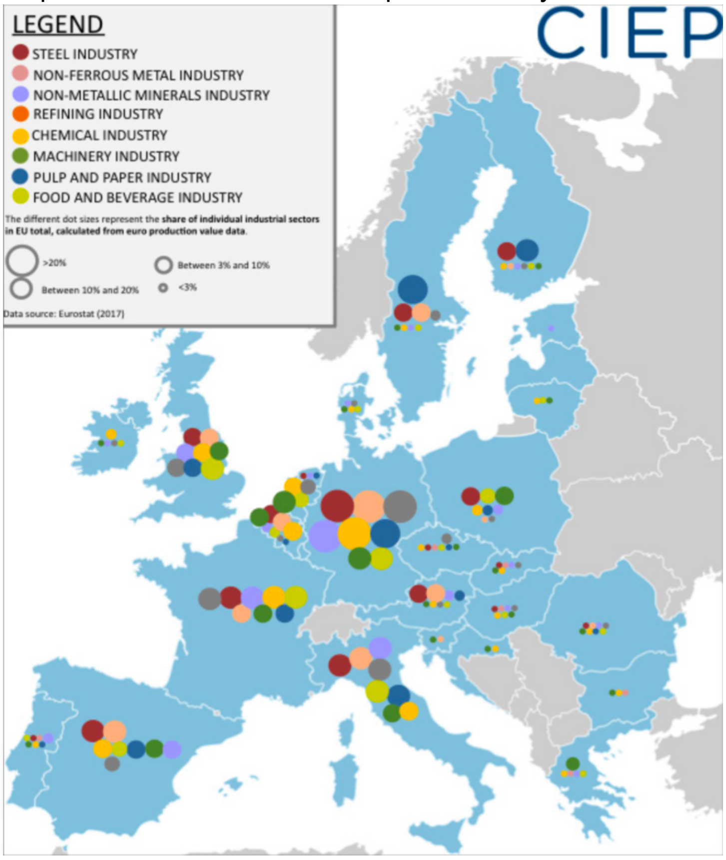
Western Germany and gathers 20% of the European sites and 40% of the potential couples of sites below 200km. Northern Italy emerged also as a hotspot, especially due to the presence of electric arc furnaces and cement plants. Other medium hotspots were identified around Krakow, Bilbao and the UK Midlands. In between, the density of industrial sites is lower and more stretched (Strane, 2016).

Map 1 Hotspots in terms of density of industrial sites in Europe (Source: STRANE, 2016)

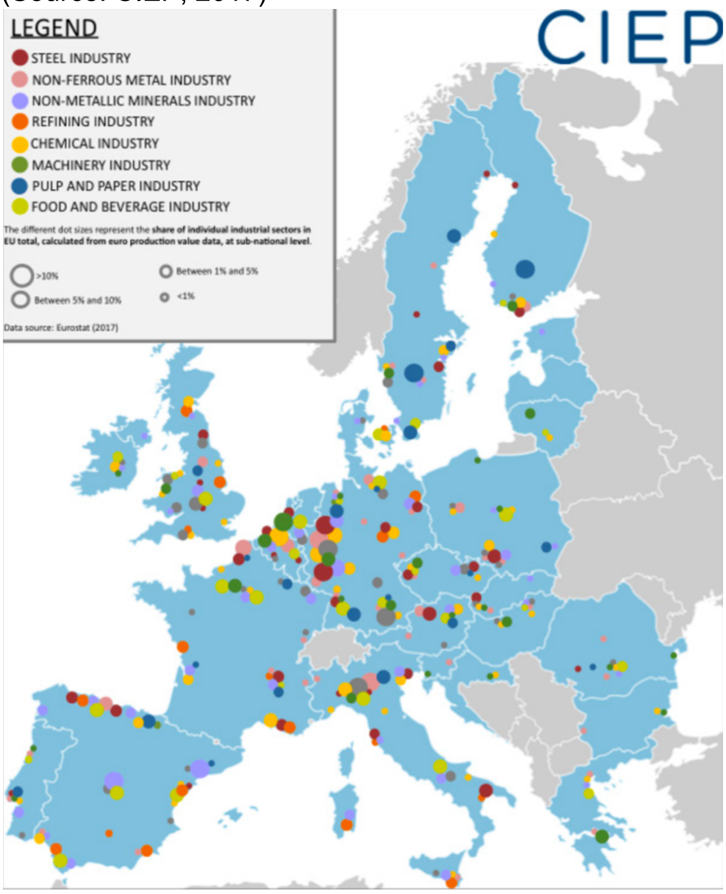


The map offered by STRANE (Map 1) allows to identify macro areas that are interesting to study in terms of spatial closedness among EIIs. Although this information is extremely valuable for initial screening purposes, detailed aspects on the various heavy industry clusters are missing. To broaden the understanding on state-of-the-art distribution patterns, a CIEP report is consulted. The report offers detailed information on the distribution of industrial activity across EU member states both on a national level and on a sub-national level (CIEP, 2017). As such, the two maps visualizing industrial production are integrated in this study. Map 2 shows distribution of industrial production by industrial sector, across member states. Map 3 shows the same distribution pattern but on a sub-national level. Finally, further specific cluster data is retrieved from the European Observatory of Clusters and Industrial Change (Hollanders, 2020). Data retrieved from the European Observatory of Clusters and Industrial Change captures detailed information on the various sub-sectors that constitute the clusters.

Map 2 Distribution of industrial production by industrial sector across EU member states (Source: CIEP, 2017)



Map 3 Distribution of industrial production by industrial sector across EU member states on a sub-national level (Source: CIEP, 2017)

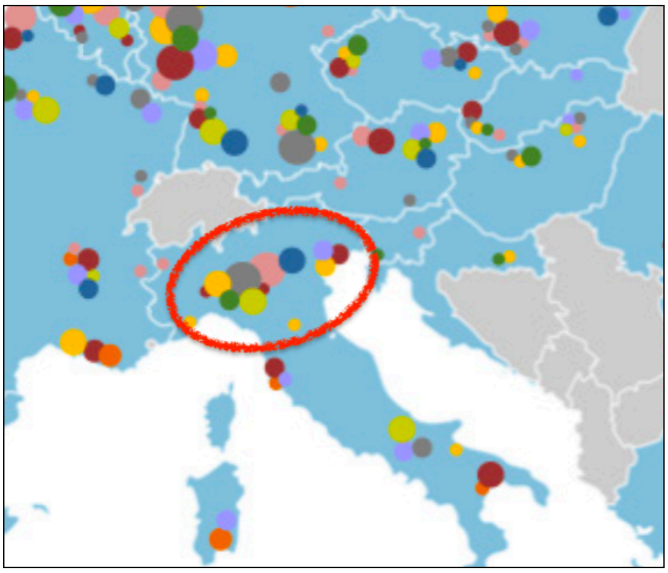


3.3 Selection of energy intensive industry clusters to use as test cases

Overall, the considered maps show very similar distribution patterns. This aspect proofs the validity of the considered artifacts and enables to reason on them for identifying interesting areas to study. Aside from industrial production, the distribution of industrial activity by relative size, is a useful proxy for understanding where industrial energy consumption takes place in the EU (CIEP, 2017). Moreover, reasoning on the maps enables to identify two major European clusters. These are the Northern Italy Po Delta cluster and the mega cluster located in northern Europe. The two clusters are selected because of the high number of enterprises and generated turnover, production of commodities is concentrated in these areas and accounts for 83% of the total EU production[7]. The rest of this section offers a brief overview of the characteristics of the two clusters. The aspects discussed are the characteristics of the geographic area influences by the cluster and the sub-sectors that constitute the clusters.

3.3.1 Italy's cluster preliminary overview

Map 4 Distribution of industrial production by industrial sector in northern Italy (Source: CIEP, 2017 adapted by the author)



A recent assessment published by Fondazione Pirelli[8] on a private blog, confirms the findings of STRANE and CIEP on Italy's new economic geography configuration. Moreover, evidence shows that the semi-novel Italian industrial triangle of Milan, Veneto and Emilia is taking steps aimed at harvesting the economic potential of Italian industries. Based on ISTAT data, a sharp snapshot of the area's real economy is presented (see Corriere della Sera, 14th June 2020). The snapshot shows that the so-called Po Delta cluster, which is represented by Confindustria, brings together industries that span the whole geographic area of interest. The expression of the

[7] EUROFER 2014 data

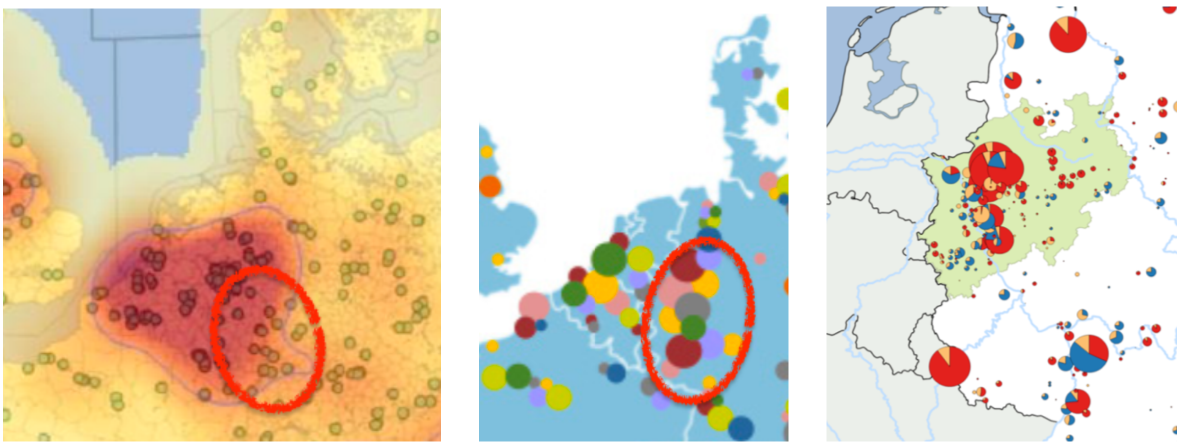
[8] https://www.fondazionepirelli.org/en/corporate-culture/blog/the-new-italian-industrial-triangle-of-milan-veneto-and-emilia-the-challenges-of-an-open-economy

cluster's interactions is worth a GDP of 324 billion euros and a manufacturing value added of 53 billion euros (Eurostat, 2019). A such, the area under study has a significant impact on Europe's industrial heart. The rational being that, the GDP figures enclosed in this cluster are greater than the combination of Netherland's, Sweden's and Poland's figures (Eurostat, 2019). Finally, the yearly ranking of the cities which are best to live in (see Il Sole 24 Ore, 6th October 2019), addresses many cities in this dense economic zone. The article motivates choices not only because of the presence of companies connected to one another by very innovative supply chains and production platforms but also due to the availability of many location factors. Examples are universities and research centers, modern services and logistics structures, labor hubs, art centers and cultural organizations of international relevance (Il Sole 24 Ore, 6th October 2019).

Based on data from European Observatory for Clusters and Industrial Change (Hollanders, 2020), Wyns and Axelson (2016), Strane (2016), EU Comission (2019), and Missiaia (2019), it becomes clear that the cluster under investigation is dominated by steel, and cement manufacturing. Chemical industries are present in the area, but their production volumes and energy requirements are limited when compared to that of the remaining manufacturing sub-sectors (Wyns & Axelson, 2016). In addition, ICF (2015) shows that Italy is the second biggest European player in cement and steel, the generated sector turnover is the second highest in Europe, Italian share of EU-28 value added within the two sub-sectors was 20%, finally production of commodities is concentrated in the northern regions (i.e. Po Delta `cluster area).

3.3.2 Western Germany's cluster preliminary overview

Map 5 Distribution of industrial production by industrial sector and density of sites (STRANE, 2016; CIEP, 2017 and Schuwer, 2018 - adapted by the author)



A recent publication by Dietmar Schüwer on the electrification of German energy intensive industry sub-sectors confirms the findings of STRANE and CIEP regarding Germany's geo-economic configuration. Since the original cluster of interest covers Northern France, Belgium, the Netherlands, Luxembourg and Western Germany it was decided to decompose it into smaller clusters. Narrowing down the mega cluster facilitates the research efforts as it makes data gathering and analysis processes less complex thus more approachable. To this end, it was decided to focus on German industries located in the Rhine-Ruhr area. The Rhine-Ruhr metropolitan region is a highly industrialized, densely populated region of Western Germany. The area includes the primary cities of Bonn, Cologne, Dusseldorf, Dortmund and Essen. Moreover, the region is one of the biggest metropolitan areas in Europe ad also one of the world's 10 largest economic regions[9].

Geographically, the area is located at the center of Germany's industrial heart. Historically, this is the where steel production, coal mining and automobile production developed in Europe[10]. Since these industries demand a functional network of logistics distribution and industrial properties, the area's infrastructure has developed accordingly. Moreover, transport networks in the Rhine-Ruhr region are dense and effective. Additionally, the region has two international airports located in Cologne and Dusseldorf. The Rhine River is Europe's principal inland waterway. Dortmund hosts the largest canal port in Europe, and Duisburg is the largest inland river port in Europe. Finally, given the region's dense population and high incomes[11], consumption and e-commerce are spurring demand for warehouses and logistics facilities.

In line with the observations made for Norther Italy's cluster, based on data from European Observatory for Clusters and Industrial Change (Hollanders, 2020), Wyns and Axelson (2016), Strane (2016), Schüwer & Schneider (2018) and EU Comission (2019), it becomes clear that all three sub-sectors under investigation play dominant roles in the German cluster. Further varication is performed by means of a targeted research in maps. This intends to verify the actual geographic location of specific steel, cement and chemicals production facilities. The outputs of the research point to the Rhine-Ruhr region as being extremely populated of heavy industry facilities. Specifically, it was found that this region is home to BASF, the world's largest chemical company; to Heidelberg Cement, the globe's second largest cement maker; and it also where Europe's largest and most diversified steel industry is. Adding to this, ICF (2015) shows that Germany is the biggest European player in cement and steel and chemicals, the generated sector turnover is the highest in Europe, the share of EU-28 value added within the three sub-sectors is 37%, finally production of commodities is more geographically distributed than in Italy. Yet, the Rhine-Ruhr area is by far the most densely populated of heavy industrial sites in Germany. In conclusion, as Europe's largest economy and industrial powerhouse, Germany plays a central and pioneering role in transitioning heavy industry.

3.4 The energy intensive industry sub-sectors of interest

Steel industry

The steel industry produces two thirds of the world's crude steel using the primary route (i.e. blast furnace and converter) and one third using electricity-intensive secondary route electric arc furnace (Grave et al., 2015; Wei, McMillan, & Can, 2019). In Europe, Germany and Italy are the countries that have a remarkable share in steel manufacturing, supplying almost 4% of the world's needs (United Nations, 2012). China is the world's leader in steel production as it supplies 47% of the world's needs (United Nations, 2012). Evidence shows that, German

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[9] PROLogis 2020 – Rhine-Ruhr, Industrial Capital of Western Germany
[6] PROLogis 2020 – Rhine-Ruhr, Industrial Capital of Western Germany
[11] Eurostat 2020

and Italian steel won't necessarily be price competitive when compared with that of developing countries, but it will be competitive on a quality scale. Local and regional purchasing preferences are identified. According to the DG Enterprise and Industry of the European Union, the potential of a domestic steel industry lies in the high quality of products, innovative capacity, material and energy efficiency, competent workforce and technical leadership (Grave et al., 2015). The most often mentioned mitigation options are modern high temperature electric arc furnaces (Wyns & Axelson, 2016), electrolysis based steelmaking (IEA, 2013; United Nations, 2012) in combination with CCS (EU & Comission, 2019; Gerres, Chaves Ávila, Llamas, & San Román, 2019).

CHEMICALS INDUSTRY

The emission reductions in EU's chemical sector are extremely large. Since 1990 the GHG emission decreased by 60%, while fuel and power consumption decreased by 24% (Wyns & Axelson, 2016). Although the chemical industry is characterized by a wide variety of processes and products, it can be summarized that it is dependent on high quality supply of electricity (EU Comission, 2019). Further emission reduction is technically feasible and requires, for example, changing petroleum-based inputs to bio-waste feedstock (United Nations, 2012). The most often mentioned technological breakthrough in this sector is the electrochemical separation via electrolysis of basic chemical compounds (i.e. ammonia, ethylene and hydrogen) (Wyns & Axelson, 2016). Moreover, CCS could be a vitally important technology for the chemical sub-sector (IEA, 2013). The CCS in the Industrial Applications Roadmap projects an impact of 25% emission reduction in 2050 when carbon capture and storage (CCS) technologies are employed (IEA, 2011).

CEMENT INDUSTRY

According to the Technology Roadmap Low-Carbon Transition in the Cement Industry by the IEA, cement production is the third-largest industrial energy consumer and the second-largest industrial GHG emitter globally (CEMBUREAU, 2013). Rising global population and urbanization patterns coupled with infrastructure development needs, increase the demand for cement and concrete and increase pressure to accelerate action in reducing the carbon footprint of cement production (International Energy Agency, 2018).Interesting, the cement sector in Brazil relies on biomass for 34% of the sector's final energy consumption (United Nations, 2012). The key takeaway is that such high shares of biomass in one of the most energy intensive sectors in Brazil imply that a similar contribution is technologically possible elsewhere. It emerges that the implementation barriers are not technical, they are oriented towards resource availability, economics and competition among other energy sources. It logically follows that the adoption potential of biomass in cement manufacturing processes is largely determined by the state of biomass trading. Finally, technologies such as CCS and CCU are promising solutions for further emission reductions (Gerres et al., 2019; Grave et al., 2015).

3.5 Defining energy pathways for cluster modernization

In order to secure the future competitive advantage of the two clusters, it is hypothesized that their modernization and compliance with future energy transition requirements are necessary. Opinions of interviewed experts and findings from reviewed internationally recognized energy transition pathways point to technologies that can function on renewable power and that have an intrinsic potential to decarbonize and electrify targeted industry sub-sectors. Table 4 summarizes the documents that have been employed in the literature review and their value.

Table 4 Overview of the reviewed RE and Transition documents and their value

Agency	Type	Title	Year	Value
IRENA	Roadmap	Global Energy Transformation a Roadmap to 2050	2018	General transition indications; Describes areas of intervention in the industry sector
IEA	Technology Roadmap	Energy and GHG Reductions in the Chemical Industry	2013	Detailed description of abatement options; focused on Catalytic Processes
EU Com	Report	Masterplan for a Competitive Transformation of EU Energy-intensive Industries	2019	Technology potential for energy-intensive sectors; Assessment of technology options; general financial considerations
UNIDO	Report	Renewable Energy in Industrial Applications An assessment of the 2050 potential	2012	Potential of RES for process heat in the industrial sector; and for biomass feedstock substitution in industrial processes
IEA	Roadmap	Low-Carbon Transition in the Cement Industry	2018	Detailed description of abatement options in cement production processes.
IRENA	Roadmap	Renewable Energy in Manufacturing	2014	Electrification of the energy sector; on site RE generation
Private	Review Article (Gerres et al., 2019)	A review of cross-sector decarbonization potentials in the European energy intensive industry	2019	Detailed description of abatement options: Furnaces; heat recovery; CCS; Biomass; Electrolysis; Catalyst processes.

Private	Review Article (Wei et al., 2019)	Electrification of Industry: Potential, Challenges and Outlook	2019	Direct and indirect electrification of industry; detailed overview of abatement technologies;
IEA	Pathways (Wyns & Axelson, 2016)	Decarbonizing Europe's energy intensive industries	2016	Detailed description of abatement options for the cement, chemicals and steel manufacturing.
Private	Executive report (Grave et al., 2015)	Electricity costs of energy intensive industries an international comparison	2015	Electricity cost considerations; cement, chemical and steel sector abatement potential; Detailed overview of potential abatement technologies

The literature review allows to identify various transition enabling technologies. These technologies are referred to as transition technology options (TTOs) and are associated to the industry sub-sectors that could profit from their adoption. To this end, Table 5 shows potential pathways held by low carbon dioxide (CO2) technologies for energy-intensive industrial applications. Table 6 focuses on the assessment of the main technology pathways across a number of relevant aspects. These considerations are based on the Masterplan for a Competitive Transformation of EU Energy-intensive Industries by the high-level group on Energy-Intensive Industries (EU Comission, 2019). Since the considerations presented in the report are of a general character, further technical information is retrieved by consulting IEA, UNIDO and IRENA documentation and expert opinions. Finally, thanks to their clarity and precision the reviews offered by Grave et al., (2015), Wyns and Axelson (2016), Wei, McMillan, and Can (2019), Gerres, Chaves, and Llamas (2019) are also employed in the analysis.

In addition, it is found that to modernize energy intensive manufacturing processes, a multitude of studies worked on proving the technological feasibility of an electrified industrial sector. Wei, McMillan, and Can (2019) and Gerres, Chave, and Llamas (2019) summarize the latest research on the possibility of electrification of the industrial sector. Their reviews highlight that "the rapidly falling cost of solar PV, wind power, and battery storage, industry electrification coupled with renewable electricity supply has the potential to be a key pathway to achieve industry decarbonization and electrification" (Wei et al., 2019). It is also argued that the transition in the energy sector entails major changes in the energy system. These changes include large scale increases in renewable electricity or nuclear power supplies, new infrastructure for hydrogen, expansion of the transmission and distribution networks and novel and cleaner technologies such as CCS and CCU (NATO, 2016; IRENA, 2019; Wei et al., 2019; Gerres et al., 2019). Although there are so many ways in which RE can change the state-of-the-art, it can be argued that some directions of change are way more likely to happen than others. In other words, even though it is not possible to anticipate with absolute precision the future state of the energy system, and the future degree of industrial electrification, overall transition patterns can be anticipated.

Table 5 Overview of low-CO2 technology potential for energy-intensive industrial applications (adapted version from Masterplan for Energy-Intensive Industries 2020)

	Electrification (via electrolysis)	Electrification (Heat & Mechanical)	Hydrogen (Heat or Process)	Biomass and Biofuels	CCU	CCS
Steel	+ +	**+ + +**	+ + +	+	+ + +	+ + +
Chemicals	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Cement	o	+ +	+	**+ + +**	+ + +	+ + +

o Limited application foreseen;

+ Possible application but not main route or widespread application;

+ + Medium potential;

+ + + High potential;

+ + + Sector already applies technology on large scale;

Table 6 Assessment of main technology options for energy-intensive industrial applications (adapted version from Masterplan for Energy-Intensive Industries 2020)

	Technology status	**Energy use**	**CAPEX**	**OPEX**	**Infrastructure**	**Co-benefits**
Electrification of heat	Hight TRL except for high Temp furnaces (cement)	Higher electricity demand; Lower use of primary energy	Varies Low for boilers High for furnaces	Function of electricity prices	Medium needs	Potential for electricity demand response
Electrification of processes	Close to demonstration phase	Higher electricity demand; Lower use of primary energy	Elevated	High dependence on electricity prices	Low/Medium	Potential for electricity demand response
Hydrogen	Demonstration of plants	High electricity consumption for electrolysis-	Elevated	High dependence on electricity prices	High expect if H2 is produced at site	Power storage via ammonia

		based production				
Biomass	Pilot and demonstration	Can be higher	High for feedstock applications; Low for fuel applications	Depends on price of biomass	Medium/High Need for logistic chains	Industrial symbiosis
CCS	Demonstration	Elevated	Elevated	Elevated	Elevated	Possible process integration
CCU	Commercialization phase	Can be very high for H2	Elevated	Depends on RE electricity price; High when H2 from electrolysis is required	Elevated	CO2 becomes a resource not a cost

As anticipated, information from the tables shows how to achieve industrial modernization through the up taking of advanced technologies. However, it must be kept in mind that although some technologies are currently more mature than others, it could be that some promising solutions won't materialize in the real world. This may be due to poorly structured policy measures or to an unexpected technological breakthrough that could increase the performance of an early stage technology, thus making it more attractive than others. Alternatively, technologies that are unsuccessful in a certain context, may become relevant in other contexts. In order to ensure technological neutrality, without excluding upfront technologies and embed flexibility in future developments of climate neutral solutions, a morphological chart is constructed (see Table 7). This artifact generates the design space which contains all potential solutions and enables to identify design alternatives within that space (Dym, Little, & Orwin, 2013). Practically, the artifact is generated by merging the considerations from the two overviews and by triangulating them with the opinions gathered through expert interviews.

Table 7 Morphological chart depicting the design space

The design space		**Means**			
		Highest potential	…	…	Lowest potential
Functions	Steel manufacturing	High Temp electric (arc)furnaces	Heat from H2 (Electrolysis)	CCS	CCU
	Chemicals reduction	Electrolysis (Catalytic process)	CCS for ammonia	Use of waste steams	Alternative feedstock and CCS

	(ammonia focused)				
	Cement production	Alternative feedstock	CCS and CCU	Electrification of heat (furnaces)	Heat from H2 (Electrolysis)

Overall, the morphological chart enables to identify four main pathway trajectories that could be embarked to modernize energy intensive industries (EIIs). Areas of abatement coloured in orange relate to providing heat form electricity. Technologies marked in green indicate alternative feedstocks, such as biomass. Blue indicates a variety of electrochemical separation processes. Finally, grey is used to indicate CCS and CCU, which aim to reduce carbon emissions. The implication rising from these considerations are critical for industrial practitioners. The presented pathways, although characterized by very different technologies, are affected by the same aspect, namely an increased power consumption that should be supplied by means of renewable generation capacity.

Although the uncertainty regarding potential adoption of TTOs remains, the morphological chart enables to reason on the general implications that energy-intensive industries will experience when shifting to these technologies. As such, at this stage, the goal is not that of prescribing perfect matches between an industry sub-sector and its most promising TTO, as this is seen as an educated guess that won't ensure technological neutrality. It is more valuable and insightful to assume that, to a certain extent, the investigated energy intensive sub-sectors will employ a combination of the presented abatement technologies in the near future. This assumption is central for the study as it enables to reason and anticipate the implications that would rise if energy intensive industries were to transition to modern technologies. Reasons to motivate this assumption are: i) a decarbonized power sector, dominated by RES is at the core of all reviewed pathways and scenarios; ii) the transformation of the energy sector makes economic sense; iii) the additional costs of the long-term energy transition are largely compensated by cost-savings from reduced pollution, better health and lower environmental damage (IRENA, 2019); iv) the transition in the energy sector stimulates economic activity by expanding state of the art levels of employment, thus improving welfare and gross domestic product (IRENA, 2018); v) industries that chose not to transition are likely to experience negative lock in effects resulting from the non-compliance with future standards.

3.6 Clusters projection on energy pathways

3.6.1 Italy's Cluster: projection of cluster's sub-sectors on energy pathways

The design space		Means			
		Highest potential	…	…	Lowest potential
Functions	Steel manufacturing	High Temp electric (arc)furnaces	Heat from H2 (Electrolysis)	CCS	CCU

	Chemicals reduction (ammonia focused)	Electrolysis (Catalytic process)	CCS for ammonia	Use of waste steams	Alternative feedstock and CCS
	Cement production	Alternative feedstock	CCS and CCU	Electrification of heat (furnaces)	Heat from H2 (Electrolysis)

Reasons that lead to the formulation of this direction of change lie on the type of industry cluster. And on the opinion of experts. Specifically, these reasons are:

1. Experts for the Italian industrial operational environment agree with the direction of change (refer to interviews reported in appendix);
2. The limited lifecycle of traditional industrial machinery points to substitution and modernization needs;
3. The identified transition technology options (TTO) enable to meet energy transition objectives by utilizing at best the expected larger shares of RE capacities. In practical terms, industry power demand can be supplied by means of utilizing artifacts that are powered trough RE;
4. Few technology options are applicable to the two sub-sectors under study, implying reduced needs for operational knowledge and associated services;
5. The adoption of transition technology options contributes to overall increases in energy efficiency (1.7% yearly increase) (INECP, 2017);
6. A number of demonstration projects are already operational in Italy. High temperature electric arc furnaces are widely used in Italy (Wyns & Axelson, 2016). In Austria a cement plant runs 100% on biomass[12]
7. The expected larger share of RE capacities can supply the power requirements of these novel technologies;
8. The technology options aren't either friends or enemies, they can coexist. This enables individual companies to decide, based on their needs, which technology suits their interest in the most advantageous way. This is seen as an important aspect that ensures technological neutrality.
9. Although the potential of hydrogen technology is gaining more and more attention, because of the technology's early stage of development in the country, the elevated infrastructure costs of H2 when not produced on site and the uncertainty deriving from the high dependence on electricity prices (EU Comission, 2019), a choice to focus on the remining technology options is made. Furthermore, the Italian experts that have been interviewed agree on the importance of hydrogen technology but see it as challenging to implement in Italy.

3.6.2 Germany's cluster: projection of cluster's sub-sectors on energy pathways

[12] Information from Expert interviews – Heidelberg Cement

The logical direction of change that concerns this cluster is a combination of technology options that target the three sub-sectors. The morphological chart below graphically depicts the envisioned technological direction of change.

The design space		Means			
		Highest potential	…	…	Lowest potential
Functions	Steel manufacturing	High Temp electric (arc)furnaces	Heat from H2 (Electrolysis)	CCS	CCU
	Chemicals reduction (ammonia focused)	Electrolysis (Catalytic process)	CCS for ammonia	Use of waste steams	Alternative feedstock and CCS
	Cement production	Alternative feedstock	CCS and CCU	Electrification of heat (furnaces)	Heat from H2 (Electrolysis)

Reasons that lead to the formulation of this direction of change lie on the type of industry cluster and on the perspectives of experts. Specifically, these reasons are:

1. The ample spectrum of transition technology options is applicable to the sub-sectors under investigation. The significance of this lies in reduced needs for operational knowledge and associated services;
2. The limited lifecycle of traditional industrial machinery points to substitution and modernization needs;
3. German experts from Heidelberg Cement, Wuppertal Institute for Climate, Environment and Energy and Technische Universität Braunschweig agree with this direction of change;
4. The adoption of transition technology options largely contributes to overall increases in energy efficiency (1.5% yearly increase hypothesized in comparison to the Italian case);
5. Demonstration projects are already operational in Germany. Many chemical processes use waste streams and catalytic processes. Additionally, electricity is employed for primary steel production (Wyns & Axelson, 2016);
6. The technology options aren't either friends or enemies, they can coexist. This enables individual companies to decide, based on their needs, which technology suits their interest in the most advantageous way. This is seen as an important aspect that ensures technological neutrality.
7. In Germany the potential of H2 is high but the high dependence on electricity prices (EU Comission, 2019) remains seen as a key barrier. Experts highlight the importance of developing domestic hydrogen technology.

3.7 Logical focal point: the need of gaseous fuels in heavy industry

The arguments presented in the previous sections of this chapter show that a suit of TTOs can drive industrial clusters to net-zero emissions via clean electrification, systemic efficiency, CCS, CCU and hydrogen (H_2). The role industrial cluster can play in the clean energy transition is central. The spatial proximity of companies in each cluster determines the size and aggregation of energy demand. Despite the opportunities for demand optimization, electrification, systemic efficiency, CCU and CCS the potential of an internal market for hydrogen emerges. Hydrogen is considered to be the most promising technology for decarbonizing hard-to-abate sectors such as heavy industry. Its adoption will diversify energy sources and hence improve energy security. The EII cluster can utilize H_2 as a feedstock for high-heat and high-pressure industries that are difficult to electrify. The production and consumption of H_2 can be co-located, reducing the need to invest in long-distance transport infrastructure. Besides, clean hydrogen production methods that eliminate emissions are advancing. For instance, it is possible to split water into hydrogen and oxygen through electrolysis by utilizing wind and solar electricity. Moreover, Italy and Germany have coastal areas as such offshore wind electricity can be converted into H_2 via the electrolysis of seawater and transported with the existing gas pipelines. Additionally, green hydrogen can be produced through nuclear generation. However, both nations have planned the phase-out of nuclear power which makes this option not suitable. Finally, by capturing, using and storing the CO_2 produced when hydrogen is made with fossil fuels, the so-called blue hydrogen is created.

Despite the great foreseeable potential of H_2 and the beneficial effects in terms of increased energy security, the focus of this research is on the power sector. The rationale is multifaced. To start with, state-of-the-art hydrogen production happens through fossil fuels such as natural gas and coal (i.e. grey H_2). Although green hydrogen production is viable, the interviewed experts express concerns regarding its adoption by the EII clusters. Heidelberg Cement identifies barriers in H_2 adoption by the cement sector. The argument is that decarbonization of fuels solves only part of the problem because process emissions will remain[13]. Secondly, Wuppertal Institute for Climate, Environment and Energy argues that in the case of steel the market readiness and economic viability of electric technologies is more attractive than hydrogen. Finally, both Wuppertal Institute for Climate, Environment and Energy and the Technische Universität Braunschweig argue that the chemical sector may be relocated if cost-effective domestic H_2 will not materialize soon enough. The main concern is the large clean electricity capacity required for the production of green hydrogen. All Italian experts acknowledge the potential of H_2 and know that Italy's existing gas pipelines could be easily converted to H_2. However, these experts are very sceptical about the timing required for the hydrogen transition and uptake in Italy. In addition, the water required for H_2 production may compete with water destined for alimentation purposes. However, the general impression is that this technology will become economically viable in Italy at the end of the time frame considered in this research.

To conclude, for the time being, the best foreseeable strategy is to focus on the further development of RE because these resources are essential for clean H_2 production. In a second phase, when the economic and technological readiness will be more mature, hydrogen can be combined with cost-effective electrification opportunities in order to increase the security of supply of the industry clusters and to further reduce carbon leakage. Until that moment,

[13] According to the expert process emission account for 60% of the total. For the time being, the adoption of hydrogen by the cement sector is not economically justifiable. The magnitude of investment required and the complexity associated with the change to H2 technology offers limited advantages in the cement sector.

energy storage systems will be critical to ensure the security of supply of the EII clusters. Promising gaseous fuels such as LNG and shale gas are not discussed in this research because of foreseeable import dependence on other nations and unpredictability of prices[14].

3.8 Concluding remarks

In summary, to predict future changes, targeted industry clusters in the EU have been identified, selected and projected on the energy pathways. Practically, this chapter reasoned on possible energy trajectories and how two specific industry clusters could embark them by adopting TTOs. Specifically, the trajectories entail utilizing heat that comes from renewable electricity, adopting alternative feedstocks, internalizing electrochemical separation processes and limiting direct carbon leakage via CCS and CCU. While the actual future developments can and will most likely differ from the developments laid out in the pathways, these pathways are intended to broaden contemporary thinking on potential future developments of EII clusters in a more renewable world.

As highlighted, the adoption of the identified transition technology options, has profound implications for the industries that choose to transition. By exploring such implications, barriers and opportunities can be identified. Examples of such implication concerns the relatively high upfront investment costs (CAPEX) needed to implement the novel technology options. It is expected that elevated CAPEX, can be mitigated through time, by a gradual reduction in operational costs (OPEX). These reductions in OPEX occur when industries choose to supply their processes through renewable power capacities. Another example of such implication points to a common denominator of the various transition technology options. Namely, a general increase in electric power demand. Considering current trends, it appears valuable for location decision-makers to root their choices on where RE capacities are going to be available, affordable and acceptable in the future. The rationale being that, by doing so further decarbonization will be achieved while coping with the OPEX issue and while improving the overall status of the company's technological advancement.

The envisioned future environment is an initiator of changes for the heavy industry clusters that chose to transition. Although it can be anticipated that the clusters under investigation are not going to experience significant spatial shifts (in the sense that they won't move away), it can be expected that their relative size is likely to experience significant variations (see it as a centrality measure, they are likely to expand or shrink but not to move away). These long-term effects are triggered by modernization choices made today. An example are the earlier mentioned abatement initiatives (i.e. CCS project) in the port of Rotterdam[15]. The next research step consists in assessing the projected clusters in terms of the location factors from chapter two. This will be done with a specific interest in the energy factor. The guiding principle is that, if industries in the EU desire to survive and remaining competitive,

[14] EU Commission https://ec.europa.eu/energy/topics/oil-gas-and-coal/liquefied-natural-gas-lng_en?redir=1
[15] Retrieved at: https://www.portofrotterdam.com/en/news-and-press-releases/port-of-rotterdam-aims-to-take-the-lead-in-the-energy-transition

they must find functional and effective ways to transition to cleaner and futureproof technologies (Hollanders, 2020).

4 Cluster evaluation procedure

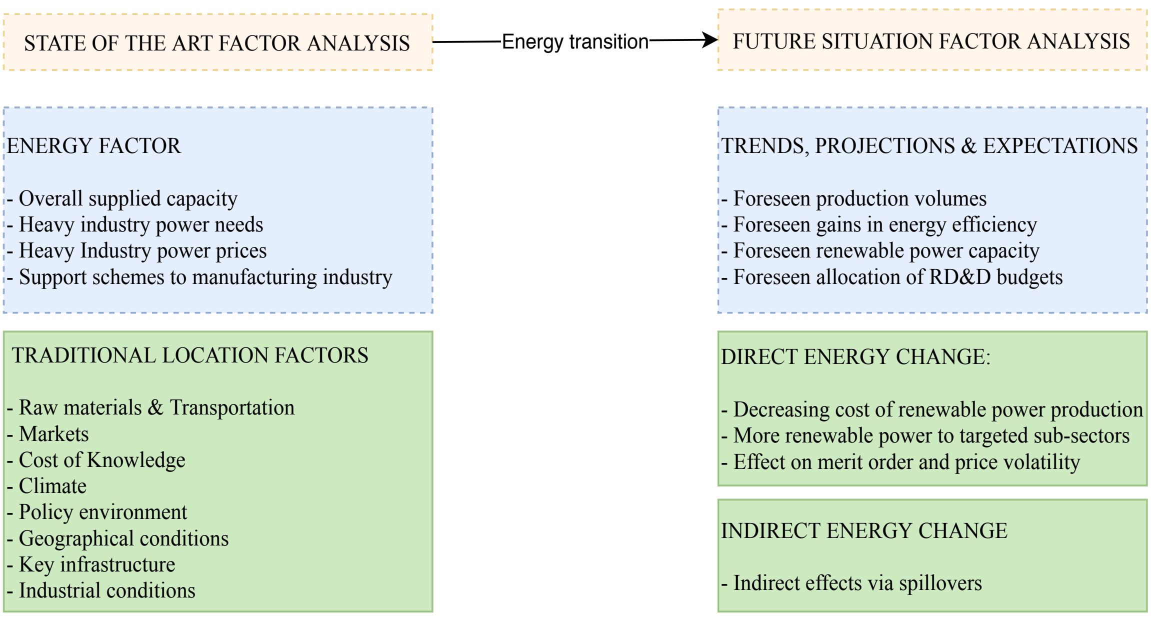
This chapter offers understanding on the suitability of industry cluster locations in Europe to a changing energy medium. To do so, a procedure to conduct analysis is developed and applied. The necessity to develop the evaluation procedure is motivated by the lack of a methodology to serve as a commonly accepted framework for the analysis of industrial location problems in the context of energy transitions. The so-called cluster evaluation procedure will be applied to the two test cases identified in chapter 3 (i.e. Italian cluster and German cluster). The goal is to understand if the EII clusters are well positioned for a renewable future or not. To convey such understanding, the two clusters will be evaluated in terms of the location factors defined in chapter 2. The evaluation will be conducted in two steps. The first step investigates the state-of-the-art of each cluster. The second step explores the future situation of the clusters (based on the directions of change defined in chapter 3). Finally, a comparison between state-of the-art and expected future enables to reason on the suitability of the sites of the clusters to the expected future renewable environment. The elegance of the evaluation procedure is that location factors are seen as variables and are all kept constant except the energy factor. Interestingly, changes in the energy factor spill over and influence the remaining location factors. Focusing on the energy factor, its change and its spillovers enable to create a future situation to reason on. Interpreting such future situation enables to predict what clusters should do in order to gain or maintain economic competitiveness. Since the success of the EII clusters is directly correlated to economic aspects of their locations, it will be possible to formulate propositions regarding the future suitability of the industrial sites of the clusters. These findings are important for industry practitioners because it allows them to make safer choices regarding future investment.

4.1 Introducing the cluster evaluation procedure

Proper interpretation of the information gathered in chapter 2 and in chapter 3 (i.e. critical factors, transition technology options and EII clusters) make it possible to formulate propositions that support and guide organizations when facing contemporary siting choices. To convey such propositions, an analysis that embraces scientific requirements while capturing all relevant aspects of the location problem under investigation, has to be performed. The central objective of the analysis is that of offering understanding on the suitability of European industry cluster locations in the context of an ever-changing energy medium. From a practical perspective, the analysis should enable practitioners to understand whether an existing industry cluster is well positioned for a renewable future or not. As such, the present historic context, suggests investigating the impact that the shift from traditional fossil fuels to renewable energy capacities will have on the selected heavy industry clusters. The rationale being that, the envisioned future renewable environment, holds the potential to greatly influence the competitiveness of state-of-the-art industry clusters, thus the economic activity of areas where clusters are located. Once quantified, this information becomes highly valuable for investors, as it enables them to base their strategic choices on aspects that capture current priorities and that act in support of sustainable growth. As such, by anticipating the implications of utilizing larger shares of RE capacities in the industry sector, it becomes possible to reason on the ways that enable safer, more secure and resilient investments. Since the magnitude of these investments partly depicts the attractiveness of industrial locations, it becomes possible to speculate on the status of an attractive future proof heavy industrial sector.

At this stage of the research, each of the analysed clusters results projected on logical directions of change (see chapter 3), in other words, energy technology pathways that promise high manifestation in the real word. Based on the proposed direction of change and on the grand scheme implications that will emerge when opting for that direction, this chapter explores and quantifies the impact of the envisioned energy transition on the clusters. To quantify the impact, an analysis that digs through complex layers of information is performed. Practically, the digging process consists in assessing the cluster transition potential in terms of location theory factors. The process is conducted with a particular interest on the energy factor. The rationale being that while traditional location factors are losing importance because of economies of scale and global supply chains (Goiri et al., 2011), the affordability and availability of RE capacities is becoming central for contemporary locational analyses. Moreover, by capturing the cluster transition potential in terms of the energy factor and its spillovers to the remaining factors, it becomes possible to offer guidance to organizations that are considering ways to gain or maintain economic competitiveness while decarbonizing their industrial processes. The elegancy in this analysis is that factors are seen as variable and are all kept constant except one, the energy factor. This makes things manageable and enables to bridge together the economic, geographic and location theory considerations that characterize each specific location problem under study. Moreover, keeping factors constant and changing only one of them, enables to notice spill overs of the changing factors onto many of the other factors. As such, reasoning logically on the outputs of the assessment, enables to offer guidance on the implications that clusters would experience if they were to transition to modern and cleaner technologies. Finally, it becomes possible to formulate a number of propositions regarding opportunities and barriers affecting the analysed industry clusters. Besides, the impact that the envisioned energy transition will have on the competitive advantage of broad European industrial areas will emerge as an output of the assessment. Figure 2 depicts the steps of the cluster evaluation procedure to be applied.

Figure 2 Graphical representation of the cluster evaluation procedure



Clearly, the quality of the outputs emerging from performing the Cluster evaluation procedure, are greatly influenced by the interpretative capabilities of the researcher. Although the benefits of performing classical statistical procedures (i.e. econometric analyses) based on large data sets are not directly integrated in the assessment, it is important to understand that in many instances performing such statistical procedures won't enable to answer interesting research questions that aim to anticipate the direction of future development. As such, to ensure validity of findings experts are consulted. At this stage of the research, they ere asked how realistic the projections are, if they agree with the hypothesized energy change and if they see other options and implications.

4.2 Current situation in Italy's Cluster: state-of-the-art cluster analysis

4.2.1 Current energy factor affecting site and cluster

OVERALL SUPPLIED CAPACITIES

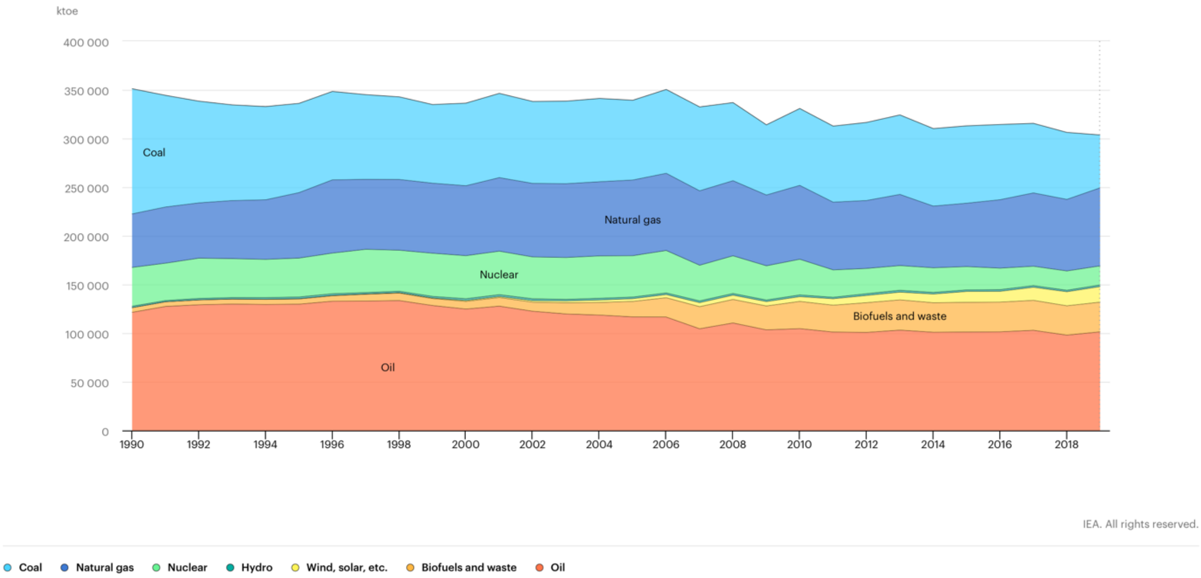
Nuclear Power

Although nuclear technology is commercially available, and in use in several European areas, the Italian energy mix does not include it for power generation purposes. Two referenda, held in 1987 and in 2011respectively, rejected this technology option and triggered a mechanism that lead to the complete phaseout of Italy's nuclear power generation facilities. The public responded this way because of the perceived risk of nuclear generation in an earthquake prone country. Secondly, the risk of pollution deriving from faulty nuclear waste management has strengthen the publics opinion.

Traditional fossil fuels

The country's energy portfolio has for a long period been dominated by oil, which is slowly but steadily being phased out. In 2018 electricity generated by oil accounted for 10762 GWh, an extremely positive figure when considering that throughout the nineties it accounted for 120888 GWh yearly. Italy has a relatively high share of natural gas (129743 GWh in 2018) when compared to that of other European countries. Moreover, a very limited use of coal (30542 GWh in 2018) characterizes the country. Italy's resource endowment in respect to fossil fuels is unfortunate forcing the country to rely on imports. Only small and poor-quality coal deposits are present within the Nation's borders. For the time being, natural gas is the dominant fuel for power generation as well as for industrial consumption. The reason that motivates this lies in the absence of cheap coal or oil alternatives. The strong dependence on imported natural gas may trigger issues concerning the country's security of supply and energy independence. In fact, only 10% of the natural gas needs are produced domestically, the remaining is imported. Data from 2013 shows that 45% of gas imports came from Russia, 20% from Algeria, 9% from Libya, 8% from Qatar and the rest mainly from Norway and other European countries (Virdis, 2015). More recently, natural gas has been losing market share to thermal renewables or renewable electricity and this trend is expected to continue apace. Moreover, without a change in industry structure, the use of solid state fuels such as coal for the steel and cement industries wont experience variations (Virdis, 2015). However, embracing the grand scheme transition drivers that are rising throughout the European Union shows that changes in industry structure are possible and make economic sense.

Figure 3 Total energy supply (TES) by source, Italy 1990-2018 Source: World Energy balances 2020, retrieved from (IEA, 2020)



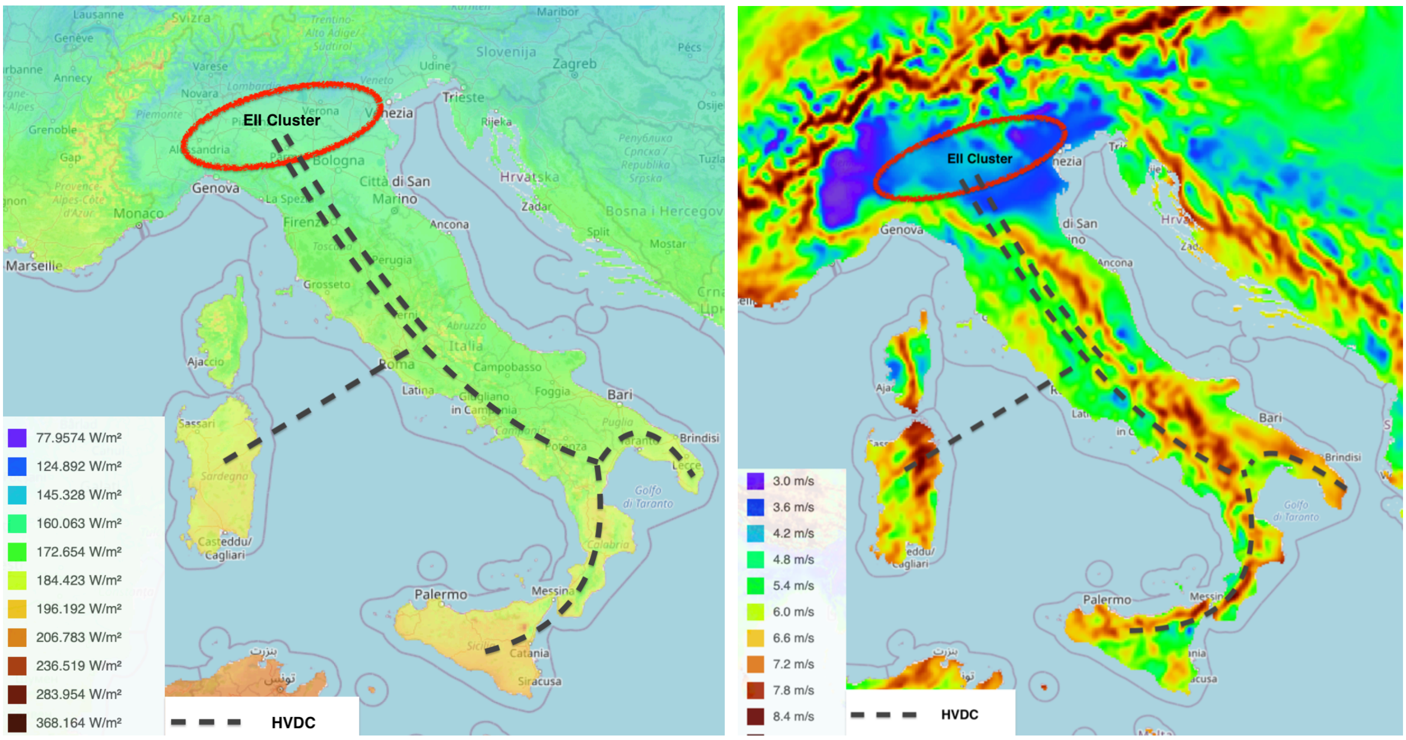
Traditional and modern renewables

The country's high temperature geothermal resources are concentrated in Tuscany. These natural resources were exploited early on and what remains as unused potential can't contribute significantly towards fulfilling the nation's needs. Geothermal production accounted for 6080 GWh in 2018. A small figure wen considering that total consumption in by energy intensive industries in 2018 accounted 203694.68 GWh (IEA, 2020). Italy always had a remarkable share of hydropower when compared to other European states. Yet, hydropower generation is not expected to increase much because the majority of the resource's potential has already been exploited. In 2018 the source supplied 49276.31 GWh, experiencing a slight and steady increase when compared to the preceding years. Generation via modern renewable technologies (i.e. wind and solar) has experienced an extremely large rate of adoption. Total electricity obtained by harvesting solar radiation through photovoltaic technologies, shifted from 1960 GWh in 2010 to 22653 GWh in 2018. A similar growth rate was experienced by capacities harvested from the wind. These accounted for 9126 GWh in 2010 and reached 17492 GWh in 2018. Finally, Biomass with its 16858 GWh supplied in 2018, is a significant contributor to the nation's energy needs.

GEOTECHNICAL CHARACTERISTICS OF (MODERN) RENEWABLE ENERGY SYSTEMS

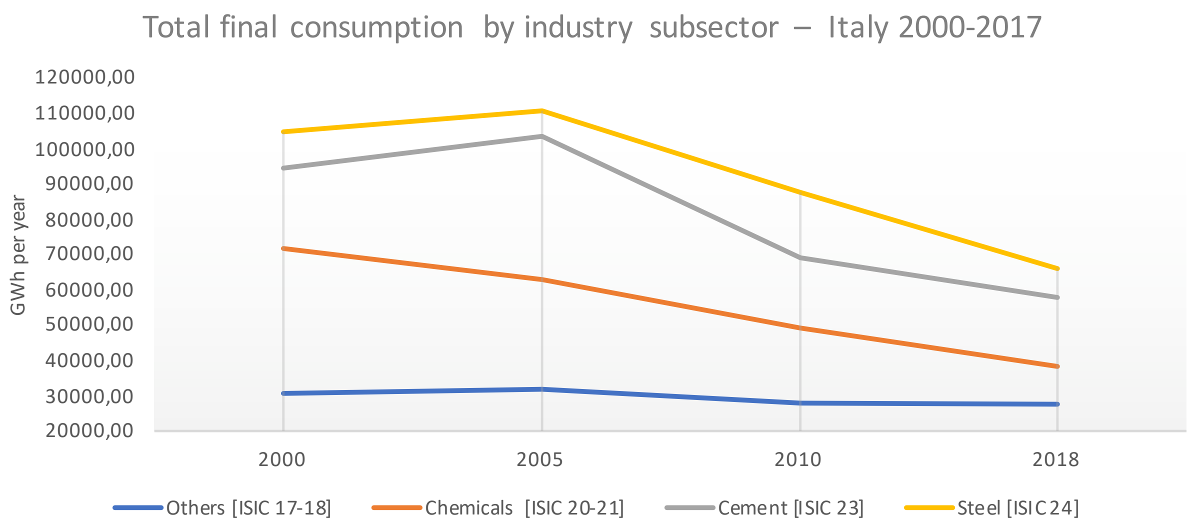
To investigate the potential of modern renewables it is important to have a clear understanding of their geographic and technical characteristics. By focusing on these relatively certain aspects, it becomes possible to formulate reasonable expectations which will serve as a hypothesis for the creation of a future situation to reflect on. To this end, the framework proposed by Scholten (2018) suggests investigating the geotechnical features of renewable energy systems such as sources, generation and distribution. Figure 4 offers a comprehensive understanding of these geotechnical features and their implications for Italy. The geographic potential of wind and solar generation is concentrated in Italy's southern regions. Since solar irradiation and wind speeds vary geographically, effective and efficient placement of RE harvesting technologies should follow these geographic patterns. However, to meet the future RE power needs of the Po Delta Cluster, its geographic location implies additional transmission infrastructure. The HVDC transmission lines depicted in Figure 4 highlight that in order to supply the future power needs of the cluster via renewable capacities major investments in enabling infrastructure are required. It emerges that new generation and transmission capacities based on power electronics, change the characteristics of the grid, especially in areas where they concentrate, creating new stability problems and operational challenges. TERNA, the Italian TSO is aware of these issues and confirms them. Additionally, the expert argues that in Northern Italy electricity prices used to be cheaper than in the southern regions. However, because of the geographic and technical characteristics of RE generation this is changing. Electricity prices are becoming cheaper in the southern regions because of higher production potential and limited transmission requirements. It emerges that the impact of such changes on the Po Delta cluster is harmful. The cluster's electricity prices (refer to page 61) are high compared to these of other EU nations. Besides, in response to the infrastructure needs a further increase in the price of electricity is expected. A deeper evaluation of the geotechnical features of RES and their interdependencies with the Po Delta cluster is offered in sections 4.2.2, 4.3.3 and 4.4. The guiding principle is that, as in the case of RES, the EII cluster is largely influenced by geotechnical features. Examples include primary raw materials and their transportation, generation technologies that are able to satisfy the power needs of the cluster and the storage infrastructure which is required for an adequate functioning of the system.

Figure 4 Geographic potential of modern RE generation in Italy and necessary transmission infrastructure to supply the Po Delta Cluster. Source: IRENA Global Atlas for Renewable Energy[16] adapted by the author.



[16]https://irena.masdar.ac.ae/GIS/?map=543&utm_medium=referral&utm_source=irenanewsroom.org&utm_campaign=privatedata

In 2018, the total primary energy supply in Italy accounted for 150577 ktoe, which translates into 1751210.51 GWh[17]. By zooming into the total consumption by sector, it can be noted that industry as a whole utilized 290563.92 GWh in 2018 (IEA, 2020). Since steel, chemicals and cement production account for approximately 70%[18] of industry's total consumption, the total consumption of the energy intensive subsectors results 203694.68 GWh in 2018. This back of the envelop calculation is confirmed by a study conducted on behalf of the Italian Ministry of Economic Development. The study stresses the fact that Italy's chemical sub-sector has way less energy intensity requirements (especially heat) when confronted to those of the steel and cement sub-sectors (Federchimica, 2019). It is also emphasized that the CO2 leakage is contained when compared to emissions from steel and cement manufacturing. Although Italian chemical industry is a major player in Italy's economy, for the end of this study it appears more insightful to focus on the cluster's dominant sub-sectors, namely steel and cement. By breaking down the cluster's total energy consumption into its constituents, it is possible to calculate that cement and steel production are accountable for 123788,89 GWh of power usage in 2018. These figures are very important because they show the volumes of power (both electricity and heat) that should be supplied via renewable sources in order to achieve decarbonization of EIIs while maintaining current production volumes. The image below graphically depicts the evolution of consumption trends by the analyzed energy intensive sub-sectors. The decreasing trend in power consumption is partly motivated by energy efficiency increases. The real driver of the decreasing trend is the relocation of industry to eastern nations[19].



Elaboration of data retrieved from (World Energy balances, 2020 and IEA, 2020)

Overall, the generation by source and the consumption by sub-sector patterns show that, in order for renewables to supply the power needs (both electricity and heat) of the industry sub-sectors under study, the existing renewable generation capacities need to be increased. Although heat needs are more severe than the electricity

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[17] IEA Energy Data & Statistics 2020 – Italy energy balance 2018
[18] Italian Ministry of Economic Development 2018
[19] Confirmed by most Italian interviewees – summary of interviews in appendix

ones, the adoption of the discussed transition technology options allows to treat them as one entity. The idea is that processes requiring the provision of heat are going to change shape. From traditional heat that comes from fossil fuel power plants, to heat that is generated on site by specific technologies[20] which are powered by renewable energy sources. It is important to understand that the presented figures reflect the total installed capacity required for the energy intensive industry sub-sectors (thus the entire heavy industry cluster) to become 100% renewable. As such, the future supply of these power volumes is considered to be a priori allocated to the consumption needs of the cement and steel sub-sectors. Although these figures are high, the time window considered in the research (2020-2050), allows to treat them as feasible or at least achievable. Adding to this, the 2050 EU objectives don't require to achieve the theoretical 100% renewable theoretical potential, but only part of it. In addition, most of the interviewees agree on the technical feasibility of supplying the required renewable capacities in the considered time horizon.

HEAVY INDUSTRY POWER PRICES

The price of electricity for industrial consumers in Italy is almost the most expensive in the EU. Only Denmark, Germany, the UK and Cyprus have a similar price. In the second quarter of 2018, Italian electricity cost for industrial consumers accounted for 10.43 c€/kWh (eurocent per kWh), whereas the average EU prices were of 10.22 c€/kWh (excluding VAT and other recoverable taxes).

Comparing Italian natural gas price to the EU-28 average price, points to a difference on the retail market between industrial and residential consumers. Although the price paid by industrial consumers was below the average European price in 2018 (2.27 c€/kWh against 2.35 c€/kWh), prices for residential users ranked third in the EU in 2018. This difference is motivated by the level of energy taxation for natural gas in Italy (Japan, 2019). The nation relied on gas imports for more than 90 percent of its demand, therefore the industry price of gas depended on the wholesale price rather than the domestic market[21].

The 2017 National Plan for Energy and Climate confirmed the closure of coal-fired power plants by 2025 (INECP, 2017). The very interesting aspect surrounding coal consumption is that industry sectors (particularly steel and cement), consume large amount of power provided by this source[22]. Moreover, The Minister for Economic Development stated in 2017 that "an exit from coal between 2025 and 2030 is possible and will cost about €3 billion" (Wynn, 2017).

Oil prices in Italy are fully liberalised, therefore they follow European prices. However, in the past decade, gasoline and gasoil prices have been constantly higher than the EU average prices (+11% for gasoline and + 10% for gasoil

[20] Electric arc furnace, electrolysis-based steelmaking etc. (For a detailed overview refer to the morphological chart in chapter two).
[21] Statista 2020
[22] Information retrieved from ENEL and ENI official websites and G20 report on coal subsidies

in 2018[23]). Taxation schemes are accountable for the gap between European and Italian prices. Pre-tax prices are very similar to the European average, however in 2018, VAT and excise taxes amounted to 66% of the gasoline consumer price and 60% of the gasoil consumer prices (Japan, 2019).

SUPPORT SCHEMES TO MANUFACTURING INDUSTRY

As reported in the NES and in the INECP, the Italian government supports specific end-user manufacturing industries through the reduction of the cost of their fossil-fuel inputs. The majority of these measures are tax reductions or exemptions on fossil fuels (INECP, 2017). These measures include bill reduction for large energy consumers agreeing for energy interruption in case of emergency. In addition, Industries agreeing for an interruptible power superior to 40 MW are exempted from payment of several electricity tariff components (INECP, 2017). Finally, the European Union's Emissions Trading System (EU ETS) acts a further support mechanism for large energy consumers. It targets sectors facing carbon leakage risks by offering them emission allowances. Manufacturing industry remains a sector benefiting the allocation of emission allowances. All experts agree on the role of well thought support schemes (i.e. incentives, emission allowances, tax and bill reductions) which are seen as key enablers of the transition of the EII cluster under study. The possible futures reported in the comparative table depicted in Table 9 highlight the role of well thought support schemes and strategic planning.

4.2.2 Traditional location factors affecting site and cluster

FACTOR RAW MATERIALS & TRANSPORTATION

Cement and steel are among the bulk commodities with the lowest value per weight ratio. With the exception of some high-value cements, transportation of cement over distances longer than 200 km is usually not economically viable (Ramirez, 2017). Thus, the supply and demand for cement is mostly local and international trade intensity is low. Although the value per weight or volume ratio of steel is higher than that of cement, a similar transportation rationale holds. Steel transportation over long distances is economically justifiable only when bulk quantities are transported by ships or when production costs are extremely low (e.g. China). As pointed by various location economists, the ease of accessing inputs and distributing outputs is crucial. It follows that facilities are usually located close to quarries due to the cost of transporting inputs, which in turn makes it necessary to secure licenses for the quarry and plant. However, because of the absence of primary raw materials within Italy's borders, the nation imports almost all primary raw materials required for cement and steel production as well as the energy sources needed for powering the related processes. This points to the fact that while the dependence on imported raw materials will remain, the dependences on imported input fuels can be reduced by utilizing domestically generated RE.

FACTOR MARKETS

[23] Data from European Commission 2018

In line with the arguments on raw materials and transportation, it emerges that the ideal market of goods produced by the heavy industry sub-sectors under study should be of a local character. Although international trade is an aspect that captures major investment interests, it should be realized that the present market structure needs rethinking. For instance, competing with China's products outside of the EU-28 free trade zone does not make strategic economic sense. Former Italian prime minister Romano Prodi argues that European choices made twenty years ago are now harming Europe's future economic competitiveness. Contemporary effects caused by the relocation of highly strategic sectors to China urge the EU to rethink its choices and to prioritize and safeguard the local interest. To conclude, on the sale side, the existence of present and future local demand, price projections, and transportation options to other markets are of key importance and offer rebirth.

FACTOR COST OF KNOWLEDGE

Although all European areas host specialized workforce, the cost and availability of expertise vary in function of geographic areas. In Italy the cost of specialized workforce is relatively high when compared to other EU areas[24]. The cost and availability of specialized workforce are aspects that require careful consideration because their absence may have severe repercussions on the success of the clusters. For example, sometimes because of power outages, machinery issues or component breakdown, downtime occurs. This is to be conceptualized as a period in which production is stopped because of unexpected issues. The cost related to downtime is very high and includes lost production, lost capacity and direct labor (Rewo, 2020).

FACTOR CLIMATE

There is a positive reinforcing feedback between the investigated EII sub-sectors and the climate. Depriving and polluting the natural ecosystem to guarantee mankind's desired level of comfort, does not come without a cost. This cost refers to the emergence of irreversible changes on the planet's ecosystem. Examples of such changes include scarcity of raw materials in the future, scattering on incoming solar radiation and consequent changes in Earth's temperature, an increasingly polluted environment, and the impact of such changes on society and people's health. To cope with the presented issues, the modernization of EII clusters (i.e. adoption of TTO and increased usage of renewable power), can have an extremely positive impact in terms of avoided emissions. The guiding principle is that, although the investments to make the transition happen are high, the avoided costs, in terms of environment and people's health, outweigh them. An estimation by Wuppertal Institute suggests that a complete transition of the Po Delta cluster to RE power cloud have an impact of avoided greenhouse gas emissions of 17 Mt CO_2eq/year in 2050[25].

FACTOR POLICY ENVIRONMENT

[24] Eurostat 2019 - Average wages EU member states
[25] The value is offered for Germany energy intensive industry in Schüwer and Schneider (2018). It is adapted to this research by comparing the power requirements of the two clusters of industries and by reasoning on the penetration potential of RE in the cluster.

The Italian case is affected by not neglectable path dependence. Choices made in the past shape the current structure of the Italian energy system and the way the Po Delta cluster adapts to it. Besides, unless functional transition choices are made today, it can be anticipated that the existing locked-in situation surrounding fossil fuels consumption will feed and reinforce itself. Currently, Italy's energetic considerations are captured in the National Energy Strategy (NES), which dates back to 2013. The document internalizes the 2011 energy and climate roadmap to 2050 of the European Commission, as well as the 1.5 C stipulated with the Kyoto protocol. Only the final chapter of the NES discusses the long-term implications and challenges of the roadmap to 2050. The main points included in the NES articulate on i) fostering sustainable economic growth, ii) meeting the targets of the EU 2020 Climate and Energy Package and iii) improving the country's security of supply while decreasing the gap on electricity costs that exists between large and small consumers. In the Po Delta cluster, these points can be met by decarbonizing power generation via the adoption of RES coupled with the TTOs, by increasing electrification of heat production and by enabling greater energy efficiency. A second document that focuses on Italy's energetic and climatic considerations is the Integrated National Energy and Climate Plan. This document rectifies the NES but delivers the same considerations. TERNA suggests focusing on the INECP because it is the scenario that will occur because it is what the Italian government opted for. Although the INECP discusses some of the industry issues that are presented in this thesis, it anticipates that coping with them is a longer-term objective for 2050 (INECP, 2017 p.124).

FACTOR GEOGRAPHICAL CONDITIONS, FACTOR KEY INFRASTRUCTURE AND FACTOR INDUSTRIAL CONDITIONS

Although the three factors under analysis were defined as belonging to distinct categories, because of strong interrelations between each other, it is convenient to study them together. Overall, the country has a functional and modern infrastructure. However, it performs poorly when compared to that of neighbour Western European countries. The peninsula is well connected through an extensive railway system, expressways, national roads, airports and seaports[26]. The Alps surrounds the northern area of the nation. Longitudinally the Apennine mountain chain splits the county in two sides. These orographic characteristics limit the utilization of railroads to move people and goods, both towards neighbour countries in the north and from the Tyrrhenian to the Adriatic coast (or vice-versa). This forces the country to rely on roads, and secondarily on maritime transport. Since most goods in Italy are transported by road, the system is constantly upgraded and improved. Moreover, Northern Italy's important economic growth rates and the geographical proximity to the industrial heart of Europe, make it a key commercial area. By contrast, the geographical isolation and poor economic development of Southern Italy meant that infrastructure was never a priority except for seaports. Finally, it emerges that the co-evolution of industry and related infrastructure needs, made the northern regions subject to an agglomeration of energy-intensive industries.

4.3 Future situation: introduction on trends, projections and expectations

4.3.1 Trends, projections and expectations

[26] Nations encyclopedia – Italy's Infrastructure, power and communications 2020

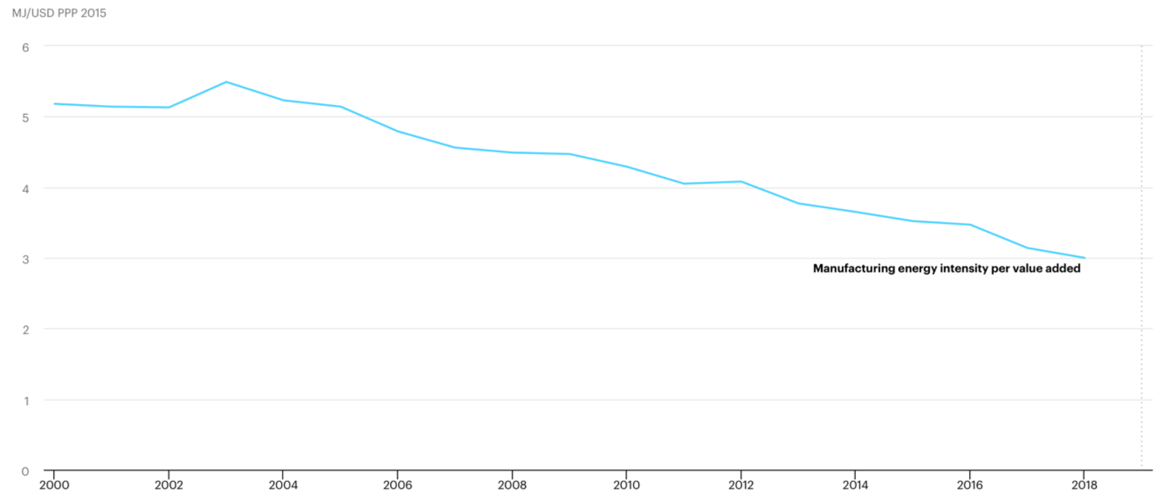
FORESEEN PRODUCTION VOLUME OF GOODS IN 2050

To anticipate the total needed capacity for future EII applications a central consideration is made. It refers to the expected future demand of products produced by the sub-sectors that constitute the Po Delta cluster. It was found that the demand for cement and steel are largely influenced by economic developments and population growth (Ramirez, 2017). The rationale is that these commodities are mostly used in the building and downstream metal sectors. As such, demand is expected to remain stable in developed countries until 2050 and set to continue to increase in emerging economies. This information is extremely valuable because it enables to use current industry production volumes as proxies. In other words, by assuming that the volume of goods delivered by the Po Delta cluster remains constant through time (because the market demand does not change), it becomes possible to reason on how to maintain the present production rates while gradually shifting the power sources.

FORESEEN GAINS IN ENERGY EFFICIENCY

Producing the same volume of goods in conditions of increased energy efficiency implies reductions in the total required power capacity. In accordance with IEA's datasets, ENEA, the national agency for new technologies predicts 1.7% yearly gains in energy efficiency for the heavy industry sub-sectors (ENEA, 2018). This yearly gain in energy efficiency internalizes the adoption of TTOs by the Po Delta cluster. Moreover, its effect will further shrink the demand of power of the cluster, leading to a lower total annual usage of GWh in 2050. Assuming this rate, power demand could shift from roughly 2036894 GWh in 2020 to 125781,30 GWh in 2050. It should be kept in mind that these values enable the comparison with state-of-the-art values.

Figure 5 Manufacturing energy intensity, Italy 2000-2018. Energy Efficiency Indicators retrieved from (IEA, 2020)



FORESEEN RENEWABLE POWER CAPACITY IN 2050

In order to verify the feasibility of the transition it is necessary to quantify the future expected energy capacities. To this end, it was decided to focus on national estimates published by the Italian government and reviewed by the European Commission. A such, the only available documents that fulfil these requirements are the NES and the INECP. The documents offer various growth targets among which the trajectories for 2030 for the renewable share in the electricity sector. Since this study is interested in a time horizon that reaches 2050, by applying linear interpolation routines, the 2030 trajectories are extend to 2050. Table 2 presents the growth rates and trajectories for 2050 for the share of renewables in the electricity sector. Finally, Italy's geographic configuration (i.e. great solar irradiance and relatively high wind speeds in the southern areas) suits the production of large volumes of RE power. However, the transportation of such power to the industrialized areas which are located in the north demands major investment in key enabling infrastructure.

Table 8 Growth targets and trajectories for 2050 for the renewables share in the electricity sector (TWh)

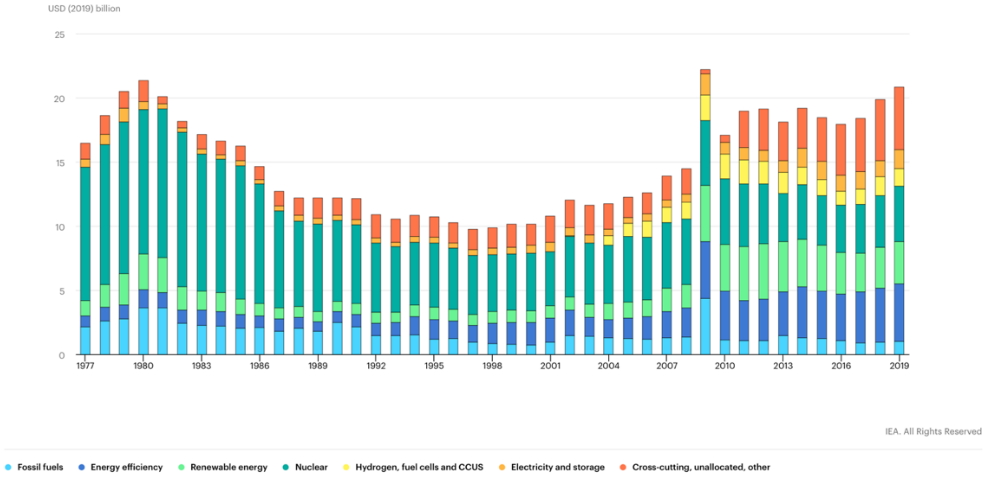
	2016	**2017**	**2025**	**2030**	**2040**	**2050**
Renewable production	110,5	113,1	142,9	186,8	203,0	228,9
Hydropower	46,2	46	49	49,3	50,7	51,9
Wind	16,5	17,2	31	41,5	48,8	57,6
Geothermal	6,3	6,2	6,9	7,1	7,4	7,7
Bioenergy	19,4	19,3	16	15,7	14	12,6
Solar	22,1	24,4	40,1	73,1	82,1	99,0

Source: Integrated National Energy and Climate Plan 2017 (INECP, 2017). Extended to 2050 by the author.

FORESEEN ALLOCATION OF RD&D BUDGET PER TECHNOLOGY

IEA data on the RD&D budget per energy technology point to the fact that large investment is already targeted to drivers (i.e. energy efficiency, renewable energy, storage and crosscutting technologies) of a successful transition. These trends are expected to keep on increasing and general patterns are offered in Figure 6. It was discussed that the role of support schemes is essential in order to enable the transition of the Po Delta cluster. The same rationale holds for the allocation of budgets to RD&D. These are seen as critical not only because key enabling technologies are essential for the transition but also because Europe's leading technological and innovative position has been gradually taken by China. At an Italian and European level, there is clear strategic interest in regaining the pioneering leadership role in innovation and in technological advancement.

Figure 6 Allocation or RD&D budget in Italy Source: IEA Energy technology RD&D budget, 2020



4.3.2 Energy change: direct effects on energy factor

DECREASING COST OF RENEWABLE POWER PRODUCTION

Generation via wind and solar technologies is expected to fulfil Italy's future power needs. The rationale is that these technologies are increasingly being accepted as means for accelerating the transition towards sustainable energy. According to IRENA's report on Renewable Power Generation Costs, the cost of RE is decreasing following a trend that should make it become a consistently cheaper source of electricity generation than traditional fossil fuels. IRENA's data show that the cost of generating power from onshore wind has fallen by around 23% since 2010 while the cost of solar photovoltaic (PV) electricity has fallen by 73%. The price falls are expected to keep following the same trend in the future for these and all other green energy options that offer a business opportunity. Further IRENA data shows that European onshore wind schemes cost on average 0.06 €/kWh, with minimums at 0.04 €/kWh. The cost of solar PV is down to 0.10 €/kWh. In comparison, the cost of electricity generation based on fossil fuels typically falls in a range from 0.05 €/kWh to 0.17 €/kWh (IRENA, 2017). Furthermore, the report predicts that onshore wind and solar PV projects could be consistently delivering electricity for as little as 0.03 €/kWh within a short time. Adnan Amin, director-general of IRENA, affirms "These cost declines across technologies are unprecedent and representative of the degree to which renewable energy is disrupting the global energy system". This proofs that a significant shift is underway in the energy sector and highlights the potential of reducing dependency on fossil fuels.

ALLOCATING MORE RENEWABLE POWER TO TARGETED INDUSTRY SUB-SECTORS

Looking at Italy's energy balance enables the conception of an argument. When focusing on the total final consumption of the industry sector it can be noted that it is dominated by the use of natural gas. The second dominant source of power is oil. Finally, coal is almost absent from this energy portfolio. The interesting observation emerges when focusing on how much power is currently being supplied by renewable energy sources. For the time being, wind and solar account for a limited proportion of the industry's final needs. History is responsible for this. The reason is that, when compared to traditional fossil fuels, modern renewable options have recently penetrated the market. Moreover, evidence shows that even though large capacities are needed in order to fulfil industrial requirements, technically these capacities can be supplied. The evidence is captured in IEA's RE rate of adoption graph. The graph enables to see that solar photovoltaic production increased from 1906 GWh to 18862 GWh in just two years. A similar but relatively slower production trend was experienced by wind harvesting technologies. In both cases, an interesting observation regards the plateau that can be observed after 2013. The plateau was triggered by the need of the national government to safeguard ENI's (a state-controlled company) economic interest of existing fossil fuel generation power plants. Changes in policy were made to disincentivize renewable energy technologies. Practically, the policy's objective was that of reducing the remuneration (eurocent/KWh) that producers of renewable electricity were receiving.

Figure 7 Elaboration of data on total production and total final consumption in 2018. Retrieved from IEA Italy balance datasets, 2020)

	Coal	Crude oil	Oil products	Natural gas	Hydro	Wind, solar, etc.	Biofuels and waste	Electricity	Heat	Total
	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe
Production		4 456		4 536	3 113	9 331	12 580			34 016
Imports	9 594	70 237	14 724	57 044			2 643	3 688		157 930
Exports	-234	-1 650	-30 487	-223			-331	-441		-33 366
Marine bunkers			-2 303							-2 303
Aviation bunkers			-3 419							-3 419
Stock changes	-16	879	-438	193			-32			587
TPES	9 344	73 923	-21 923	61 549	3 113	9 331	14 861	3 247		153 445
Transfers										
Statistical differences	298	-55	127							370
Electricity plants	-7 207		-501	-8 620	-3 113	-8 954	-2 736	15 810		-15 319
CHP plants	-722		-3 663	-16 366			-3 444	9 469	5 252	-9 474
Heat plants			-2	-247		-38	-99		323	-63
Gas works				7			-7			
Oil refineries		-75 671	76 359							688
Coal transformation	-889									-889
Other transformation		1 803	-1 872				-7			-77
Energy industry own use	-56		-3 062	-1 417				-1 817	-1 403	-7 755
Losses				-329				-1 605	-58	-1 992
Total final consumption	769		45 463	34 577		340	8 568	25 104	4 114	118 934
Industry	707		1 954	8 871		13	625	9 941	2 874	24 984
Transport			31 421	1 064			1 062	979		34 525
Residential			2 087	17 261		155	6 757	5 631	905	32 797
Services			546	6 590		122	88	8 039	308	15 693
Agriculture / forestry			2 010	136		16	35	488	10	2 696
Fishing			161			34		27		222
Non-specified			85						16	102
Non-energy use	61		7 198	656						7 915

4.3.3 Energy change: indirect effects via spillovers to traditional location factors

Factor Raw Materials & Transportation

Aspects regarding transportation of commodities are not expected to be directly influenced by the envisioned energy transition. Besides, changes in state-of-the-art transportation may be triggered by a change in market structure. Regarding primary raw materials and fuel inputs, it can be anticipated that current import dependence will be difficult to overcome. The absence of queries, coal mines, petroleum and natural gas reservoirs is an intrinsic characteristic of the country that can't be changed. The primary raw materials required for steel making ad cement production could come from recycled products. Since Europe is subject to an abundant supply of scrap metals, their utilization could reduce import dependence. However, important changes in the production process and in the technology are necessary (i.e. adoption of electric arc furnace for steel production and clinker substitution). Ideally, there is room to alleviate dependence on fuel inputs by installing more renewable power generation capacity. A further solution to reduce import dependence of primary raw materials lies in the negotiation of win-win trade solutions within the EU-28 market members.

FACTOR MARKETS

Markets of goods provided by heavy industry are experiencing variations as a direct result of the energy transition. Geo-economic changes are taking place. These are global changes pointing to emerging economies, which become important markets, both in size and in growth. In particular, the demand of cement and steel commodities are largely influenced by economic developments and population growth. The rationale is that they are mostly used in the building sector and in the downstream metal sector. Demand is expected to remain stable in developed countries until 2050 and set to continue to increase in emerging economies (Ramirez, 2017). Ideally, the goods produced by Europe's heavy industry should be competitive on international markets, however competition with Chinese, Brazilian and Indian production is challenging. Izsak, Markianidou and Rosemberg (2015) argue that emerging markets are increasingly changing from low-cost production locations to large consumer markets. Perspectives for the future growth of EII clusters in Europe and their cluster members may very well depend on their ability to adapt business models to these economic realities. On the other side of the spectrum, because of the very low value rate per weight or volume, cement and steel trade acquire a competitive character when markets are in the proximity of the production site. As such, to safeguard the interest of Europe's market power and its production volumes, thus the existing clusters that operate in these sectors, it appears appropriate to design market mechanisms aimed at incentivizing trade in the Eurozone. This way, dependence on imports will decrease, high quality materials will be available domestically and significant emission reductions will be met when shares of renewable power will be integrated and coupled with the adoption of the transition technology options.

FACTOR COST OF KNOWLEDGE

The impact of this factor on location determination is expected to change shape while gaining more and more relevance as the transitions happens. The rationale is multifaced. Although, on the one hand, the cost of transporting people is experiencing a rapid decline and where knowledge can be easily shared through ICT means (i.e. online platforms), pointing to a decline in importance for location determination. On the other hand, the degree of innovation required to enable the transition, points to the necessity of a highly skilled and productive workforce both at national and European level. In addition, operating in a cluster implies communication and alignment among the entities that constitute the cluster. This highlights the need of highly prepared and educated workman.

FACTOR CLIMATE

The impact in terms of emission reduction deriving from a complete transition of the cluster under study is considerable. Moreover, the emission reduction potential implies that emissions can be narrowed down to almost zero, but this requires a fully decarbonized power sector[27]. Hence, industrial electrification would only make sense if the utilized electricity is produced without CO2 emissions.

[27] Institute for EU studies 2018 – Industrial value chain long term emission reductions

FACTOR POLICY ENVIRONMENT

Interviewing experts pointed to the fact that the required transition in the heavy industry cluster will not take place in the absence of smart and committed public policies. The government has to assist these industries through their modernization. The high capital intensity of investments affecting these industry sub-sectors acts as barrier for investments. For example, sovereign loan guarantees can help reduce the cost of capital of these investments, in particular for sectors and companies that are underperforming at the moment. Governments can also help to create markets for new low-carbon products through public procurement. Market presence in Europe, incentivizes production of low carbon commodities and urges industry to transition. Avoiding regulatory misalignment is a third important element, as punishing industries that move to low-carbon processes or business models slows down the transition process. Finally, bringing promising TTOs to the commercialization stage is the most challenging part of the industrial low-carbon transformation and demands governmental support. Since required investments are capital intensive but also, due to their pioneering nature, risk intensive, ensuring a fair playing field by means of clear and unambiguous national industry strategy is necessary. According to the interviewed experts, political stability and development of national strategy are central for TTOs to be market-ready by 2030 thus allow for their deployment across the EU by 2050. The EU ETS innovation fund for the period 2020-2030 can become an important tool to enable a timely commercialization of these process technologies.

FACTOR GEOGRAPHICAL CONDITIONS, FACTOR INDUSTRIAL CONDITIONS & FACTOR KEY INFRASTRUCTURE

Geographic conditions are intrinsic thus not affected by the transition. Key infrastructure plays an enabling role for the transition of EII as well as for the overall feasibility of the energy transition. As it was in the past, it can be expected that infrastructure will keep developing proportionally and in accordance to the economic growth and development of regions. To incentivize industry investment the necessary parallel infrastructure must be made available in time. This targets infrastructure designated for the transport of large quantities of electricity, the storage of large quantities of electricity, and sequestration and utilization systems such as CCS and CCU.

4.4 Comparison between present and future: similarities and differences

OVERALL SIMILARITIES AND DIFFERENCES

Performing the Cluster evaluation procedure makes it possible to identify similarities and differences between the state-of-the-art and the envisioned future in Italy. As it is today, because of the social and political landscape, nuclear power is not going to serve the country’s future power needs. Moreover, traditional fossil fuels shares in the energy mix of the country will keep on decreasing through time, eventually reaching phase-out. Similarly, the current trend depicting penetration of RES in the country’s energy portfolio is expected to keep increasing. Interviewing TERNA, the Italian TSO led to understand that although in Italy RES are incentivized through auctions that guarantee certain incentives for certain capacities, “the last auction was a complete disaster”. Not even half of the needed capacity was allocated to investors because of faulty guidance on the incentive scheme being offered. In addition, all interviewed Italian experts highlight the necessity of a national industry and energy strategy to enable further RE development and TTOs adoption by industry. It is expected that companies will not make the necessary transition investments if the economic and regulatory long-term environments are unclear and uncertain. The interview with Zintec underlines that Italy has been neglecting the strategic importance of its industry for a long time, resulting in a situation where companies were forced to think of survival in terms of decreasing costs and quality of final products. This highlights the delicate situation the Italian industry is experiencing. Actors focus on options that allow for business opportunities in the short term which implies short term survival. Practically, Italian industry actors seek clear political signals aimed at demonstrating that the national government intends to support them through their modernization actively. Reasoning on companies as a rational economic actor points to three possible future options:

- Invest in climate-neutral technologies in this investment cycle and update business models accordingly;
- Shut down existing production units at the end of their service lives (disrupting the local economy and integrated value chains);
- Invest abroad and import the commodities that are needed domestically (triggering dependence on other nations).

As it was demonstrated, heavy industry power needs have followed a decreasing trend over the past decade. Because of further efficiency development, power needs are expected to keep decreasing, implying production of commodities with less intensive power requirements. Adding to this, the decreasing trend that will impact heavy industry power prices (due to increased competition on wholesale markets from larger availability of RE, improved interconnections and presence of a more integrated electricity market), serves as initiator for the transition process of the EII cluster. Future availability of affordable power motivates industries to adopt TTOs, which in turn implies a further reduction of power requirements. This positive feedback mechanism motivates further electrification and modernization of industries, as well as the emergence of important system level changes. These changes point to the need for major parallel infrastructure development, which should ensure the functionality of the envisioned future energy system. The rationale being that, as electrification of industries becomes more and more attractive, industries will transition causing an overall increase in energy demand. As this increase should be covered by RE, need for storage technologies or backup powerplants becomes central[28]. To ensure that the storage needs of the system are met, the Italian TSO subject to authorization from the ARERA, and based on the guidelines issued by the Ministry of Economic Development, is responsible for constructing and operating storage systems directly connected to the national transmission network[29]. The development of such storage systems in combination with adequate expansion of the national transmission and distribution network and of interconnector capacity should enable to cope with possible volatility of energy prices as well as with grid balance issues.

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[28] Although of RE's penetration potential, traditional fossil fuels have certain advantages when compared to modern variable renewables. Namely, output can be ramped up or down to meet demand. For instance, solar and wind technologies can't do that, outputs can be harvested only when the sun shines and the wind blows. This implies the necessity to develop parallel technologies (i.e. capacitors and batteries) aimed at storing energy for when it is needed. The INECP discusses the criticality of developing storage systems that are instrumental in managing the security and efficiency of the national transmission network.

[29] Information from Integrated National Energy and Climate Plan 2017 p. 209 – The information is confirmed in an official interview with TERNA, the Italian TSO.

An important similarity between Italy's present and future is the allocation of RD&D budgets and targeted support schemes to the EII cluster. Currently, the nation is investing huge sums in researching key transition enabling technologies. Since the vast majority of technologies enabling industry's climate neutrality are close to market readiness or can be brought to market readiness shortly, it is important to keep on allocating funds in this direction. Moreover, since these modern technologies are currently more expensive than traditional ones, demonstrating CAPEX and OPEX reductions will serve as an incentive for companies to invest and transition. The reason being that demonstrating additional cost reductions is expected to make the business case of such technologies more secure and attractive. The biggest challenge affecting TTOs lies in the fact that additional costs cannot be fully passed on to the consumers. According to the interview with Confindustria, if this was to happen, this last category of actors will tend to purchase cheaper and lower quality commodities offered by the international market. The effect of this is to be conceptualized as the absence of an incentive for industry to transition. Finally, the combination of

Factor specific similarities and differences

An important similarity between present and future, concerns transportation and utilization of primary raw materials for cement production. According to the interview with Heidelberg, cement industry relies on clinker production, which demands the utilization of limestone as primary raw material. Production of clinker is expected to remain in the proximity of limestone quarries. The reason is that transportation of biomass is economically more attractive than transportation of limestone. A further reason is that building new limestone quarries comes with acceptability issues by the public at large. Theoretically, cement production out of the clinker could be done elsewhere, possibly where there is a local market for it. Practically it is more convenient to keep it close to the clinker facility. Heidelberg expects plants that will remain operational to change from only cement plant to a combination of cement plus chemical plant. The idea is that CO2 could be produced on site and used for various purposes (i.e. re-carbonization, mineralization of aggregates, recycling and geological storge). In addition, the interview with Confindustria and ASSO-Energia highlights that in Italy, cement companies have not yet taken major modernization initiatives.

Transportation and utilization of primary raw materials for steel manufacturing is more prone to change. For instance, high temperature arc furnaces can fuse scrap metals, making it possible to initiate domestic recycling and circularity in steel manufacturing. Urban mining can play a major role in the collection of the required primary raw materials. Since Europe relies on high availability of such metals, domestic steel production is expected to offer major economic opportunities. Italian market players could adapt their business models to accommodate the emerging opportunities of domestic steel production. Critical enablers of this novel market creation process are rules and institutions, that should be designed in a way that safeguards local investment. EU's strategic intention of supporting adequate local returns is expressed by the existence of the EU28 free trade zone. In other words, a territory where no customs duties are paid on goods moving between EU Member States[30]. Making this artifact respond in a more restrictive manner to international trade of steal and cement related commodities, results in a fair playing field for local actors.

The impact of cost and availability of specialized workforce changes shape as the transition happens. Decreases in both cost and time required for transporting people and knowledge point to a resizing of the importance of this factor. Concomitantly, to enable a successful transition, highly educated and skilled workman must be present and adequately remunerated. A transition enabling workforce needs to be highly prepared and educated, not only to be able to face the challenging technological environment to be created, but also to be able to communicate and effectively share knowledge. In accordance with a recent reflection of former Italian prime minister Romano Prodi, to prepare for a futureproof industry, Italy must reinvent its education system. Adding to this, the interview with Zintec points to misalignment between the high academic preparation of young Italian engineers and the very limited practical knowledge possessed. The suggestion is to include technical preparation for operational environments in high school formation.

In conclusion, an attractive industry environment for Italy's future implies the realization of the presented key enablers. According to Italian interviews, monetary expenses are not the real issue, these sums are seen as necessary for modernization and should be shared by all actors involved. The real issue lies in the absence of security for long-term investment, emerging in response of Italy's unstable political environment. This aspect is complicated to cope with, internal conflicts of interest and arguable political decision-making have affected Italy for a long time. Mario Draghi warns Italian politicians highlighting that failure in the utilization of the incoming COVID-19 recovery fund won't make the present political party go home, but it will make Italy go home. Predictability of legislation and alignment of interests must be achieved to enable industry investment and modernization. These considerations are central but further elaboration and design of solutions goes beyond the scope of this thesis thus it is left to future research. Table 9 summarizes the findings emerging from the comparison of the present and future situation of the Po Delta cluster. A future with incentives and support schemes is more attractive for the interest of the companies of the cluster. Availability of sources (AV) and their affordability (AF) are integrated next to each factor. The impact of each factor is expressed by a coloured gradient ranging from orange (negative impact) to green (positive impact). The color blue refers to a neutral impact.

[30] European commission trade helpdesk – EU Customs Union https://trade.ec.europa.eu/tradehelp/eu-customs-union

Table 9 scores of factors influencing the location decision of the Po Delta cluster

Scores of factors influencing the location decision of the Po Delta cluster															
Contextualization		Indicators of the energy factor								Traditional location factors					
		AV	AV	AF	AF	AV	AF	AF & AV	AV	AC	AV	AV	-	AV	AC
Time reference	Cluster name	Supplied capacities [GWh]	HI power needs [GWh]	HI power prices [€c/KWh]	Support schemes to HI [M€ per year]	Allocating RE to HI [GWh per year]	Expected cost of RE [€c/KWh]	Gains in energ eficciency [%]	Foreseen RE power capacity [GWh]	Raw materials & Transportation [€/tone & €/km]	The market [M€]	Cost of Knowlede [€ per year]	The Climate [avoided tones of CO2 per year]	Policy environment [descriptive index]	Geographycal conditions; Industrial conditions & Key infrastructure [descriptive index]
Present 2020	Po Delta Cluster						n.a.	n.a.	n.a.						
Future 2050 no incentives	Po Delta Cluster	o	o	-	+	-	-	o	-	-	-	-	-	-	o
Future 2050 incentives	Po Delta Cluster	o	o	o	+	o	+	+	+	o	+	o	+	-	+

5 Application of cluster evaluation procedure to the Rhine-Ruhr cluster

This chapter applies the cluster evaluation procedure more directly. The reason is that the effects of the transition on the location factors are similar to those of the previously investigated case. However, the way the changes in factors influence the industry clusters differs. As such, it is of added value to internalize the theoretical rationales presented in chapter 4 but focus more on what happens to the industries and companies rather than what happens to the factor itself. Nevertheless, to explore the cluster-specific implications arising because of changes in factors, it is important to have a clear understanding of how and why changes in factors occur. The guiding principle is that to enable a clear comparison between cases, one must understand the dynamics that govern the changes in the factors and use them to reason on the implications that such changes will have on the industry cluster.

For instance, the trends, the projections and the expectations for the two cases follow the same line of reasoning. Moreover, according to the experts, the aspects influencing changes in the energy factor are similar because of the common objectives of the energy transition in the EU. Additionally, similarities apply to the changes in traditional siting factors because of how the energy factor spills over to the remaining location determinants. Finally, the foreseen volume of goods and the foreseen increases in energy efficiency throughout the considered time horizon are similar.

5.1 Current situation in Western Germany's Cluster: state-of-the-art analysis

5.1.1 Current energy factor affecting site and cluster

OVERALL SUPPLIED CAPACITIES

Nuclear Power

The country has adopted a strategy for an energy pathway to 2050, which includes an accelerated the phase-out of nuclear power by 2022[31]. Throughout the nineties, nuclear electricity supply accounted for an average of 160000 GWh yearly. From 2006 onwards, steady declines in supplied capacity occurred. Finally, in 2018 the total supply of nuclear power reached 75000 GWh. IEA data points to the fact that electricity generation shifted from nuclear to solar, wind ad biomass. Nuclear heat generation is almost absent today. From 1995 nuclear heat generation was gradually substituted by means of natural gas heat production (IEA, 2020). Finally, the relative dependence on this source of power must be compensated by means of green sources before 2022 (IRENA, 2015).

Traditional fossil fuels

[31] Germany 2020, IEA https://www.iea.org/reports/germany-2020

The country's energy portfolio has a completely different outlook when compared to Italy's. For instance, there is much more dependence on oil. In 2018 electricity generated by oil accounted for 101400 ktoe in 2018. The share of power deriving from natural gas accounted for 80218 ktoe in 2018. Finally, the use of coal in 2018 was of 54215 ktoe. The country's resource endowment in respect to fossil fuels is not as unfortunate as Italy's so it less dependent on imports. High quality coal deposits are present within the Nation's borders and are located in the proximity of the cluster of industries under investigation. Although through the last 50 years a significant volume of nuclear power served as baseload for guaranteeing the continuity of operations of EII's, because of the imminent phaseout, natural gas is now dominating the power generation needs associated to industrial consumption. The reason that motivates this lies in expected phase out of coal and the absence of cheap oil alternatives. The strong dependence on local coal, and the expected phase out of both coal and nuclear by 2030 and 2022 respectively, may trigger issues concerning the country's ability to ensure security of supply and future industrial competitiveness.

Traditional and modern renewables

The country's does not use geothermal resources for power production purposes. These natural resources depend on specific topographic features that the German area does not possess. The rationale on topographic features applies to hydropower as well. The share of this resource is extremely low when compared to other European nations. Moreover, power harvesting by both technologies cannot be expected to increase because of the absence of the necessary topographic conditions. This unfortunate situation acted as a driver and pushed Germany to become a worldwide leader in modern renewables. Generation via wind and solar technologies is outstanding. Total electricity obtained by harvesting solar radiation through photovoltaic technologies, shifted from 11729 GWh in 2010 to 47517 GWh in 2018. A similar growth rate was experienced by capacities harvested from the wind. These accounted for 38547 GWh in 2010 and reached 125975 GWh in 2018. Finally, Biomass with its 44629 GWh supplied in 2018, is a significant contributor to the nation's energy needs.

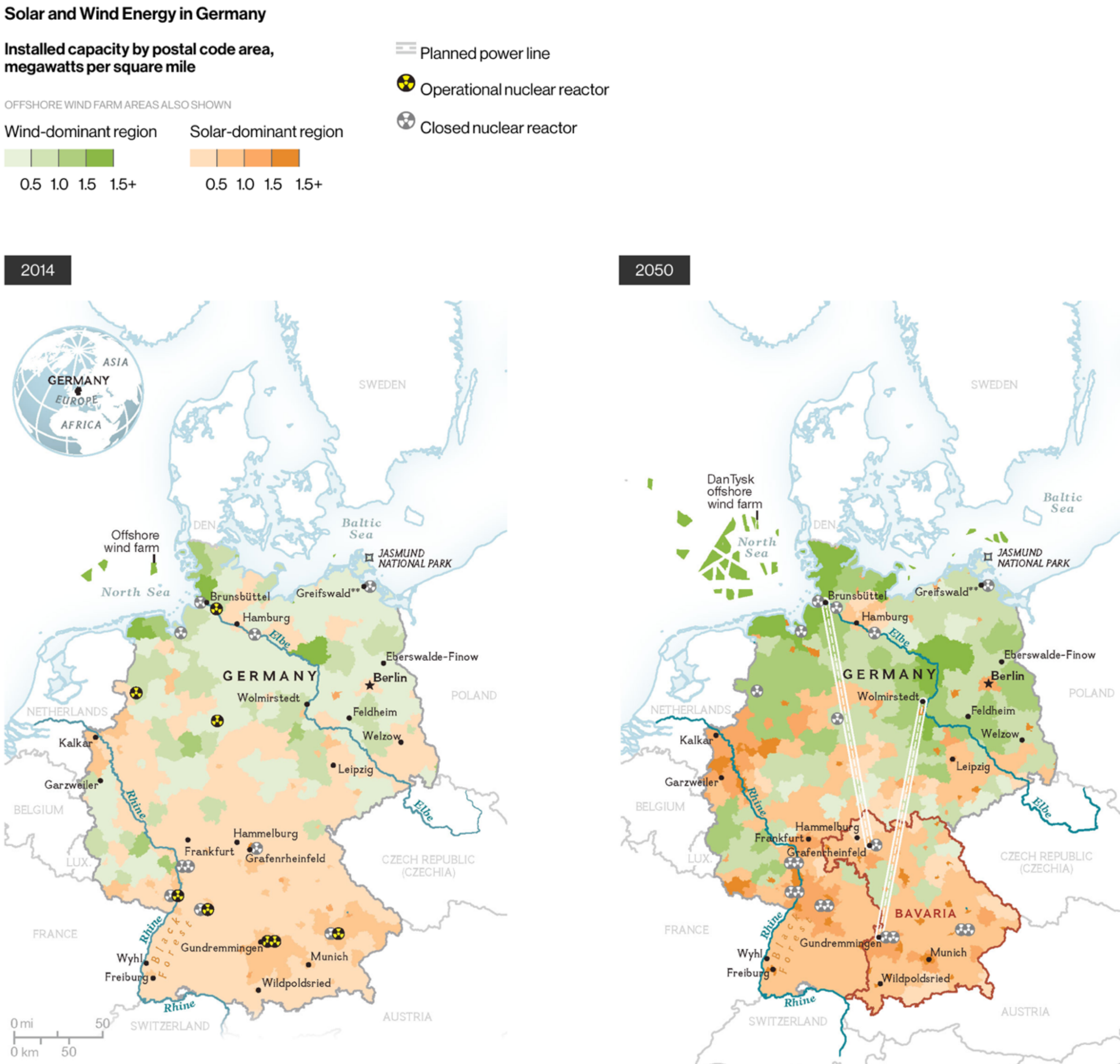
GEOTECHNICAL CHARACTERISTICS OF (MODERN) RENEWABLE ENERGY SYSTEMS

As it was argued in the Italian case, to investigate the harvesting potential of modern renewables, their geotechnical characteristics (i.e. sources, generation and distribution)[32] should be assessed. Figure 6 offers a comprehensive understanding of these geotechnical features and their implications for Germany. The figure internalizes the geographic potential of wind and solar generation across the nation. Since solar irradiation and wind speeds vary geographically, an effective and efficient placement of RE harvesting technologies should follow these geographic patterns. As such, based on the geotechnical features, the regions where RE installed capacity will be located in the future are identified (see Figure 6). It emerges that in order to supply the future power needs of the Rhine-Ruhr cluster, major transmission and distribution infrastructure needs to be built. The two power lines depicted in Figure

[32] Focusing on these relatively certain aspects enables to formulate credible expectations which will serve as a hypothesis for the creation of a future situation to reflect on. For in in depth understanding refer to the framework offered by Scholten (2018). Particular on the geotechnical features of renewable energy systems.

6 are transition enabling technical requirements. Although issues such as efficient management of demand and long-distance losses affect this technology, its beneficial functions are multifaced. A power line helps mitigate the issues arising from the geographical widespread of wind and solar sources in Germany. The abundance of wind sources in the northern regions and of solar sources in the southern regions can be efficiently managed with powerlines. A powerline enables to actively cope with the fluctuations cause by the variability that affects energy harvesting with modern RE technology[33]. Deeper analysis of the geotechnical features of RES and their interdependencies with the Rhine-Ruhr cluster are offered throughout section 5.1.2 and 5.2.3. The guiding principle is that, as in the case of RES, the EII cluster is largely influenced by geotechnical features. Examples include primary raw materials and their transportation, generation technologies that are able to satisfy the power needs of the cluster and the required storage infrastructure for adequate system functioning.

Figure 8 Geotechnical features of RES in Germany and implication for the future. Source: National Geographic[34]



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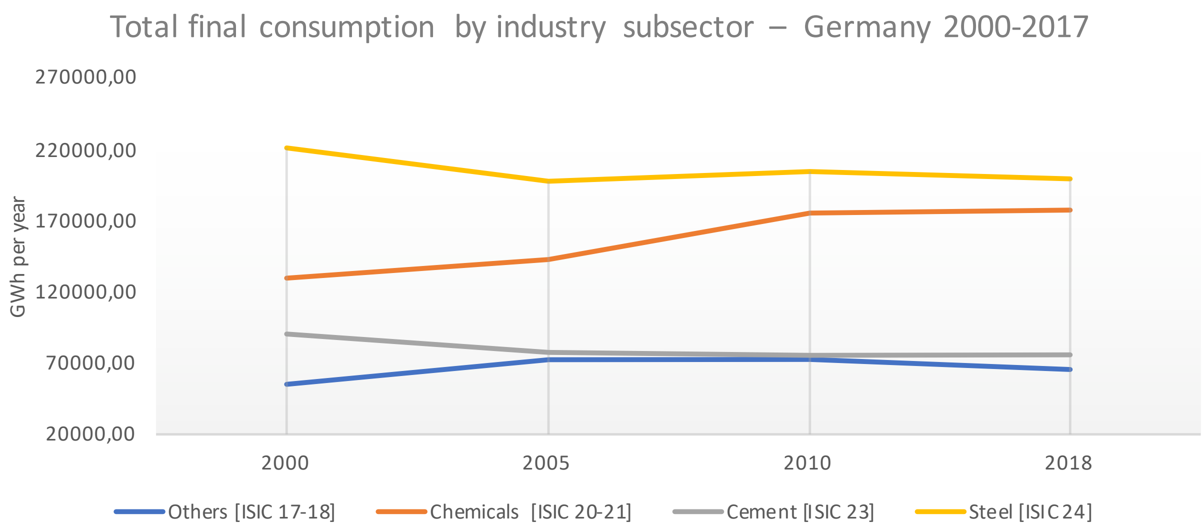
[33] Transportation of wind electricity to the southern regions when solar production does not meet demand and vice versa. This aspect secures the power needs of clusters

[34] Retrievable at https://www.nationalgeographic.com/magazine/2015/11/germany-renewable-energy-revolution/.

HEAVY INDUSTRY'S POWER NEEDS

In 2018, 674039.91GWh were destined to the industry sector (IEA, 2020). By breaking down German industry's total energy consumption into its constituents, it is possible to calculate that cement, steel and chemicals production account for 404153.95 GWh of power usage in 2018. The calculation is based on the assumption that the cluster under study requires approximately 60%[35] of the total consumption of energy. These figures are very important because they show the power capacities (both electricity and heat) that are needed by the cluster. The graph below utilizes IEA data to depict the evolution of consumption trends by sub-sector in Germany.



Overall, the generation by source and the consumption by sub-sector patterns show that, in order for renewables to supply the power needs (both electricity and heat) of the industry sub-sectors under study, the existing renewable generation capacities need to be significantly increased. Although heat needs are more severe than the electricity ones, the adoption of the discussed transition technology options enables to treat them as an entity. The idea is that processes requiring the provision of heat are going to change shape. From traditional heat that comes from fossil fuel power plants, to heat that is generated on site by specific technologies[36] which are powered by renewable energy sources. It is important to understand that the presented figures reflect the total installed capacity required for the energy intensive industry sub-sectors (thus the entire heavy industry cluster) to become 100% renewable. As such, the future supply of these power volumes is going to be treated as a priori allocated to the consumption needs of the sub-sectors under study. Although these figures may seem extremely high, the time window considered in the research (2020-2050), allows to treat them as feasible or at least achievable. Adding to this, the 2050 EU objectives don't require to achieve the theoretical 100% renewable theoretical potential, but only part of it.

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[35] Cembureau 2050 Roadmap Low carbon economy

[36] Examples of such technologies are high temperature electric arc furnaces – various application of electrolysis which allow to harvest heat form hydrogen.

OVERALL INDUSTRY POWER PRICES

German electricity is among the most expensive in Europe (Wyns & Axelson, 2016). High prices imply competitive disadvantages for German industry. For instance, the price of industrial electricity for industrial companies consuming 20 to 70 GWh per year in Germany in 2018 was 12,81 Euros per MWh[37], making it substantially more expensive than remaining European nations. This disadvantage affects companies ongoing costs as well as decisions on future investments. High energy costs should be conceptualized as a threat to production and jobs in Germany. As it the Italian case, over half of the price of electricity is made up of taxes and fees, and the trend is clearly rising.

In 2016, the EEG (German Renewable Energy Sources Act) has already reached nearly the same level as the costs to energy providers for procurement, grids and sales[38]. Companies in the industry sectors are not excepted from EEG allocations. They pay the full rate. Since this allocation will continue to rise, thus imposing a further burden, it appears that energy policy should not allow the price differences in Europe to become too great. The existing price differences for electricity in different countries, and the differences in changes in price, show how nonuniform the European energy market is. Tax and fee burdens vary widely, and German electricity customers did not experience any direct benefit from the recent global drop in energy prices.

SUPPORTING SCHEMES TO MANUFACTURING INDUSTRY

EU ETS

In the German case, electricity procurement costs can be reduced by an array of special provisions for the energy-intensive industries. The EU Emissions Trading System allows member states[39] to compensate the energy-intensive industries for the carbon costs priced in on the electricity market. In Germany this happens since 2013. Practically, a company is directly reimbursed for a certain percentage[40] of the reference cost mark-up for value of grams of CO_2 per kWh. This is based on sector-specific electricity consumption values. However, too many permits are in circulation, and they are so cheap that industry has little incentive to cut emissions.

Broad exemption from network access fees

Energy-intensive companies can exempt themselves largely from paying network access fees if they meet certain criteria. The legal foundations for this are provided in section 19 (2) sentences 1 and 2 of the German Electricity Network Charges Ordinance[41].

Broad exemption from taxes and levies

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[37] Statista 2020 – electricity prices
[38] VDA Verband der Autoimobilidustrie 2020
[39] Communication from the Commission, Guidelines on GHG emission allowance trading scheme (5 June 2012, p. 4).
[40] Electricity Network Charges Ordinance (StromNEV) - July 2005

German electricity supply is subject to a series of taxes, levies and surcharges. Energy-intensive industries, however, benefit from significant deductions of these taxes, levies and surcharges. For example, supply to end consumers is subject to an electricity tax at a standard rate of 20.5 €/MWh. Energy-intensive industrial production processes are fully exempted from the tax (Matthes, 2017). Besides, energy-intensive industries are required to financially support the cost of the remuneration scheme for electricity generation from renewable energies to a very limited extent.

5.1.2 Traditional location factors affecting site and cluster

Factor Raw Materials & Transportation

Factor Markets

In line with the Italian case and with the arguments on raw materials and transportation, it emerges that the ideal market of goods produced by considered heavy industry sub-sectors should be of a local character. Yet, because of its very large production volumes, German international trade is an aspect that should be considered carefully. For instance, competing with china's products outside of the EU-28 free trade zone doesn't make economic sense but it could become a successful practice for German light weight products. In international trade, success is expected to be achieved when the high-quality products of EEI will internalize the overall environmental costs. Tis is see as a way to penetrate a different market than the one supplied by Chinese products.

Factor Cost of Knowledge

As anticipated, the impact on location determination of such factor is expected to gradually change shape. The rationale has been explained by means of an application to the Italian case. It is expected that the application to other western European countries will lead to similar conclusions. However,

Factor Climate

The important consideration concerning the climate is that electrification of industry would only make sense if electricity is produced without CO2 emissions. The shift from fossil fuels to renewables, electrification and further efficiency will deliver in terms of socio-economic opportunities. In addition, positive externalities such as improved air quality, will reduce human health cost and contain the environmental harm caused by anthropogenic climate change. The avoided emission deriving from the transition of Rhine-Ruhr's large industrial pollutants will have an extremely beneficial effect on the Earth's ecosystem.

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

Large production of cement, steel and chemicals commodities are agglomerated in the Rhine-Ruhr region. This is a very strategic location because of the existing infrastructure and the overall geographic features of the region.

For example, the spatial proximity of the Rhine-Ruhr cluster to the mega-cluster located in central Europe highlights the highly strategic properties of the area[42]. Closeness to ports and airports enables international trade of light products (mainly chemicals and light steel) while the major buyers of high material index products are located in the proximity of the Rhine-Ruhr cluster.

5.2 Future situation

5.2.1 Introduction on trends, projections and expectations

FORESEEN PRODUCTION VOLUME OF GOODS IN 2050

The rationale presented for Italy's cluster applies to the German case as well. It was shown that the demand of manufacturing commodities is directly correlated to population growth and urbanization. In developed courtiers the expected future demand of products produced by the sub-sectors that constitute the cluster under study is expected to remain constant through time. This information is critical because it enables to use current industry production volumes as proxies. Industry clusters should internalize this information strategically. Current German production volumes are among the highest in the world. Embarking the energy transition could lead German industry to maintain its leading position while incrementing the value added of its commodities by making them carbon neutral.

FORESEEN GAINS IN ENERGY EFFICIENCY

The rationale presented for Italy's cluster applies to the German case as well. Since the German government does not provide exact figures on expected energy efficiency gains, it is decided to hypothesize a 1.5%[43] yearly energy efficiency gain. This value is forwarded by the Italian agency for new technologies for energy and sustainable growth (ENEA). Considering that Italy is investing substantially more than Germany in RD&D in key enabling transition technologies, allows to expect that the German yearly energy efficiency gains will be relatively lower. To conclude, it is expected that such gains in efficiency will further shrink the demand of power by the heavy industry cluster to a total annual usage of less GWh in 2050. Practically, its effect on power demand could shift from 674039.91GWh GWh in 2020 to 428324.12 GWh in 2050. Industry clusters should internalize this as a significant reduction in operational expenses that won't affect a firm's ability to compete with its competitors.

FORESEEN RENEWABLE POWER CAPACITY IN 2050

In order to verify the feasibility potential of the transition, it is necessary to quantify the future expected energy capacities. In contrast to the Italian case, the German government does not offer direct documentation on growth targets broken down by year and production technology. Therefore, it is decided to use information on the expected power capacities in 2030 from IRENA's renewable energy prospects (IRENA, 2015) and to extend them to 2050.

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[42] Consider the rationale on economic viability over distances of the manufacturing products under study intruded in chapter 2.

[43] ENEA. (2018). Energy Efficiency trends and policies in Italy - it offers targeted information regarding Germany.

IRENA's report is tailored for the German case and offers valuable insight on future production trends. Table 9 offers and overview of future power capacities and electricity generation. The figures offered in the Table 9 show that in Germany, the future offers abundant renewable power. EII clusters can reason on these figures and should understand that adopting TTOs that electrify processes will largely benefit them in a nearby future.

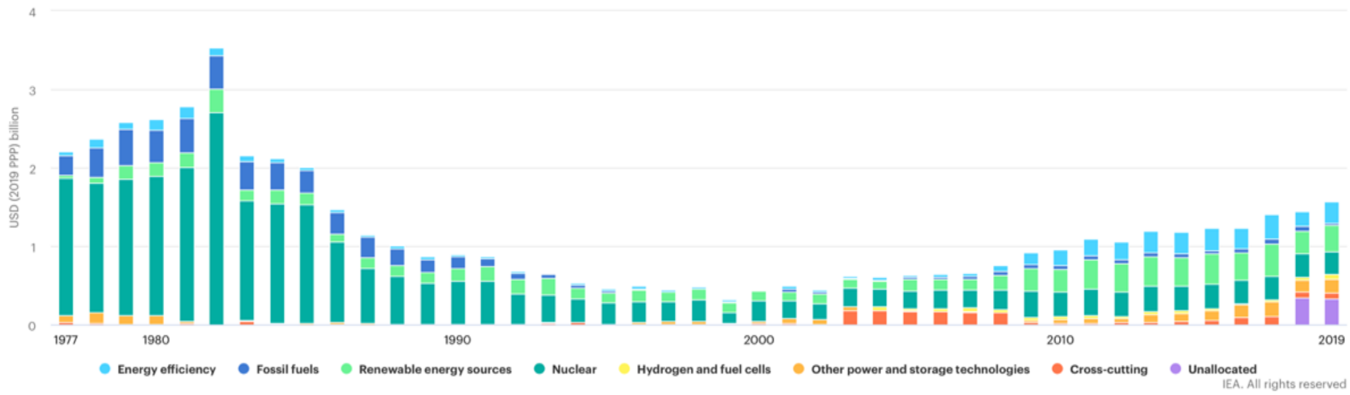
Table 10 Germany's future power capacities Source: IRENA 2015 adapted by the author

		Unit	2010	Remap case 2030	REmap case 2050
	Electricity				
Power Capacity	**Renewable energy**	**GW**	**56,5**	**177,0**	**297,5**
	Hydropower	GW	4,5	5,4	6,3
	Wind (onshore)	GW	27,0	72,3	117,6
	Wind (offshore)	GW	no info	16,4	40,0
	Bioenergy, including biogas (power only)	GW	2,7	3,1	3,5
	Bioenergy, including biogas (CHP)	GW	2,3	3,9	5,5
	Solar PV (utility-scale)	GW	5,0	16,4	27,8
	Solar PV (rooftop)	GW	15,0	58,9	102,8
	Geothermal	GW	0,0	0,6	1,2
Electricity Generation	**Renewable energy**	**TWh**	**103,4**	**376,6**	**649,8**
	Hydropower	TWh	21,0	20,2	19,4
	Wind (onshore)	TWh	37,8	160,0	282,2
	Wind (offshore)	TWh	no info	56,0	88,0
	Bioenergy, including biogas (power only)	TWh	17,6	30,0	42,4
	Bioenergy, including biogas (CHP)	TWh	15,3	37,0	58,7
	Solar PV (utility-scale)	TWh	3,5	17,8	32,1
	Solar PV (rooftop)	TWh	8,2	51,6	95,0
	Geothermal	TWh	0,0	4,0	8,0
	Industry heat		140,0		
	Solar heating	PJ	no info	25,0	50,0
	Biomass heat, including CHP (industry)	PJ	140,0	174,0	208,0
	Geothermal heat, including heat pumps (industry)	PJ	no info	22,0	45,0

FORESEEN ALLOCATION OF RD&D BUDGET PER TECHNOLOGY

IEA data on the RD&D budget per energy technology shows that German investments in areas that are critical for enabling a successful energy transition are relatively low. Since this research observes past and present patterns and makes projections of the future based on them, it appears critical to highlight certain aspects of the German RD&D allocation pattern. A first aspect regards missed investments. Figure 8 shows that large amounts of monetary flows, which were mainly targeting the nuclear sector, were redirected in the mid-eighties. However, these monetary flows seem to vanish from the allocation of RD&D budget of technologies that are essential for the energy transition. The second aspect worth mentioning points to the role of European countries in the future. Since international competition of goods in the future is expected to be at least as challenging as it is today, a pioneering role in RD&D is an advantageous strategy that EU countries should apply to safeguard themselves. This should support EII clusters in innovation and market penetration of novel products and services. The key lies in the market potential of these innovative products and services, which are enablers of a prosperous carbon free market.

Figure 9 IEA Energy technology RD&D budget, 2020 https://www.iea.org/reports/energy-technology-rdd-budgets-2020

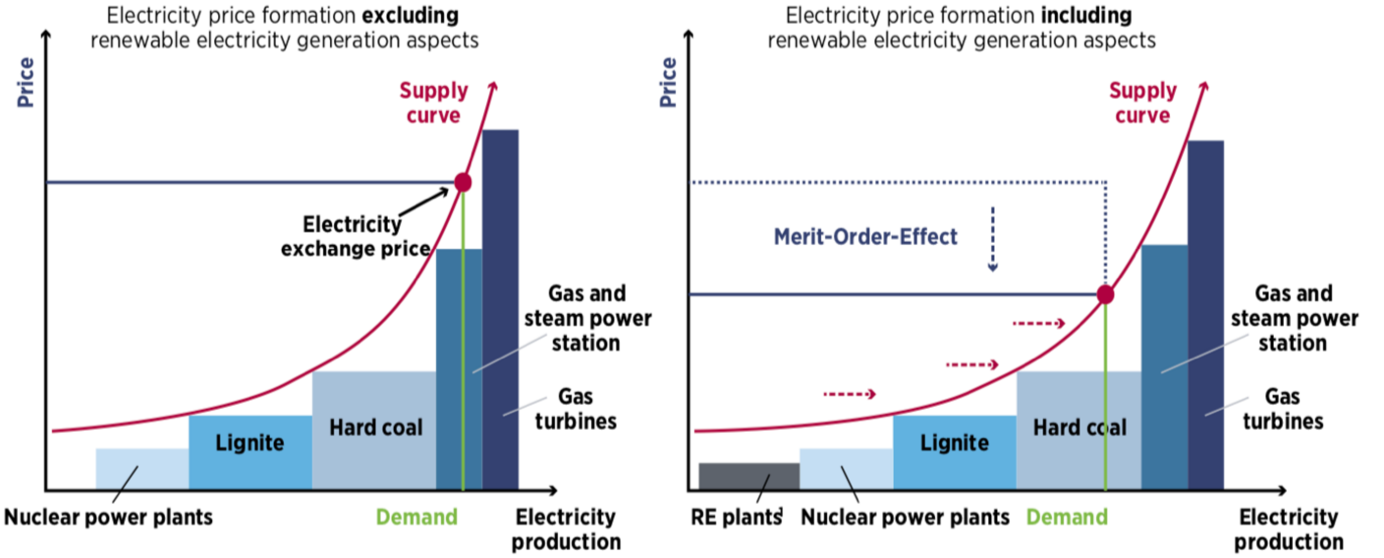


5.2.2 Energy change: direct effects on energy factor

DECREASING COST OF RENEWABLE POWER PRODUCTION

The rationale presented for Italy's cluster applies to the German case. In both cases it is very important to think of the implications that a decrease in energy cost will initiate. Lower cost attracts investment favouring a more rapid development of RE technologies. This implies that larger volumes of RE power will be available and able to penetrate the market. Currently, the increased penetration of RE in the electricity market is causing lower electricity exchange prices. The reason of this variation in prices is triggered by the very low marginal cost of generation of variable renewable energy technologies such as wind and solar. This amount of energy is added on the left side of the merit order of generation causing a shift to the right of the supply curve, while demand remains constant. The effect of this mechanisms consists in pushing the expensive fossil fuel generation technologies out of the market, resulting in lower market clearing price. This is known as merit order effect and Figure 9 graphically depicts its functioning.

Figure 10 Representation of the merit order effect - Source BMWi, 2014b



In the long term, the increased availability of RE power will keep on lowering the marginal cost of generation making it hard for traditional fossil fuel power plants to recover their investment cost. A further implication concerns times of RE overproduction. When this happens, electricity prices may drop below zero making the business case of traditional fossil fuel companies unfortunate. To earn back investment, fossil fuel producers will use peak hours (i.e. times of price spikes) to recover expenses of the plants operating on the extreme right side of the merit order. Stranded fossil fuel assets make industries of the EII cluster understand that traditional advantages of fossil fuel generation don't offer competitive advantage in the long term. A gradual transition of existing technologies to TTOs enables companies to safeguard their long-term economic interest.

ALLOCATING MORE RENEWABLE POWER TO TARGETED INDUSTRY SUB-SECTORS

Table 10 depicts Germany's energy balance in 2018. The table enables to observe that the total final consumption of the industry sector is largely dominated by oil by natural gas. Although coal as primary raw material is abundantly present within the nation's borders, it is almost absent from this energy balance. The reason is Germany's complaisance with its strategy of imminent coal phase out. Besides, interesting findings emerge when focusing on how much power is currently being supplied by renewable energy sources. For the time being, wind and solar are not contributing to industry's final power needs. As in the Italian case, history is responsible for this. The reason is that, when compared to traditional fossil fuels, modern renewable options have only recently gained economic competitiveness. Finally, when focusing on industry's total final consumption, it emerges that relatively large shares of biofuels and waste are utilized. To conclude, Table 9 shows that in 2050 the availability of RE power will be 6 times higher than it is today. Reasoning on the merit order effect highlights that future of fossil fuel energy will be significantly more expensive than it is today. The Rhine-Ruhr cluster should internalize this information to substantially increase its shares of RE power utilization.

Table 11 Germany's energy balance in 2018. Elaboration of data on total production and total final consumption retrieved from (IEA Germany balance datasets, 2020)

	Coal	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Wind, solar	Biofuels and waste	Electricity	Heat	Total
	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe
Production	37 616	3 491		4 715	19 804	1 545	14 435	30 078			111 685
Imports	30 280	86 507	41 050	70 531				2 596	2 728		233 693
Exports	-1 479		-22 462					-2 553	-6 919		-33 413
Marine bunkers			-1 684								-1 684
Aviation bunkers			-9 871								-9 871
Stock changes	2 351	511	501	-1 694							1 669
TES	68 768	90 509	7 534	73 552	19 804	1 545	14 435	30 122	-4 191		302 079
Transfers		5 176	-4 532								644
Statistical differences	-772	-2	-946	2 322				-3			599
Electricity plants	-47 344		-630	-3 702	-19 804	-1 545	-13 544	-5 118	44 235		-47 453
CHP plants	-5 755		-406	-11 793				-8 398	10 536	8 470	-7 345
Heat plants	-284		-109	-1 803			-43	-974		2 690	-524
Gas works											
Oil refineries		-100 761	99 259								-1 502
Coal transformation	-6 868		-337								-7 205
Other transformation		5 078	-5 213					-8			-144
Energy industry own use	-807		-5 141	-1 557				-520	-4 184	-365	-12 575
Losses	-275							-82	-2 292	-1 247	-3 897
Total final consumption	6 663		89 478	57 018			848	15 018	44 104	9 549	222 678
Industry	5 735		3 675	20 169				3 983	19 822	4 573	57 957
Transport			51 787	613				2 701	1 039		56 141
Residential	495		10 207	22 265			753	5 781	11 023	3 656	54 181
Services	21		3 264	10 713			94	1 782	11 788	1 319	28 981
Agriculture / forestry			2 138	250			1	771	432		3 592
Fishing											
Non-specified			77								77
Non-energy use	412		18 330	3 007							21 749

5.2.3 Energy change: indirect effects via other location factors

FACTOR RAW MATERIALS & TRANSPORTATION

Aspects regarding transportation of commodities are not expected to be directly influenced by the envisioned energy transition. However, changes in state-of-the-art transportation may be triggered by a change in market structure. Regarding raw materials and fuel inputs in the Rhine-Ruhr region, it can be anticipated that the current dependence on oil and natural gas can be overcome because of abundant presence or RE harvesting. The primary raw materials needed for production of steel and cement are also abundantly present in Germany. German interviews highlight that various strategies (i.e. clinker substitution, diversification of cement types, scrap metals, recycling and reuse) are well known. In the Rhine-Ruhr cluster manufacturing processes may not transition because of the comfortableness that characterizes state of the art routines. The presence of economically viable traditional primary raw material and of coal resources within the nation borders may act as a barrier. However,

Finally, there is room to alleviate dependence on foreign fuel inputs by utilizing more renewable power capacity which is produced domestically.

FACTOR MARKETS

Negotiation of win-win trade schemes within EU-28 members is critical for boosting the European market. The effect of thus trade schemes is that of safeguarding the economic competitiveness of the Rhine-Ruhr cluster. All stakeholders and policymakers in particular are advised to use long-term value for a country as the main criterion to optimize the transition of the Rhine-Ruhr cluster. In practical terms they should develop specific plans for each demand sector and align incentives with the longer-term perspective.

FACTOR COST OF KNOWLEDGE

A critical component that is often neglected is a transition plan for the management of the labouring workforce. Their support is central to guarantee a successful transition of EII clusters. This entails the retraining of those already in the workforce, and rectification of the formation process in technical schools where heavy duty machineries and electricians are trained.

Factor Climate

The further expansion of renewable energies, the gradual phasing out of electricity from fossil fuels and the transition of EIIs will drastically reduce emissions. The reduction target for industry is 49 to 51 percent by 2030 compared to 1990[44]. These are the objectives of the German Energiewende[45].

Factor Policy environment

The Rhine-Ruhr cluster experiences a relatively stable political environment. However, the required transition of the industry cluster will not take place in the absence of smart and committed public policies. First of all, the national government will have to assist the cluster through its modernization and rationalization. The high capital intensity of investments affecting the cluster is a key barrier. The national governments can help to create markets for new low-carbon products through public procurement. Avoiding regulatory misalignment is a third important element. Alignment will avoid punishing industries that move to low-carbon processes or business models. Among the most challenging parts of the industrial low-carbon transformation will be to bring promising low-carbon process technologies to the commercialization stage. The EU ETS innovation fund for the period 2020-2030 can become an important tool to enable a timely commercialization of TTOs. It will act as indirect incentive for the cluster because of its large emission volumes.

Factor Geographical conditions, Factor Industrial conditions & Factor Key infrastructure

As it was in the past, it can be expected that infrastructure will keep developing proportionally to the economic growth of the region. In conditions of a successful transition in the Rhine-Ruhr cluster, various spillovers to the geographically bounded EII clusters (of the original mega cluster that covers parts of Northern and Central Europe). This will act as attractor for other forwardly or backwardly linked industries and for investment.

5.3 Comparison current and future: similarities and changes

Overall similarities and differences

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[44] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2020 available at https://www.bmu.de/en/topics/climate-energy/climate/national-climate-policy/greenhouse-gas-neutral-germany-2050/#c12735

[45] Based on Bundesministerium für Wirtschaft und Energie (2014)

Performing the Cluster evaluation procedure makes it possible to identify similarities and differences between state-of-the-art and the envisioned future in Germany. Because of pressures from the German green party and the public at large, nuclear power is going to be phased out by 2022. The 75000 GWh coming from nuclear in 2018 have to be compensated by means of alternative sources of power. Moreover, traditional fossil fuels shares in the energy mix of the country will keep on decreasing through time, eventually enabling the expected phase out of coal in 2025. Similarly, the current trend depicting penetration of RES in the country's energy portfolio is expected to keep increasing. Interviewing German experts enables to consider the German political environment as participative in the transition process. Yet, actions taken so far are not sufficient because they don't internalize the risk of not transitioning industry, thus leading to eventual relocation or close down. Heidelberg cement and Wuppertal agree on the need for very clear action by the government and not only on indicative directions to achieve carbon neutrality. Adding to this, Heidelberg cement points to necessity of an industrial strategy and long-term vision to accommodate the expected change. Since the decision process on a target for 2030 is open, industry isn't capable of formulating a long-term vision of what is going to happen, therefore there isn't a benchmark. Often, fingers are pointed to the EU environment which is offering general messages that don't indicate how to make the transition a successful story, which in turn becomes a barrier for industry investment. Additionally, it is found that German experts are pleased by the actions taken by the TSO to further develop the national transmission and distribution network as well as the parallel technologies required for overall future system functionality. Interestingly, because of the nature of the Rhine-Ruhr cluster and its geographic closeness to Europe's heavy industry mega cluster, the transition will lead to spatially concentrated demand for clean energy. Today's industrial structure and localization shows that expansion of electricity and storage infrastructure should focus on these core industrial regions. As in the Italian case, reasoning on companies as rational economic actors, points to three possible future options:

- Invest in TTOs in this investment cycle and update business models accordingly;
- Shut down existing production units at the end of their service lives (disrupting the local economy and integrated value chains);
- Invest abroad and import the commodities that are needed domestically (triggering dependence on other nations).

As discussed in the Cluster evaluation procedure, heavy industry power needs have followed a decreasing trend through the past twenty years. Because of further efficiency development, power needs are expected to keep decreasing, implying production of commodities with less intensive power requirements. In addition, the decreasing trend that could impact heavy industry power prices (due to increased competition on wholesale markets from larger availability of RE, improved interconnections and presence of a more integrated electricity market), serves as initiator for the transition process of the industry cluster. Availability of affordable power motivates industries to adopt TTOs, which in turn implies further reduction of power requirements. In itself, this positive feedback mechanism motivates further electrification and modernization of industries, as well as the emergence of important system level changes. These changes point to the need of major parallel infrastructure development, which should ensure the functionality of the envisioned future energy system. The rationale being that, as electrification of industries becomes more and more attractive, industries will transition causing an overall increase in energy demand. As this increase should be covered by RE, need for storage technologies or backup powerplants becomes central. The development of such storage systems in combination with adequate expansion of the national transmission and distribution network and of interconnector capacity should enable to cope with eventual volatility of power prices as well as with grid balance issues.

An important observation regarding Germany concerns the current allocation of RD&D budgets. When compared to various EU nations, Germany is investing limited sums in key transition enabling technologies. The present historic context sees international competition to be challenging. Therefore, maintaining a pioneering role in RD&D is an advantageous strategy that EU members should apply to safeguard themselves. This supports companies in innovation and modernization and acts by creating added value for domestic commodities.

FACTOR SPECIFIC SIMILARITIES AND DIFFERENCES

An important similarity between the present and future concerns transportation and utilization of primary raw materials for cement production. According to the interview with Heidelberg, the cement industry relies on clinker production, which demands the utilization of limestone as primary raw material. Production of clinker is expected to remain in the proximity of limestone quarries. The reason is that the transportation of biomass is economically more attractive than the transportation of limestone. A further reason is that building new limestone quarries comes with acceptability issues by the public at large. Theoretically, cement production out of the clinker could be done elsewhere, possibly where there is a local market for it. Practically it is more convenient to keep it close to the clinker facility. Heidelberg cement expects plants that will remain operational to change from only cement plant to a combination of cement plus chemical plant. The idea is that CO2 could be produced on-site and used for various purposes (i.e. re-carbonization, mineralization of aggregates, recycling and geological storage). Heidelberg cement is taking major steps in the uptake of TTOs. It highlights that limited supply of required equipment is available in Europe and that the additional costs of clean cement will not impact the construction industry.

In line with Wuppertal Institute for Climate, Environment and Energy (Division Future Energy and Industry Systems), the transition of the German chemicals sector is a big question mark. The transition of this sub-sector requires domestic availability of cost-competitive hydrogen (H_2). If this resource will be imported, it will cost a lot and will cause further import dependence and energy insecurity. However, hydrogen production in Germany is challenging because of insufficient installed renewable energy capacity. The eventual supply of necessary carbon-free hydrogen to EIIs can be deployed by repurposing the existing natural gas grids and storage facilities. For a purely economic perspective (i.e. long led time and extremely high cost), it makes more sense to move chemical industries somewhere else and then import the necessary commodities. This conflicts with the interest of the national government to support local production and maintain domestic industry chemical production. Because of the high uncertainty regarding the transition of this sub-sector, specific considerations are left for further research. Future research should aim to quantify the effects on social welfare of depriving Europe of its domestic chemical production powerhouse (i.e. loss of jobs, loss of domestic commodities etc.)

Transportation and utilization of primary raw materials for steel manufacturing are changing in Germany. For instance, high-temperature arc furnaces are functioning on scrap metals, making it possible to perform domestic recycling and circularity in steel manufacturing. Urban mining plays a major role in the collection of the required primary raw materials. Since Europe relies on high availability of such metals, domestic steel production is expected to offer major opportunities. German market players need to be supported in the readaptation of their business models to accommodate the emerging opportunities of domestic steel production. Critical enablers of this novel market creation process are rules and institutions, that should be designed in a way that safeguards local investment. EU's strategic intention of supporting adequate local returns is expressed by the existence of the EU28 free trade zone.

The impact of cost and availability of specialized workforce changes shape as the transition happens. Decreases in cost and time required for transporting people and knowledge point to a resizing of the importance of this factor. Concomitantly, to enable the transition, highly educated and skilled workman must be present and adequately remunerated. A transition enabling player present in Germany is Fraunhofer[46], which assist and supports third parties in their transition process. The role played is central as it guides and informs industries on attractive options and ways to take advantage of them. Examples are the demonstration and the adoption of TTOs, technical support and compliance with the regulatory environment. It appears that attention should target how to put the CO2 costs at the customer so that the customer makes the choices. The industry has to limit costs, but it is critical to guarantee that society is willing to move in that carbon-neutral direction and take up the consequences (i.e. infrastructure cost, CO2 pipeline cost, renewable energy production cost).

In conclusion, an attractive industry environment for Germany's future implies the realization of the presented key enablers. German interviewees agree that monetary expenses should be negotiated and shared by all actors involved. The political environment of the country favourites the transition through the Energiewende. An initiative supported by the German Federal Ministry of Education and Research based on innovations and research. However, IEA data reflecting RD&D budget allocation highlight that the country should invest more in this direction. Table 12 summarizes the findings emerging from the comparison of the present and future situation of the Rhine-Ruhr cluster. A future with incentives and support schemes is more attractive for the interest of the companies of the cluster.

[46] Fraunhofer official website 2020 https://www.fraunhofer.de/en.html

Table 12 Scores of factors influencing the location decision of the Rhine-Ruhr cluster

Scores of factors influencing the location decision of the Rhine-Ruhr cluster															
Contextualization		Indicators of the energy factor								Traditional location factors					
		AV	AV	AF	AF	AV	AF	AF & AV	AV	AC	AV	AV	-	AV	AC
Time reference	Cluster name	Supplied capacities [GWh]	HI power needs [GWh]	HI power prices [€c/KWh]	Support schemes to HI [M€ per year]	Allocating RE to HI [GWh per year]	Expected cost of RE [€c/KWh]	Gains in energ efficiency [%]	Foreseen RE power capacity [GWh]	Raw materials & Transportation [€/tone & €/km]	The market [M€]	Cost of Knowlede [€ per year]	The Climate [avoided tones of CO2 per year]	Policy environment [descriptive index]	Geographycal conditions; Industrial conditions & Key infrastructure [descriptive index]
Present 2020	Rhine-Ruhr Cluster						n.a.	n.a.	n.a.						
Future 2050 no incentives	Rhine-Ruhr Cluster	-	o	-	o	-	-	o	o	-	-	o	-	o	+
Future 2050 incentives	Rhine-Ruhr Cluster	o	o	o	+	o	+	+	+	o	+	o	+	+	+

6 Comparison of EII clusters

This chapter compares the results of the evaluation of the two clusters. By reasoning on the outputs emerging from the cluster evaluation procedure, it is possible to highlight what was learned about the clusters, their locations and what can be expected regarding the cluster's economic suitability to the envisioned renewable future. The process of comparison is conducted by reasoning on the changes that each location factor experiences because of its projection into the future. Finally, in response to the main research question, the aspects that impact the economic suitability of the sites of the EII clusters to a more renewable future are presented.

6.1 Comparison of the Rhine-Ruhr cluster and of the Po Delta cluster

The changes that occur because of the projection of location factors in the future point to two main findings. Although these findings emerge in response to other findings of the cluster evaluation procedure, their importance suggests presenting them first. Firstly, when looking at the companies of both EII clusters as rational economic actors it emerges that the current context offers three possible options:

1. Invest in TTOs in this investment cycle and update business models accordingly;
2. Survive the shorth term and shut down existing production units at the end of their service lives (disrupting the local economy and integrated value chains);
3. Invest abroad and import commodities that are needed domestically (triggering further dependence on other nations).

A second relevant finding concerns the effects of changes in the energy factor of both clusters. This factor was hypothesized to be the only variable of the location problem allowed to change. All other factors were seen as variables, but to cope with complexity, they were kept constant. However, performing the cluster evaluation procedure showed that the spillovers triggered by changes in the energy factor significantly affect most of the remaining factors. For instance, changes in energy factor spill over to infrastructure that becomes essential (i.e. expansion of the national transmission and distribution network, expansion of existing interconnector capacity, construction of power lines and of energy storage systems, hydrogen production and transportation). Neglecting this effect would imply to reason on an industry system that cannot function adequately in a transitioned word. Adding to this, further implications emerging from the spillovers of the energy factor concern the creation of added value carbon-neutral commodities that necessitate the existence of a market for successful commercialization. If the EU and the local governments fail in delivering dedicated and coordinated planning, investment support and appropriate policy, it becomes hard to expect that industry cluster in the EU will be able to face international competition. There is a strategic interest in ensuring that this happens. Current competition with China is unsustainable if the rules of the game do not change. However, the creation of added value commodities that internalize the cost of the transition and the design of a market for their commercialization changes the rules of the game and offer new business opportunities to the EII clusters that populate Europe.

The following are the other findings that emerge by comparing the outputs of the cluster evaluation procedure of the two EII clusters:

- Although very different energy portfolios have characterized the two countries, the energy transition is reshaping this trend. Italy phased out nuclear power generation early on while Germany is expected to phase it out by 2022. Both nations plan to phase out coal by 2025 and decrease their dependence on oil consumption. Since these energy sources come from foreign nations, this trajectory will reduce energy dependence on non-EU energy suppliers. Concomitantly, to compensate for the phase-out of nuclear power and fossil fuel generation, both nations are installing considerable amounts of domestic RE harvesting technology. Both EII clusters can experience the benefits of this shift in energy sources by updating their manufacturing processes in ways that accommodate for RE utilization.
- The geotechnical characteristics of both nations suit well the energy transition. The availability of wind and solar sources within both nations secures the transition process because it enables to foresee a future dominated by domestically produced sustainable energy. However, there are technical implications. The location of both EII clusters is not in the proximity of where generation via renewable sources will take place. Therefore, to transport the expected large volumes of electricity needed by the EII clusters transmission infrastructure (i.e. power lines) needs to be built. A further technology that can secure the continuous power requirements of the EII clusters is energy storage. The impact of batteries in securing the electricity supply of the EII clusters is remarkable because they enable to cope with the fluctuating nature of RE supply. In addition, if the companies of the clusters invest in storage and charge batteries during times of RE overproduction, they will limit the negative impact of high prices in moments of scarcity.
- The future power needs of both EII clusters decrease similarly due to energy efficiency increases. However, there is a reinforcing feedback mechanism at play because a massive technological shift will also cause an overall increase in industrial energy demand. Industry actors are prone to adopt technologies that decrease their power consumption requirements. Compared to the state-of-the-art, a modernized cement plant will require approximately a 30% increase of power consumption to produce the same volume of commodities. Similarly, modernization of steel manufacturing processes will result in a 50% increase in power consumption. Figures depicting the power consumption requirements of a modernized chemical sector remain uncertain. The reason lies in the relatively high unpredictability of hydrogen (H_2) developments in the EU. Hydrogen is seen as the main route for the modernization of chemical production units. However, according to the experts, in Italy the H_2 topic does not capture sufficient attention while in Germany there is clear interest, but no action is taken. The best strategy is to focus on the further development of RE because these resources are essential for clean H_2 production. In a second phase, when the economic and technological readiness of H_2 will be mature, it can be combined with cost-effective electrification options. This will increase the security of supply of the industry clusters and will further reduce carbon leakage. Until that moment, energy storage systems will be critical to meet the continuous energy supply needs of the EII clusters
- RE harvesting technologies are experiencing different adoption rates. In Italy, investments were made early on because a financial incentive scheme allowed investors to foresee profitable returns. Subsequently,

changes in the incentive scheme made the business case of RE technologies less profitable, and investment slowed down. In Germany, considerable investments in RE technology started in 2012 and kept on increasing year after year. The EII clusters should anticipate the relatively certain future develop of RE power production and its utilization across Europe and align their manufacturing processes accordingly.

- Foreseen availability of sustainable power motivates industries in both clusters to modernize their processes by adopting TTOs. Availability of the required RE power capacities is not seen as a key barrier. The interviewed experts confirm that present adoption rates will continue. The real issue concerns the management of the load through the day, which is a responsibility of the TSO. Besides, future affordability of power is relatively uncertain. The increased penetration of RE in the electricity market will cause lower electricity exchange prices because of the lower marginal cost of generation. Moments of overproduction imply very low or negative electricity prices, while moments of scarcity come with extremely high prices. However, the financial impact arising because of transportation and storage requirements will tend to increase the price of energy until the returns on investment (ROI) for these technologies will be met. This aspect poses uncertainty to the EII clusters.
- Both EII clusters are facing a similar investment risk. RE's low variable cost of generation will lower the long-term market price of electricity. However, investment in RE is currently higher than other sources of energy, investments still need to be repaid, and part of that repayment includes selling energy at the current price for long periods of time. In addition, the utilization of renewable energy requires considerable investment cost for investors. To enhance the attractiveness of these investments, the national governments should design attractive public support schemes. Since EII clusters are the largest consumers of energy, the increase in electricity price due to the financial support schemes will affect them most. The expectation is that prices of electricity will keep increasing until the status of the technology will be sufficiently developed and investments will be earned back.
- To comply with responsibilities, the TSO of both nations have to expand the existing national transmission and distribution networks, build new interconnector capacity and install and manage energy storage systems. The combination of these measures enables to cope with the price volatility and with the grid balance issue that will arise because of increased reliance on variable RE. Finally, the energy transition will lead to a spatially concentrated demand for clean energy. The short-term increase in energy prices (2020 to 2035) won't motivate the relocation of EII clusters to other nations. As such, the national TSO of both countries should prioritize investment in the geographic areas considered in this research when designing future interventions.
- The two clusters are living in two very different political environments. The Italian case is affected by an unstable political environment which is unable to safeguard its industry players. On the other hand, the German political landscape supports its industry through the Energiewende. However, the opinion of German experts points to the fact that more strategic guidance to industry players is necessary. Besides, industry stakeholders ask for clear directives by the EU Commission and not only indicative directions. Finally, experts from both nations highlight the necessity of an agreed-upon industrial long-term strategy to enable further RE adoption and industry modernization. Governmental stakeholders and policymakers

must understand that EII clusters will not make the necessary transition investments if the long-term economic and regulatory environments are uncertain and unpredictable. The implications that could occur because of faulty regulatory measures may trigger massive job losses and negatively impact the technological leadership of the two nations. More importantly, enabling the transition of the EII clusters implies strategic infrastructure development in both countries. The implementation of the various measures discussed in this thesis will reduce the effect of scarcity on electricity produced with foreign energy sources. In today security environment there is much more at stake than cheap reliable energy. Supporting the transition and modernization of the EII clusters will enhance the diversification of energy sources, it will fortify EU's energy market by decreasing its reliance on non-EU players. In a nutshell, it will make energy cheaper and more secure in the long term. In other words, the transition of the EII clusters can be seen as a way to initiate a collective energy defence mechanism for the European union at large.

- Based on the observed trend regarding the decreasing cost of renewable power production, renewable energy has the prerequisites to undercut the cost of legacy fuels in both nations. If this is the case, governments and large corporations building new power plants will be attracted to invest in RE for any new capacity. The effect of this shift will reduce the demand for traditional fossil fuels, thus increase the energy independence of both nations. Adding to this, reasons for the fast-improving cost performance of the key RE technologies are i) preference among governments for competitive bidding processes when handing out contracts to develop new power plants, ii) increasing number of experienced developers competing for project opportunities around the world, iii) advances are being made in the technologies themselves.
- In Germany, the current allocation of RD&D budgets is much lower than in Italy. Moreover, when compared to various EU nations, Germany is investing limited sums in key transition enabling technologies. The present historic context sees international competition as challenging. Therefore, investment aimed at maintaining a pioneering role in RD&D is a profitable strategy that both nations should apply to safeguard themselves. In addition, these investments will facilitate the innovation and modernization of the EII clusters.
- Overall, the spillovers of the energy factor on the remaining siting factors affect both clusters. Primary raw materials for cement production are not expected to undergo radical changes because of technical reasons. Primary raw materials for steelmaking are prone to change. The expectation is that the market structure of steel production and distribution will change. High-temperature electric arc furnaces (i.e. generally the most adopted TTO in Italy and Germany) enable the utilization of scrap metals for the production of commodities. The availability of such metals within EU's borders offers major economic opportunities to industry players that will adapt their business models. To speed up the development of a market that doesn't have the economic power to be autonomous yet, rules and institutions should be designed to create a fair playing field for local actors.

Table 13 summarizes the finding emerging from the comparison of the two clusters.

Table 13 Comparison of the scores of both clusters

Scores of factors influencing the location decision of energy intensive industry															
Contextualization		Indicators of the energy factor								Traditional location factors					
		AV	AV	AF	AF	AV	AF	AF & AV	AV	AC	AV	AV	-	AV	AC
Time reference	Cluster name	Supplied capacities [GWh]	HI power needs [GWh]	HI power prices [€c/KWh]	Support schemes to HI [M€ per year]	Allocating RE to HI [GWh per year]	Expected cost of RE [€c/KWh]	Gains in energ efciciency [%]	Foreseen RE power capacity [GWh]	Raw materials & Transportation [€/tone & €/km]	The market [M€]	Cost of Knowlede [€ per year]	The Climate [avoided tones of CO2 per year]	Policy environment [descriptive index]	Geographycal conditions; Industrial conditions & Key infrastructure [descriptive index]
Present 2020	Rhine-Ruhr Cluster						n.a.	n.a.	n.a.						
	Po Delta Cluster						n.a.	n.a.	n.a.						
Future 2050 without incentives	Rhine-Ruhr Cluster	-	o	-	o	-	-	o	o	-	-	o	-	o	+
	Po Delta Cluster	o	o	-	+	-	-	o	-	-	-	-	-	-	o
Future 2050 with incentives & coordinated planning	Rhine-Ruhr Cluster	o	o	o	+	o	+	+	+	o	+	o	+	+	+
	Po Delta Cluster	o	o	o	+	o	+	+	+	o	+	o	+	-	+

7 Discussion

7.1 Theoretical relevance

Industrial location decisions are complex because they require the consideration of a wide range of factors. These factors are multidisciplinary (Maniezzo et al., 1998). They span across various disciplines (Smith, 2017), ranging from geography, history and social sciences to economics, physics and mathematics. Location theory literature results overpopulated of factors and a common and agreed definition is missing. To cope with this issue, Badri (2007) reviews location theory literature identifying 205 different location factors and classifies them in 14 categories. The publication is very insightful but the influence that factors have on different siting problems is not clear. The reason is that the review captures all possible factors that could influence any location problem. Besides, the application of the factors to perform analysis is not discussed. Terouhid et al. (2012) builds on previous work and associates positive or negative risk to the factors in terms of sustainability criteria. Nonetheless, location theory literature remains affected by the presence of many factors and it is unclear what problems they influence and how. This knowledge gap was bridged by focusing on the location determinants of a specific location problem, namely the EII location problem. By investigating the historical evolution of location theory and by identifying the factors that are critical when making decisions regarding the siting of EIIs it was possible to create a clear and documented classifications of a narrower set of location factors. The methodology can and should be extended to other industry sub-sectors because it prevents the misinterpretation of factors and the influence that they have on different location problems.

Exploring location theory literature showed that scholars employ MCDA and GIS techniques when conducting locational analyses. MCDA techniques use location factors to identify a single most preferred site for a facility (Negi & Jain, 2008; Ohri & Singh, 2010; Ohri et al., 2009). MCDA techniques are also applied to rank industrial alternatives (Briassoulis, 1995; Ohri et al., 2009; Rahmat et al., 2017). GIS techniques generally build on MCDA results and graphically distinguish acceptable from unacceptable siting options (Onwe, 2018). However, by applying these techniques it is not possible to capture the implications arising because of the energy transition on location decision-making. In contrast to previously published research, this thesis internalizes the location factors and reasons on how their change will impact the suitability of industrial sites to a more renewable future. This enabled to highlight the role played by the availability of traditional fossil fuels and renewable energy sources, transportation and distribution systems, storage systems, gains in energy efficiency, changes in energy prices and incentive schemes on the location decision of EIIs. Additionally, since the energy transition is of a global character it appeared appropriate to investigate the collective behaviour of clusters of industries. The literature studies the siting of one facility while the present study utilizes a cluster-based mindset to explore a larger population of industries and their suitability to broader geographic areas. The results of the cluster evaluation procedure are not intended to have the same empirical accuracy as the results emerging from traditional methods. There is a trade-off in accuracy to be accepted when investigating and analysing possible futures[47]. However, econometric techniques can be integrated to increase the analytic depth of the cluster evaluation procedure. They enable to quantify interactions between characteristics of regions and characteristics of specific industry sectors (Missiaia, 2019; Takano et al., 2018).

Data can be compared with reports by the EU commission that mention the role of industry clusters as facilitators of industry modernization. For example, the Methodology report for the European Panorama of Clusters and Industrial Change (Hollanders, 2020) and Europe's Cluster trends Methodological Report define and classify the clusters of industries in Europe. However, they do not perform analysis or reason on the data.

Industry modernization literature offers few comparable studies. Decarbonization techniques of cement, steel and chemicals manufacturing are deeply investigated (ICF, 2015; Kitson & Wooders, 2012; Schüwer & Schneider, 2018; Wyns, T., Khandekar, G., Robson, 2018; Wyns & Axelson, 2016). The central role of strategic and coordinated planning (Kitson & Wooders, 2012), of supportive policy interventions (ICF, 2015) and the utilization of renewable energy sources in EIIs (Schüwer & Schneider, 2018; Wyns, T., Khandekar, G., Robson, 2018; Wyns & Axelson, 2016) are also treated in previous research. However, no previously published study was able to relate these aspects to the location choices of EIIs. This study internalizes the considerations of previous research and broadens their application by reasoning in terms of location factors. The result is that previous research will advise siting EIIs where minimization of cost and maximization of profit occurs. This research points to necessary system level changes and highlights three possible economic options for European industry players.

7.2 Practical relevance: implications for stakeholders

Interpreting past historical events allows to reason on the main findings emerging from the cluster evaluation procedure. Three possible options were identified for the clusters. Except for the option regarding the uptake of TTOs, the remaining two options have already influenced nations in the past. When focusing on what happened to Romania after the collapse of the communist party in 1989, it is clear that option two applies. Certain actors have been able to take control of the nation's manufacturing industry. They used the availability of very cheap labour force to operate manufacturing plants at full capacity. They did not invest in modernization because it was not perceived as a strategic choice. The result is that these industries survived the shorth term, and then production plants were shut down because the investment cost for modernization was not justifiable. This dynamic has disrupted the local economy and the integrated value chains. The effects start to be evident today. A second example concerns Italy, which back in the '90s opted for option three. Industry relocated to eastern Europe and

[47] Validating the time dimension of this location problem poses limitations. In fact, it is very complicated to cope with the uncertainty which relates to the future developments that this study explores. To cope with this uncertainty, one must realize that it is not actually possible to prove with certainty what will happen in 2050. In order to demonstrate the resilient nature of the proposed methodology it is important to realize that if factors and input variables are correct then reasoning logically will lead to logical results. By doing so, based on the expected degree of change, it is possible to push the limits on what can be said on the future of industry sites and of industry clusters.

then to China. The driver of this delocalization was motivated by the availability of a more advantageous combination of location factors elsewhere. This consideration can be proved by observing the significant decrease in industrial power consumption that affected Italy from the ’90s onwards. Less power is consumed in Italy because the industry closed and relocated.

In order for industry clusters to foster a prosperous future in Italy and in Germany, stakeholders are associated with their responsibilities:

- **The TSO** should keep in mind that intensive energy demand will be spatially bounded in the future. The TSO should prioritize grid expansion, storage infrastructure development of the areas where EII clusters are located. The TSO should negotiate early on the win-win allocation of cost with the remaining stakeholders. Finally, the balance of the electricity grid will become even more central in the envisioned future. The expected increased penetration of variable renewable energy sources must be accommodated in the energy mix of the countries in a way that prevents failures.
- **The national government** should consider the disrupting consequences of losing its manufacturing industry. Therefore, it should deliver smart and committed public policies that support the industry through its modernization. It should process by which EIIs can bid for carbon contracts and continue to advocate for a global carbon price. Besides, it should help to create markets for novel low-carbon value-added products through public procurement. Finally, regulatory misalignment should be avoided by all means.
- **The EU Commission** should deliver targeted direction of change and actively inform and monitor the EII clusters of its member states.
- **Industry Players** are urged to initiate negotiation of win-win allocation of cost with the remaining stakeholders. Adaptation of business models according to the energy transition is a further requirement for industry players that seek to remain competitive in the Eurozone in the future.
- **Society at large** should seek in purchasing added value carbon-neutral commodities. To support sustainable growth, information campaigns should be utilized in order to inform society about the effects of their purchasing preferences.

7.3 Reflection on the thesis and on the cluster evaluation procedure

The process of developing this thesis was challenging. The literature does not offer much insight into how to conduct analysis that considers the expected future suitability of industry cluster locations to a more renewable word. Therefore, it was necessary to deduce what information was important for the problem at hand, which played a secondary role and what was noise. Location factors are important because they are what the industry takes into consideration when making siting choices. Selecting the factors was a tough process because the literature internalizes to many, does not explain how they are defined and how they influence the problem. Since these considerations are seen as mandatory when approaching a problem, it was decided to review the literature to understand how they influence the problem and to classify them in a way that will facilitate their application when performing this and eventual further analyses.

It was decided to shift from the mainstream usage of MCDA, GIS methods and develop a method based on the functioning of the system. This is motivated by the fact that the literature does not offer methods to consider possible future developments of energy intensive industries in the context of energy transitions. Compared to state-of-the-art methods, the developed method is seen as an alternative way to think when making siting choices. It enables to push the limits of what can be said on the future preferences regarding the siting of EIIs. As a matter of fact, current research is much devoted towards demonstrating how to transition or how to stimulate the transition. On the contrary, by applying the developed cluster evaluation procedure, it becomes possible to investigate the changes and effects of the transition on the location of the industry clusters. Besides, all locational studies that have been reviewed, consider only past, and state-of-the-art data. Although this is the standard way of conducting research, the energy transition entails major system level changes that these analyses are not always able to internalize. This study integrates the state-of-the-art and the expected future developments; thus, it is more insightful when facing location investment choices with long term consequences. In the end, when investors make strategic choices such as siting, they try to anticipate what will come next rather than what happened in the past.

This attempt to explore the economic suitability of cluster locations in an envisioned future teaches that when considering a medium that is transitioning, it becomes very difficult to keep factors constant. This study treated location factors as variables. Among all factors, to limit complexity, only the energy factor was allowed to change. It was found that changing the energy factor caused spillovers to most of the remaining siting factors. The remarkable aspect is that the spillovers have to be internalized because they influence the problem in a way that cannot be neglected. An example is the parallel infrastructure needs that must be available in order to allow for the hypothesized energy factor change (i.e. ensure system functionality). A second example is the need of a market to enable industry player to foresee returns on investment. A third example is a political and regulatory climate required for these investments to occur. A fourth example is a change in primary raw materials required for hypothesize changes in the energy factor.

Identifying and reasoning on spillovers made the research effort very time and knowledge intensive. The interpretative capabilities of the researcher have influenced the quality of the outputs emerging from the thesis and from performing the cluster evaluation procedure. To limit bias, experts of the industrial operational environment were asked how realistic the projections are, if they agree with the hypothesized energy change and if they see other options.

This exploratory study conducted interviews on a limited population of actors. A broader more comprehensive study could provide a deeper understanding of the perspectives of experts in the field regarding the location factors, the indicators, the directions of change and the considerations applied for performing the Cluster evaluation procedure. A set of actors that was not interviewed in this study are governmental authorities. An example is those entities in charge of making choices regarding the allocation of budgets for RD&D, those in charge of the industrial economy and industrial planning.

8 Conclusion

The objective of this research was to answer the main research question “How will the energy transition influence the economic suitability of sites of selected industrial clusters in the EU?”. To do so, various sub-questions that help to build up the answer of the main research question were created. Next, answers to each of the sub-questions are presented, followed by an answer to the main research question.

8.1 Answering sub-questions

7.1.1 How do energy intensive industries decide on siting and why is it so?

To understand how EIIs decide on siting and why it is so, a literature review was conducted. By investigating the historical evolution of location theory, it was found that location decisions are based on specific siting factors. These factors are largely influenced by the historical context that motivated scholars to consider them in their locational analyses. Early location theories focused on agriculture, later interest shifted to industry, and now they are focusing on specific industry sub-sectors. Besides, it was found that the majority of these factors are based on cost considerations and that they are taken into consideration for safeguarding the economic interest of corporations. Because of the path-dependent trajectory experienced by location theory, it is expected that location factors will keep on changing through time. For example, the present energy transition is changing a very important factor affecting EIIs, namely, the energy factor. To remain competitive, EIIs need to internalize these changes and adapt to them. Modernization is seen as an effective mean for embracing the changes of the energy factor.

7.1.2 What are the current EII industry clusters in Europe and how to modernize them?

By investigating the density of energy-intensive industrial sites, it was found that industrial activity in Europe is geographically bound. In total there are five main hotspots, two large ones are located in Northern Italy, and Central Europe and three smaller ones are located around the UK Midlands, Bilbao and Krakow. These industry hubs possess characteristics (i.e. geographically bounded facilities and interconnectedness) that enable to treat them as local industry clusters. To perform further analysis, two specific clusters are investigated. Only the cement, steel and chemical industry sub-sectors are considered as elements of the clusters. The problem is narrowed down further by focusing on Europe’s industry dominant powerhouses. This exercise points to the Northern Italy Po Delta cluster and the Western Germany Rhine-Ruhr cluster.

To modernize the clusters, each of their subsectors was projected on logical energy directions of change. The directions of change were created by triangulating literature findings with expert opinions. They are composed of a tailored combination of transition technology options (TTOs) that are market-ready or close to market readiness. These technologies share the characteristics of functioning on renewable power and of enabling decarbonization, energy efficiency increases and electrification of industry.

7.1.3 How to analyse industry clusters that are facing contemporary transition siting choices?

To offer an understanding of the suitability of European industry cluster locations to a changing energy medium, a procedure to conduct analysis was developed and applied. The necessity to develop the analysis procedure was motivated by the lack of a methodology to serve as a commonly accepted framework for the analysis of industrial location problems in the context of energy transitions. The so-called Cluster evaluation procedure was applied to the two test cases identified in chapter 3 (i.e. Italian cluster and German cluster). The goal was to understand if they are well-positioned for a renewable future or not. To convey such understanding, the two clusters have been evaluated in terms of the location factors defined in chapter 2. The evaluation was conducted in two steps. The first step investigated the state-of-the-art of the cluster. The second step explored the future situation of the cluster (based on the directions of change defined in chapter 3). Finally, a comparison between state-of-the-art and expected future enabled to reason on the suitability of the sites of the clusters to the expected future renewable environment.

The elegance of the developed analysis procedure is that location factors are seen as variables and are all kept constant except the energy factor. Interestingly, it was found that changes in the energy factor spillover and influenced the remaining location factors. Focusing on the energy factor, its change and its spillovers enabled to create a future situation to reason. Interpretation of the future situation enabled to predict what clusters should do in order to gain or maintain economic competitiveness. Since the success of clusters is directly correlated to economic aspects of their locations, it was possible to formulate propositions regarding the future suitability of the industrial sites located in Europe. These findings are important for industry practitioners because it allows them to make safer choices regarding future investment.

7.1.4 What does the analysis show in respect to cluster changes and their locations?

The analysis shows that, when reasoning on the companies of both clusters as rational economic actors, the present historical context offers them three possible options:

1. Invest in TTOs in this investment cycle and update business models accordingly;
2. Survive the shorth term and shut down existing production units at the end of their service lives (disrupting the local economy and integrated value chains);
3. Invest abroad and import commodities that are needed domestically (triggering further dependence on other nations).

It should be kept in mind that both industry clusters are in a luxury position because they are located in Europe, which is where the Energy Transition is a priority. Even though Europe is home to demand innovative products, it is more a matter of being able to offer these commodities to the market. Industry players capable of seeing solutions and innovate their business model accordingly, will survive and enjoy the benefits of the transition. For industry players incapable of doing so, a prosperous future cannot be envisioned. They can survive the short term, but they will find themselves in a future where there is no space left for them. By analogy, it is similar to what happened to the manufacturers of horse carriages when the internal combustion engine was introduced. They had to adapt because there was no space left for them.

8.2 Answering the main research question

This thesis started by asking:

How will the energy transition influence the economic suitability of sites of selected industrial clusters in the EU?

The present energy transition has a severe impact on the suitability of sites of the investigated EII clusters. This occurs because of the changes in the energy factor. This factor was hypothesized to be the only variable of the problem allowed to change. All other factors were seen as variables, but to cope with complexity, they were kept constant. However, performing the Cluster evaluation procedure showed that the spillovers emerging from changes in the energy factor significantly affect most of the remaining location factors. For instance, changes in energy factor spill over to infrastructure that becomes essential (i.e. expansion of the national transmission and distribution network, expansion of existing interconnector capacity, construction of energy storage systems, hydrogen production and transportation etc.). Neglecting this effect would imply to reason on an industry system that cannot function adequately in a transitioned world. Adding to this, further implications emerging from the spillovers of the energy factor concern the creation of added value carbon-neutral commodities that necessitate the existence of a market. If the EU and the local governments fail in delivering dedicated and coordinated planning, investment support and appropriate policy, it becomes hard to expect that industry cluster in the EU will be able to face international competition. There is a strategic interest in ensuring that this will happen. Moreover, current competition with China will remain unsustainable if the rules of the game do not change. The necessary change in the rules of the game is the internalization of the cost of the transition and the design of a market. In conclusion, the economic suitability of the sites changes because the energy transition impacts the energy factor. The consequence is that this factor changes spills over and forces the majority of traditional cost-related factors to change accordingly. The implication is that the economic suitability of sites asks the cluster to adapt to transition changes.

It was not possible to carry out cost-benefit analyses, optimization or modelling within the framework of the study. As these evaluations could lead to different or new conclusions, they should be investigated by further research. Moreover, this study observed that all interdependencies and interactions between the various location factors are central for the siting effort. As a deeper understanding of the feedbacks between the static variables was not part of this thesis, further in-depth studies should analyze this phenomenon and determine the functioning and the impact on locational decision-making.

8.3 Future research

The author of this thesis believes that European member states find themselves at a critical moment in history for their industrial development. Thanks to the market readiness of TTOs and product innovations deep emission reductions in the coming decades are possible. Based on realistic assumptions, informed ideas and expectations of a possible more renewable future, options for EII clusters are delivered. However, with the present knowledge, and by having developed and applied the cluster evaluation procedure, it appears valuable to keep investigating likely changes and their implication for the future of EII clusters and industrial sites across Europe. Because of the novelty of this field of research it was necessary to create a comprehensive understanding of the dynamics governing the location decisions of EII clusters in a transitioning context. Future research should internalize these dynamics and use them to shed light on possible future implications. What are the implications of the three economic options that EII clusters can opt for in terms of growth? Moreover, how to ensure that industry clusters will choose option one? These considerations are important and should be considered in future research. The expectation is that if the national governments would fail in delivering supportive financial mechanisms and coordinated planning and if the national TSO would fail in delivering the required energy infrastructure, the economic competitiveness of EII clusters will be harmed. In cases of failure, the effect of eventual foreign investment in the required parallel infrastructure and RE sources becomes an aspect that deserves attention.

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Appendix – summary of each interview

A Germany 1

Interview: Rob van der Meer - Group Communication & Investor Relations HeidelbergCement AG Germany

What do you think of (transition technology options) TTOs ad their penetration potential in the cement sector?

Yes, there are many technologies and there are many pathways for the decarbonization of the cement industry. I see four major leavers for emission reduction in this industry and as a consequence three conditions to fulfill to achieve carbon neutrality.

1. Alternative fuels use, biomass use and clinker substitution. These are the traditional levers. In Austria there is a cement plant running 100% on biomass. An interesting concept but two major issues need to be taken into account. First, availability of the biomass; second relates to assessing biomass as actually being climate neutral. This comes from an EU Commission requirement. The applicability of waste biomass in cement production cannot be criticized. Yet, the moment you produce the biofuels or biomass for use in the cement industry then it becomes challenging (i.e. competition with food crops). Be aware that the fuel component is delivering 30% of the emissions. Good to reduce emissions from fuels but it does not solve the decarbonization of the sector objective. Ideally, if resources are available, they could supply 100% of the process.
2. Route on new products (i.e. low carbon products, alternative clinkers, alternative cements and more diversification of cement types). Yet, this implies the need of market for these new products.
3. A carbon neutral society entails to broaden focus not only to the cement but to the whole product portfolio including the built environment. Ideally, the benefits taken into account relate to using concrete for climate change; adaptation to climate change effects; energy efficiency of building; advantage of concrete absorbing CO2 during its lifetime.
4. CCS and CCU hold high potential.

Ideally, the combination of these option should enable to achieve a carbon neutral concrete by 2050 on global level. It is hard to say the impact of each lever but what can be expected is that each of the levers will contribute significantly. Carbon neutrality entails focusing on all.

I see three conditions to be fulfilled in order to have carbon neutral concrete in 2050 in EU:

- Technical: (the TTOs) I see this as a responsibility of the cement industry. This is something we can do and have to do. We do need support (i.e. develop novel technologies that are very costly) in the innovations. The Commission or the German government won't say how to come to carbon neutral concrete. This is our business we have this knowledge. And we are the ones making the choices.
- Infrastructure: you will need infrastructure for CO2, one for hydrogen (not specifically cement but for instance steel), for renewable electricity (i.e. connecting northern to southern Germany), recycling infrastructure, waste infrastructure. We need this to be ready on time. Now there is a lot of talks but little action and progress. The government plays a major role in this discussion. Long led times required to develop the infrastructure but we need it now.
- Economic feasibility of the transition. We talk about a fare level playing field because if we are going to invest in a plant there must be a business case for it. There must also be an incentive for cement companies to reduce CO2 emissions. Currently, there is no incentive to put the CO2 costs at the customer. So that the customer makes the choices. We as industry try to limit costs as much as possible (it is our job) but how do you arrange that society is willing to move in that carbon neutral direction and take up the consequences (i.e. the infrastructure, CO2 pipeline, renewable energy production)? The mindset of people has to change if we want to reach our collective objectives.

How do you see the location factors that I have presented?

- Availability of raw material and transportation remains important. Cement industry relies on a particular process. Split the process in two. Produce clinker and then produce cement out of the clinker. For clinker production you need limestone (there is no escape). In Russia there was a plant at 300km from the limestone site but transportation via railways is cheap because subsidized. A similar case exists in The Netherlands (limestone supply comes from Belgium). Normally you don't transport limestone over 20km. So, clinker production occurs in the proximity of limestone plants. It is cheaper to transport biomass than limestone this is the reason. Moreover, people on want a limestone query in their backyard. Cement production out of the clinker can be done everywhere where there is a market.
- Markets for cement in theory is of a local character (200km). In practice there are bulk carriers (i.e. ships) that enable to transport cement over long distances. Markets for CO2 neutral cement is fundamental (now it is missing). We can produce much better cements by using CCS, but our customer is not buying it. Then, when you go to the government and show that you are capable of producing 100% recycled concrete for a little extra cost, the answer is no, we are not interested. Similarly, saying you can produce low carbon cements that is a bit more expensive will result in a general no answer. Governments that are asking for climate change mitigation in industry is not supporting it.
- Policy environment: Governments should play major roles. The change to carbon neutrality is needed and there is no discussion about that. But it has to be initiated by the government. When the government doesn't move the citizens, won't move either.

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

The consumption of electrical energy will change as well as its price. To decarbonize cement industry, we need to double out electrical power requirements. Significant changes that entail the use of renewable electricity otherwise it won't help. But then we need to have this renewable energy so again the infrastructure should develop accordingly. We see a significant increase in costs, from CO2 direct emissions and from electrical power cost.

Hydrogen as clean fuel and novel energy source. Some think that cement should go for hydrogen, but I do identify barriers. You need to have hydrogen infrastructure, more importantly when fuels are decarbonized, I still have the process emission which are 60% of the total. To me, working on decarbonization of fuels is not sufficient. You need to consider alternative clinkers, alternative raw materials or alternative cements, it is a combination.

Who should bear the transition costs?

At the end it has to be played by the consumer. But talking of transition means that we have to do that together. Industry will have to pay a share; the public government and society at large will have to pay their share.
4 billion tons of CO2 emitted annually in the EU. EU population 400 million people. Do the calculation and you end up with 10 tones per person per year. If you charge all citizens in Europe it will account for 1000 EUR per year per person. This is an interesting indicator. Students pay a higher tuition fee. Then if you charge this 100 EUR per ton of CO2 how much in addition would a house cost? 500 to 1000 EUR. In Europe the cost is not the reals issue we can manage. But then how do you divide the cost? Condition: consumers are to pay for futureproof cement and not to buy the cheaper cement that comes from China.

Is the German government taking steps towards this modernization?

The key point is that you need for and industrial strategy to accommodate for this change. You need a long-term vision. In reality, in 2021 the new EU phase starts. Yet there isn't a benchmark. There is no decision on a target for 2030 because the debate is open. Everything you need from an industry perspective (long term vision of what is going to happen) we don't have. For economic feasibility you need predictability of legislation, you have to know what will happen or at least the plans of what it is expected to happen.

The main challenge for Germany is that it has to operate in a European environment. So, when the EU environment is not delivering this strategic consideration it becomes a barrier for us. EU is offering general messages that don't point on how to do it. Operating within the EU boundaries is the challenging thing. What has to be answered in Brussel is not yet answered.

Do you see the various projects to increase RE capacity as feasible or can you identify specific barriers?

In the grid sector, people are working on increasing the capacity. If for cement, we have to double our electric power demand think also of all other sectors.

Do you have anything to add? Similarities and changes

- I believe that in 2050 the majority of cements will remain based on clinker. Limestone as raw material will remain the way it is.
- I expect to see more differentiation in the cement types (based on availability of materials). Cement with less clinker vs cement with more clinker. Driven by the changes in the construction industry.
- Volume of cement won't change significantly. Plants that will remain operational will change from only cement plant to a combination of cement plus chemical plant. Produce the CO2 and use it for purposes (i.e. re-carbonization, mineralization of aggregates, recycling and geological storge). From cement only to cement plus chemistry.
- Shifts in energy use. Same places as today but a novel type of cement plant.
- All cement plants need to be modified in the next years.
- I'm convinced that HeidelbergCement is devoted on making this happen. We are not alone; the other plyers need to share the same goal.

Additional information

We as HeidelbergCement have approximately 40 to 50 cement plants in the EU. Hard to say how many will survive till 2050. All of those will need to be converted on new technologies. Yet, we have very limited supply of that equipment in Europe and they can deliver 6 plants a year globally. So, at a global level it becomes challenging to do things in time. We produce 200 million tons of cement per year.

B Germany 2

Interview: Sascha Samadi PhD - Research Fellow at Wuppertal Institute for Climate, Environment and Energy; Division Future Energy and Industry Systems; Research Unit Sectors and Technologies

How do you see the location factors and respective indicators that I have presented?

Yes, they definitely make sense. We are thinking to look into this more in our own research. Your factors motivate why industry is where it is now.

Factor Raw Materials & Transportation

Factor Markets

Energy sources

Factor Cost of Knowledge

Factor Climate industry has to contribute to climate targets. Only efficiency increase is not enough.

Factor Policy environment

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions grid development is a must

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

The energy factor is definitely changing a lot of things. I personally think that the degree of RE production and Industry electrification may lead to relocation. It is very hard to quantify the extent though. We need H2 to be produced in Germany and in Europe. Much more renewables will be in the mix.

What about the specific changes on the factors? Are those reasonable?

Now everyone is making the optimistic assumption that industry that we have here will remain here. But in reality, specific changes may lead to differences in the future. The energy system infrastructure will have to be readapted.

What do you think of TTOs ad their penetration in potential in heavy industry?

In the case of steel, we see the opportunity relatively quickly. Replacement of blast ovens is feasible, and they need to be changed. Industry is already looking into this. Technologies are ready. For cements energy efficiency increases are possible but CCS is increasingly perceived as needed. For chemicals is a big question mark. They may be the most likely to relocate if we don't manage to have cost effective H2. If we import hydrogen it will cost a lot. Yet, H2 production in Germany is hard because we don't have sufficient installed renewable energy yet. I'm taking of renewable H2 production. Economically it makes more sense to move these chemical industries somewhere else and then import the goods. Then there may be interest by the government to support local production and keep industry here.

Opportunities and barriers that influenced choices?

Competitiveness issues. Particularly for the industries you are focusing on. This is why governments should support them in the transition process. The question of how to protect these industries is central. TTOs need further RD&D because they are not 100% technologically ready in most cases.

The big opportunity is to develop the technologies here. So, keep our central role. Then it becomes easier to help our industry install and use these new technologies. Ideally in the long term this could make industry more competitive.

Is the German government taking steps towards this modernization?

The German government should asses the risk of not transitioning industry thus forcing them to relocate or close down. Steps have been taken in the proper direction much more than a few years ago. There has always been support for efficiency improvement. We need very soon a very clear action by the government. Direction to achieve carbon neutrality. Not only vague considerations. On the energy and climate perspective currently, what is being done is not sufficient.

Who should bear the costs?

TSO are doing their best to expand the grid. They also have an incentive to build what is needed. Plans are there but is taking a lot of time because of NIMBY. Big topic relates to H2 network. The costs should be divided by the actors involved.

Do you have anything to add?

We have pioneering work here in Germany. If we want to transition, we must start investing in TTOs right now!

C Germany 3

D Italy 1

INTERVIEW: Maurizio Fauri professor of Electric energy systems at the Universta' delgi Studi di Trento, Italy

What do you think of (transition technology options) TTOs ad their penetration potential in the cement sector?

You need to distinguish between power intensive and energy intensive. For instance, electric arc furnaces do not consume much energy but their require significant power (in a short timeframe).

Do you consider this to be a barrier?

It is not a barrier, it is a consideration to take into account. If you consider the illumination system of the San Siro stadium it requires a couple of MW of lights, but they stay on only for a couple of hours per day. This means that they have very high-power requirements but little energy. For instance, furnaces have intensive power requirements and their cycle implies a fusion every 2 to 3 hours. Therefore, they need high power for 15 to 20 minutes and then they end up not using it for the remining time. So the idea is that the technology options you treat generally ask for much power but for short periods of time.

Does this imply issues for the function of TTOs with renewable power?

Renewable have the big issue of non-programmability (and variability). Yet, in our country during summer sometimes 100% of the energy in the grid is from renewable sources. This means that the installed power capacity that we have in our grid is actually more than sufficient for fulfilling Italy's power needs but only for the peaks. The issues are that you can't produce all the energy that is required for all times through RES. The 30 GW of solar PV are active only during daytime.

Therefore, for industries there are two aspects to consider: the shift to novel TTOs and the need for continuity of power supply.

You should also consider that this "issue" in practice is solved. Batteries are available (i.e. Toshiba, LG) the problem is that we don't have sufficient. They are expensive. 1 MWh once installed (including management system) it accounts for 400 to 500 thousand euros.

GW electricity to GW thermal is definitely not an issue. Don't worry, conversion works fine. In the 70's there was an annual increase of 7% in electricity production. So, it implies that every 10 years this doubled. So, in 1o years we were able to double production. I don't see the issue because we have an installed power capacity which is double when compared to peak demand (120 GW installed vs the 60 GW of peak consumption).

To conclude, I don't see future issues with delivering the power because we have sufficient installed capacity. It is a matter of manganin the load during the days. Therefore, it is the TSO that needs to take care of this.

What barriers and opportunities do you see for industry and TTOs?

Machineries need to be changed it won't make sense to buy the same technologies.
The mentality of people. Energy cannot be wasted. Thing that today in Italy does not happen. We are wasting almost 70% of energy. Think of cars and their performance (not more than 30%). We are used to comfort. It is just like with COVID, people need to be 'forced' to change. They are not informed for understanding the implications of their actions.

Gestore Sistema elettrico GSE data enable to understand how much tones of CO_2 can be saved by shifting technologies.

How do you see the location factors that I have presented?

Yes, they are central. Interesting approach to look how history set these factors.

Factor Raw Materials & Transportation *geographical distribution of raw mater*ials

Factor Markets *presence of markets, access to markets & metropolitan areas*

Energy sources *abundant and secure supply of energy sources cost of fuel*

Factor Cost of Knowledge *availability, productivity and cost of the needed workforce*

Factor Climate *ways manufacturing industries influence the climate*

Factor Policy environment *actions taken by government agencies, at state or local level policies* that include *tax incentives, grants and RD&D and training programs*. Sanction industries that pollute.

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

topography of land, accessibility of land and space for future expansion

Agglomeration forces

transportation facilities, alternative modes and freight rates

existing infrastructure

energy sources *I think the indicators you are using are insightful are more than enough for analyzing the case. Think of percentage of energy in the products. You may want to try to rank the relative importance of these factors (here further research should apply MCDM method such as BWM to evaluate the importance of factors compared to other factors). Raw materials and workforce may lead to relocation energy to a lower extent. Prices of energy are not that diverse, especially in the EU. For instance, in Italy prices are higher because of taxation issues. There is a tax for further PV development. Overall increase in electricity demand. Because if industry transitions it needs way more electricity.*

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

Yes, your perspective is valid. They are definitely going to influence them. I think is also good that you use as common denominator the price and availability of renewable power.

Factor Raw Materials & Transportation they won't change much. Economies of scale might limit their impact on location selection. Then if you change the type of production you may need novel materials.

Factor Markets Our market is quite structured. from export to a more local market. Competition outside EU free market is challenging. Market for novel CO2 neutral products.

Factor Cost of Knowledge digitalization is going to impact the criticality of this factor. There is a dichotomy between the financing and production. Think of Apple, it makes beautiful products (but it makes them in China). It is very hard to speculate on this factor

Factor Climate the impact of transitioning industry on the climate. You see the effect of the 2008 economic crises on the climate. The closure of plants impacted.

Factor Policy environment incentives, tax reductions. We need an environment that sanctions (heavily) the industries that pollute. So, if you don't use RES and you pollute you must pay (compensate) carbon taxes. Now they have an economic advantage in using polluting systems. The EU ETS has failed, it has to be rethought. We need to start monitoring the population growth.

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

They develop accordingly and serve as drivers for location determination.

Who should bear the transition costs?

You should consider the role of incentives. They have two functions. They can maintain the industries (this takes the name of subsidy and in Italy they are very poorly allocated causing huge issues). Or to help develop markets that don't have yet the economic power to be autonomous.

Is the Italian government taking steps towards this modernization?

We need a well thought strategy that incentivizes industries to develop further.

Do you see the various projects to increase RE capacity as feasible or can you identify specific barriers?

The present perspective is that of incentivizing local production and consumption. They are incentivizing local energy communities. Ideally you produce and consume without injecting energy in the grid. Then they are acceptable to the grid only if it is renewable.

Do you have anything to add? Similarities and changes

An often-made mistake relates to expecting that industries that today produce by means of a certain system will keep on relying on this system also for future operation. Not because we change the system of production but because the product changes. 10 years ago, LED illumination did not exist, now everyone produces LED (the product radically changed). Mercury lamps are banned. Half of Iceland's energy is utilized for bitcoin miming purposes. How can you predict this stuff?

I don't see energy as a driver for relocation. We expect an electrified system that enable transportation of power capacities from here to there. Yet, they might close down because of their unappropriated medium.

Production is set by the market. The market should be regulated by appropriate legislation. Then you see an entity as Trump that creates serious unbalances. Same reasoning with our dear Berlusconi.

Additional information

The transition implies economic considerations. Example of incentives from 2005 to 2013 then the plateau. A carbon tax should have a higher impact.

E Italy 2

INTERVIEW: Professor Franco Bonollo at Università di Padova. Department of technique and management of industry systems

How do you see the location factors and respective indicators that I have presented?

I'm particularly prepared on the steel industry. No doubt that these factors are a must for industry location selection.

<u>Factor Raw Materials & Transportation</u> Changes in raw material are happening because of the transition

<u>Factor Markets</u> change that enable to safeguard EU industry players; transition suits the need

Energy sources

Factor Cost of Knowledge there is need for very competent workforce

Factor Climate the impact industry has on the climate can be significantly reduced

Factor Policy environment need for operators is central. Simulating processes enables to predict what will happen. To read this data experience and background are needed. The transition is asking for a specialized workforce and for knowledge sharing. Interdisciplinary expertise is required. Not all can ne done through IT but automation will impact labor force. Processes will result less dependent to man work. Human supervision will always be required.

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

Industry will tend to cluster up. Agglomeration forces are now becoming very important when choosing a location.

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

Yes, the spill over idea makes quite a lot a sense. Definitely reasonable to expect larger power requirements from these industry sectors in the future. And from this expectation changes are initiated in most of the remaining factors.

What about the specific changes on the factors? Are those reasonable?

As we have discussed most of the factors will be impacted by the energy change.

In some sectors dimensions matters a lot. Closure of small industry and subsequent aggregation are leading towards this future. In Italy we need to enable clustering of small firms that are strategically interlinked. We have a lot of Small and medium enterprises. What I mean is that steel production volumes are not changing. What is changing is number of industries delivering commodities. 20 years ago we had 300 to 400 ghisa producers now we have 100. Volumes are the same. Those that were in difficulty were “both” by others. Aggregation phenomena will dominate the future. 700 steel production facilities now. It cannot be expected to have them all in 20 years. S and medium were competitive but now they must work together in order to accommodate the changes imposed by the transition.

What do you think of TTOs ad their penetration in potential in heavy industry?

Approximately 70% of the steel produced in Italy is done through high temperature electric arc furnaces. Therefore, penetration of this technology is guaranteed. The other sectors are also transitioning but the technologies are very different. We generally talk of CCS, CCU and alternative feedstock.

What are the barriers that influenced choices?

It is very important to consider future reparability of primary raw materials. These will be novel primary materials. It is about utilizing scrap metals in an efficient fashion. It will be necessary to understand what to recycle and what to leave out of recycling. The market here is critical enabler. The perspective for steel production from recycled metals is already recognized as a direction to follow. Moreover, in the EU there is high availability of these products. These are called urban mines. What is also gaining much relevance is to be able to deliver commodities on the market. So the logistics and distribution are becoming more important than the production volume itself. It is really the logistics that are gaining importance. These together with energy efficiency and raw material. It is the whole value chain that is undergoing changes. This change will also change the energy needs.

Is the Italian government taking steps towards this modernization?

In the domain of financial support schemes to EIIs and related to the covid emergency an important project was presented. It involves approximately 15 regional partners in the steel sector. The goal is to enable a faster and more efficient production cycles. In the first place a necessity to offer new products that are essential in EU. Then, based on the scenarios of final markets (which are subject to various changes) being able to change the product to be delivered based on market changes is seen as the strategy that enables industry to safeguard themselves.

Who should bear the costs?

It is a mix. Effective and efficient management of the grid by the TSO (you enable this by remunerating). Incentives from the state level are central in my perspective. To activate industry there must clear action taken in their direction. For large steel producers are starting to prescribe sustainability standards form their suppliers. The automotive industry for instance is focusing on energy efficiency and sustainability standards. Then a key stimulus comes from the end user which is the one deciding to buy a clean or dirty product. When the final demands a certain standard industry as a whole will seek in delivering that standard. This is a necessary equilibrium.

Do you have anything to add?

Except ILVA that is in the south the remaining energy intensive industries are located in Northern Italy. These facilities function on electric power therefore there is a very high demand of energy. The production of commodities demands intensive energy use. Therefore, there is increasing attention on this topic.

Energy efficiency is seen as a key priority as well as contracts between industry and power producers.

Industry reconversion in a scenario as the one we are living today urges us to take action soon.

F Italy 3

Interview: Chiara Vergie – real time dispatch for TERNA the Italian TSO. Worked for the Italian ministry to create energy pathways and projections (worked on INECP).

How do you see the location factors and respective indicators that I have presented?

Your speech is very targeted. These factors are central. Saying that you study siting also by factoring changes in power (availability and price) makes the research on point with the present transition and its implications.

When I was working on developing scenarios for the INPEC we modeled the expected price of power at a regional level. We did that for both pending development intervention and for without.

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

For the way you formulate the problem it logically follows that they are going to be influenced by these changes. For instance, we considered grid development for instance HVDC lines between north and south. (NB clear change in infrastructure because of energy change)

What about the specific changes on the factors? Are those reasonable?

The logic is consistent therefore changes are reasonable. It is hard for me to tell you the extent to which they will change but I do agree on the various changes you describe.

What do you think of TTOs ad their penetration in potential in heavy industry?

There is potential and there is also much interest. It is not my field, but I would assume that that's the direction that we are aiming for.

TSO Specific:

How to bridge the huge difference in prices between small and large consumers in Italy?

First thing, helping industries by reducing the final bill is something that Europe does not allow. You cannot facilitate your industry sectors in detriment of the German ones. This is what the free market entails. Any form of direct financing is seen as state aid so you risk being sanctioned by the EU as Italian state.

Italian state emended the interconnector law in 2009. Which is in a way and aid (your industry contributes to the development and growth of the state, in return we offer relief on the final bill). Then these saved expenses are to be use for the infrastructure development of the country. (e.g. a group of steel producers used the saved expenses to build an interconnector between Italy and Montenegro just a few years ago).

To support industry, we have interruptible contracts. So, the industry agrees on allowing TERNA to disconnect them in cases of grid balance emergencies. Then they earn certain advantages.

What is TERNA doing to keep prices manageable?
We look at the national price. For us every consumer is equal. Our way to manage the prices is by further development of the grid.

Who should bear the costs? TERNA costs and Industry cost?

It is very complicated to say. Because it involves the whole system. It is a necessary aspect to think of. Because of COVID we were not able to balance properly because the interruptible was already offline. Our objectives target general system costs.

Is public financing critical for TERNA in order to ensure prices of energy that are not affected by elevated volatility?

Yes. What we work on is based on public money. You either have private investment from industry or you must go with public money.

Do you see the various projects to increase RE capacity as feasible or can you identify specific barriers?

In Italy RES are incentivized for reaching EU targets. This is performed through auctions that guarantee certain incentives for certain capacities. The last auction that was done in June and it was a complete disaster. Not even half of the needed capacity was allocated to investors. It is very hard to participate at this auction. There are no clear incentives being offered.

There is increased difficulty in taking parts of the auctions.

How have energy prices changed through time? How do you explain the price gap between small and larger consumers in Italy?

This is something that ARERA is in charge of. ARERA being responsible of the composition of the final prices to different categories of consumers. ARERA is the body appointed by the Italian government to regulate the energy and gas sector but also the water and waste sector. In general, in northern Italy prices used to be cheaper but now because of RE this is changing. They are becoming cheaper in the southern regions for production reasons.

Do you have anything to add?

I think there is a lot of consistency in what you asked for.

I would look at what Confindustria said and compare it to what the industries it represents said.

INECP is the scenario that wil l occur because that is what the government opted for. This is important because it enables to align TERNA's grid developments with the developments of the gas grid. So focus on that for information gathering.

G Italy 4

INTERVIEW: Gianni Schiavon – CEO of Zintek S.r.l. Porto Marghera, Venezia, Italia.

How do you see the location factors and respective indicators that I have presented?

The factors are very important. When you think of it, some are more important than others.

Factor Raw Materials & Transportation there are international brokers and traders for raw materials. They set prices of metals on an international level.

Factor Markets the current market is 'forcing' metal industries to focus on short term survival. Hard to face competition with Asian countries.

Energy sources definitely critical but it is hard to say how much we can innovate our processes. We need to change the way we use energy.

Factor Cost of Knowledge this is a big topic for us. It depends on the geographic areas you look at. There is unprecedent need of communication between the academic world and the real industrial word. This is a vacancy.

Factor Climate ways manufacturing industries influence the climate

Factor Policy environment It depends a lot if you talk of public or private industries. Often the public ones are favorized. Privates face more difficulties. We need a new culture regarding the controls in the company. This people are often not kept discussing but more to sanctions. There must be balance between those that are controlled and those that control.

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions
accessibility of land and space for future expansion, existing infrastructure are definitely fundamental.

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

Indeed, as we just discussed.

What about the specific changes on the factors? Are those reasonable?

Yes, I believe we discussed them. Nowadays, talking of sustainability, circularity and recycling are well internalized topics within the industrial medium. This because there is a politic vision going in this direction. Industry has to adapt to this in order to deliver products that are marketable. Things are changing and we know it. Adaptation is challenging.

What do you think of TTOs ad their penetration in potential in heavy industry?

Regarding the fusion of primary materials, we use electric furnaces that work on the induction principle. Those are traditional furnaces of the primary industry. We have never supplied them through renewable sources. In some of my other facilities we used renewables for power supply. This was motivative by the presence of attractive financing schemes that enabled to foresee a return on the investment.

What are the barriers that influenced your choices?

There are certain traditional cycles and processes that we prefer to keep as such. Innovation will always ask for an adequate economic return. Investment costs are very high, and the lifetime of machineries is long. The idea is that once you invest in innovation you will keep the technology you opted for as long as possible. Our market develops according to the construction market.

Is the Italian government taking steps towards this modernization?

I think that the tertiary sector has been supported a lot while strategic sectors (i.e. steel manufacturing) have been neglected. Industrial politics and incentives for industrial development are unfortunate. Think of closure of ILVA, Fiat and all those key players that have been forced to leave the country or close down. According to Bonimi from Confindustria we have an unprecedent opportunity due to the large sums of capital that are intended for the economic redevelopment following covid. Personally, all nations that will fail in properly utilizing these funds will inevitably pay the consequences. Mario Draghi said a very similar thing in its last speech. Again, Bonomi told the Italian government that if we fail this time is not politics that goes home, its Italy that does it. We see the EU directives, but we need political support and strategic guidance to get there. To conclude, industries have been neglected for a long time. Now we need to be at supported and properly incentivized.

The political stability and the industrial politics of a nations act as determinants for firms' investments and choices. When this environment fails, firms froze their investments, produce at maximum capacity until there is market and then shut them down. This is an unfortunate destiny, but it is how it works.

Who should bear the costs?

In the 70's I was working for ENI (state owned). At the time ENI decided to unbundle and privatize its metallurgic industries. These state-owned agencies were acting as containers for people, but they were not competitive on the market. The unbundling was driven by the fact that these industries were not following traditional principles of earning profits. This proofs the fact the state is not able to able to manage industrial activities. Huge opportunities that our nation was not able to use properly. We need security for our long-term investment. Money itself is not the issue. It is more how to use it. Costs are to be shared by all actors involved, but the proportion of investment needs to be agreed beforehand and accepted by the parties.

Do you have anything to add?

Today the European steel market is experiencing difficulties. Clearly, success depends o proper incentives, financing, economic returns and the political direction. Form the Industrial perspective we focus on options that allow for business opportunities in the short term. We want to survive. Very nice to talk of a green future and novel resources but I believe that industry now is living another situation. If you focus on the development of this sector, in the last 15 years we shifted from production of top-quality products to lower quality once that are price competitive. Factories were forced to think of survival in terms of decreasing costs of final products. This happened from 2008 onwards.

The site where one of my facilities is located till the 70's was the biggest (on international standards). It was counting 70 thousand employers. Today, we have around 15 thousand. This means closure of important and strategic plants.

H Italy 5

Interview: GIUSEPPE LESS CEO Eurocoperture S.R.L. Metalwork in Italy

How have energy prices changed through time?
How do you see the location factors and respective indicators that I have presented?

Very much in line with what I have considered when I decided to build my facility. If I would invest in a new facility today, I would give more importance to the energy aspect you have highlighted. I think the other factors remain important too.

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

You have an interesting perspective on the topic. Yes, I see the argument as valid and useful for practice.

What about the specific changes on the factors? Are those reasonable?

Factor Raw Materials & Transportation
Factor Markets.
Energy sources
Factor Cost of Knowledge -
Factor Climate
Factor Policy environment
Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

What do you think of TTOs ad their penetration in potential in heavy industry?

I think the potential is high. At some point we need to change machineries and these novel options are pointing to new possibilities. We also don't want to be left behind.

What do you mean with possibilities?

Think of renewables. I have invested in renewables early on (before the conspicuous incentives offered by the state in 2009). I have invested a significant amount of money that I will never earn back.

For instance, those that invested between 2008 and 2011 were rewarded 0.40-0.42 EURcent/KWh. So a lot, this people made a deal.

Now solar panels cost way less than back then. So by considering how much power and energy you need, your fixed cost, but bare in mind that excess energy produced is not properly rewarded any longer. But if you are able to use what you produce then it would make much sense for a company because here in Italy electric power is very expensive.

Now my panels are 20 years old. They are not as efficient as they used to be but also not that much worst. So, I thought of buying batteries because it could have made me self-sufficient. But unfortunately, it made no sense for me. Although I want to decrease my footprint, I could have not afforded that investment. I thought of this because I could have stored the energy in summer and use it during winter. I considered 50 KW.

What about subsidies and incentives? Do you see these as useful means for enabling penetration?

I have produce 30-50 KW in a day but I don't use them. Back with the old meters it made quite a lot of sense. I was spinning left or right and consumption was balanced of. Now the new meter don't allow to do that any longer. Now I'm wasting 2000KW each year on average.

Moreover, I'm using a lot of heat pumps (8 or 9). That In wither function almost 24hr per day.

People that made investments inn solar farms in those years made a fortune because of the incentive scheme. Now the story has changed. We are not sufficiently incentivized. I'll rather keep things as they are.

What do you see as barriers and opportunities for RE integration in industry processes?

In My case it will become particularly convenient to cluster up with someone that is not producing renewable energy. I could get rid of my losses and they could use renewable power as well. Unfortunately, I don't think there is a legal way to do so. You are expected to inject into the grid for very low returns.

Do you have anything to add?
My strategy was to diversify. I tried to integrate renewables as much as possible. Now I'm able to provide the domestic needs of the company (and all employees with RE). The industry processes only partly. I need security in the supply. If my machinery would fail and shut off because of power issues this will mean huge losses.

Concentrated solar power is very convenient in my case. Consider continuous gains in energy efficiency.

And consider that in Italy things must be incentivized. Otherwise people will not accept the associated risk.

I Italy 6

Interview: Federico De Col – Technical specialist for AssoEnergia and Confindustria, Italia.

How do you see the location factors and respective indicators that I have presented?

All these factors are definitely important. Generally, the topic you present is central.

Factor Raw Materials & Transportation In the norther cluster a lot of scrap materials are being used.

Factor Markets

Energy sources transitioning from fossil fuels to cleaner options. Changes of price are important. In the past years prices have increased.

Factor Cost of Knowledge as long as we have unions representing workforce we are not going anywhere. There is misalignment in objectives and perspectives.

Factor Climate ways manufacturing industries influence the climate

Factor Policy environment incentives play an important enabling role. (i.e. energy efficiency titles, amortization).

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

Certainty. We are living a moment were a very important energy transition is taking place. I can see why you think that factors are going to change. These changes ask for our infrastructure to develop accordingly. Italy could run on renewables (during the day) the problem here is the transmission and distribution. From south where we produce to north were, we use it.

What about the specific changes on the factors? Are those reasonable?
During the lockdown that happened this spring gas turbined had to be ramped up in order to ensure balance of the grid. This impacted the costs 5 EUR/MWh. There is need to update our infrastructure. When we will have storage, this will be solved. For industries will be good to use RE because they may have to purchase less CO2 allowances.

What do you think of TTOs ad their penetration in potential in heavy industry?
They are critical for the transition. Contract of energy efficiency are playing an important role in enabling the uptake of these technology. You often see a third party that offers the main client a support in investment and it makes profit on the energy efficiency gains of the client. The decreased consumption is divided between the company and the third party. They are called EPC energy performance contract. Moreover, Italian factories are generally old, so they are shifting to new technologies.

Who should bear the costs?
We cannot allocate all costs to a single actor. Making companies pay for a common goal also does not sound fair. The government needs to help, by favoring investments through incentives, it should move towards banks. Make banks inclined to support transition investments with reasonable interest rates. The Italian government should act as guarantor of the credit. Confindustria is working at national level on the development of strategies to properly use the money flows coming from Europe.

Is the Italian government taking steps towards this modernization?

Industries now are not properly supported by the government. Our CEO in a public conference pointed to the fact that we do not have properly prepared actors working in the government. This is people that have never worked, that don't know its value and importance. We are the second manufacturing country in Europe, but the firs joke worldwide. There is ascendence of strategy. It seems as the government worked on way to prone our industry to move away from the country or close down.

Similarities and differences?
There must a change in the way people think. The same hold for industry. Thanking maximum advantage of energy when it is available. This point to changing working shifts and production cycles. For companies that work 24hr per day this is harder, but we are working on it. Before we can fix our consumption, we need to understand how we consume. More monitoring is needed. This way you will be able to know where every KWh goes.

Do you have anything to add?
The impression I have personally is that here in Trentino the topic is quite felt, at least among the big ones. We are lucky enough to live in a reality where renewable hydroelectric has always had a great importance and many companies are still interested in photovoltaics beyond the now virtually non-existent incentives (except for specific

calls from the PAT). Of course, at the national level, the big gap is still the non-programmability of the renewable resource (sun in particular, but also the wind has its importance) and the still undeveloped storage technology. Let us then consider the structural shortcomings of the national grid, another major problem that Terna and the Local Distributors will have to face immediately.

In the real-world Italian cement industry has moved very little towards transition goals. The steel making word is quite different. All factories have an energy manager and a team that takes care of energy efficiency. For these industries energy cost is the second highest cost incurred. Changing energy price will thus have an important impact.

G Italy 7

INTERVIEW: Antonio Reverdito Eureka Italia – services of energy efficiency in industry

How do you see the location factors that I have presented?

The Factors you utilize are definitely important. Especially because of the size of the industry you analyze.

Factor Raw Materials & Transportation *geographical distribution of raw materi*als
Factor Markets *presence of markets, access to markets & metropolitan areas*
Energy sources *Availability and affordability and accessibility of future capacities*
Factor Cost of Knowledge *availability, productivity and cost of the needed workforce*
Factor Climate *ways manufacturing industries influence the climate*
Factor Policy environment *actions taken by government agencies, at state or local level*
policies that include *tax incentives, grants and RD&D and training programs*. Sanction industries that pollute.
Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions
topography of land, accessibility of land and space for future expansion
Agglomeration forces
transportation facilities, alternative modes and freight rates
existing infrastructure
energy sources *I think the indicators you are using are insightful are more than enough for analyzing the case. Think of percentage of energy in the products. You may want to try to rank the relative importance of these factors (here further research should apply MCDM method such as BWM to evaluate the importance of factors compared to other factors). Raw materials and workforce may lead to relocation energy to a lower extent. Prices of energy are not that diverse, especially in the EU. For instance, in Italy prices are higher because of taxation issues. There is a tax for further PV development. Overall increase in electricity demand. Because if industry transitions it needs way more electricity.*

Do you agree with the fact that changes in the energy factor will influence the remaining factors?

Yes, your perspective is valid. They are definitely going to influence them. I think is also good that you use as common denominator the price and availability of renewable power.

Factor Raw Materials & Transportation they won't change much. Economies of scale might limit their impact on location selection. Then if you change the type of production you may need novel materials.

Factor Markets Impose tax for products coming outside EU from export to a more local market. Competition outside EU free market is challenging. Market for novel CO2 neutral products. *current market needs rethinking. Listen for rationale.*

Factor Cost of Knowledge digitalization is going to impact the criticality of this factor. There is a dichotomy between the financing and production. Think of Apple, it makes beautiful products (but it makes them in China). It is very hard to speculate on this factor

Factor Climate the impact of transitioning industry on the climate. You see the effect of the 2008 economic crises on the climate. The closure of plants impacted.

Factor Policy environment incentives, tax reductions. We need an environment that sanctions (heavily) the industries that pollute. So, if you don't use RES and you pollute you must pay (compensate) carbon taxes. Now they have an economic advantage in using polluting systems. The EU ETS has failed, it has to be rethought. We need to start monitoring the population growth.

Factor Geographical conditions, Factor Key infrastructure and Factor Industrial conditions

They develop accordingly and serve as drivers for location determination.

What do you think of (transition technology options) TTOs ad their penetration potential?

Modernization is something that will happen, but it takes time. The technologies you present to my knowledge are the once that are already in the market. I consider it a good choice to focus on these options.

How do you see the future of RE in Italy (intended as future installed capacity)?

I expect it to be way better than it has been in the last few years. After the faulty incentive scheme, it was understood that the attractiveness of technologies that depend so much on incentives needs to change. Because you can't control. Now the attractiveness of solar PV is intrinsic in the technology. The reason is that costs decreased so much that industry can invest without the need of incentives. This PV systems now guaranteed good returns without support schemes. So it is healthy technology.

OBSERVANTION of the author: these incentives initiated a chain reaction that lead to emergence of a new technological standard. In other words, in the beginning solar PV was very expensive and it needed support to become attractive. (in 2008 the cost of the interviewed expert was 3,600 EURO per KW. Now he can sell the finalized system attached to the grid for 1,100 EURO/KW).

So, it has penetrated the market in a way that incentives are not required. It is an autonomous technology. Therefore the 'faulty incentives' lead to development, growth and increased production capacities probably now we would not have producers able to deliver such attractive components.

The next step is storage technology. Our calculations currently show that storage is not economically convenient. Costs are so high that as soon as you reach ROI you need to change technology because of end of lifetime. In addition, in Italy we have a sort of virtual storage. The energy you produce is divided in components. Own consumption, and that you inject in the grid (for 0.13 EURO cent/KWh) when the energy you pay is around 0.20 Euro cent/KWh. So storage would mean that you save that 0.07 EURO cent/ KWh. But this is not economically attractive at all. This is a barrier for storage technology development in Italy.

What barriers and opportunities do you see for industry and TTOs?

Those are long term and difficult projects. What we need in the energy and climate realm is a global strategy. Because if we do it only in the EU then China's industry will eat us all. And you must consider that if Industry modernizes but energy production remains based on fossil fuels then the thing won't make sense. A carbon tax definitely helps here. You incentivize industry to become more efficient and use less energy. To do so you adopt TTOs and produce your energy on site and store it.

Who should bear the transition costs?

Tough question. I think governments should promote progress and transition. In principle you can not only punish industry. You also need have to help them out (facilitations on the investments made, bring the depreciation to much higher figures). You need to force change and also to incentivize it.

Is the Italian government taking steps towards this modernization?

Now it is interesting because the Ministry is saying: if you produce 100 and you are able to utilize 70, on that 70 I give you a premium. On the remaining 30 that you inject on the grid I do not give you a premium.

Do you see the various projects to increase RE capacity as feasible or can you identify specific barriers?

There are many faulty measures. When you focus on the PV remuneration scheme and its effects it one cannot defend the government choices. The whole market of PV was 'drugged'. Faulty incentives on the one side, prices of components on the other. The cost of these components was not responding to an industry production capacity but to the incentive itself. This highly incentivized market worked great for a few years but as soon as the incentive decreased the whole market collapsed.

The issue was the extremely high remuneration deriving from the incitive. An incentive should help not industry return on investment. What happened is that investment in PV made sense only because of huge returns. Moreover, a second issue is that the incentive was given for all generated KWh's for all type of utilization. Geographic locations are important! You cannot remunerate the same If you produce in the middle of the forest or on the rooftop of industry. You should incentivize local consumption of the generated electricity.

Do you have anything to add? Similarities and changes

True. We have created the conditions for china to become so powerful. By delocalization of production and getting habit to cheap cost. The only way to make it come back at very severe taxes for products that come outside the EU.

Then again. Example on PV – a premium on the incentive was proposed in the EU. They were not taxing china's products, they were offering an even more attractive incentive when PV system was composed of at least 70% of EU products. Result? China came out with panels that cost 70% less than the day before. To maintain their market leader position. Then in the Eu it is hard to meet the needed production capacities in the EU.
Efficiency can help Italy it if ensures performance and/or warranties. (compared to china's product). What we do: PV production, TTOs that reduce consumption (which are made in china). Yet china is 60 days away by boat. We commercialize Italian products with a 10 years warranty which is higher than china's products with a warranty of maximum 4 years. So, spend more but we try to protect you!

Additional information

When you talk of energy efficiency, we are usually asking how much it costs. This is the wrong question. You need to ask how much you save and for how long. The real deal is about saving energy for a certain time. So, you seek for the maximum savings guaranteed for the longest possible time.