Perspectives for digitising energy-intensive industries – findings from the European iron and steel industry

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Abstract

Industry has to contribute substantially to the low-carbon transformation if carbon dioxide reduction targets of 80 % to 95 % are to be met. Energy-intensive industries like the steel industry play a major role in this transformation since energy-intensive industries account for about 75 % of total industrial carbon dioxide emissions (e.g. IEA, 2009). Digitalisation or Industry 4.0 might substantially affect the way the steel industry operates. Digitalisation could strongly affect production processes, it might lead to fundamental changes in the use of labour and it might turn upside down the structure of entire companies. Visions for factories of the future include concepts such as *one site – one tablet – one worker*, *zero-waste-production* and *complete recycling*. Such major changes are likely to affect energy efficiency, as well. Studies on the current state and future implications of digitalisation in the steel industry are scarce. This contribution reviews policy activities, R&D projects and activities as well as patents in the field of digitalising the European steel industry. The contribution concludes with a qualitative impact assessment of digitalisation's impact on energy efficiency.

Introduction

Digitalisation and *Industry 4.0* are much discussed these days. Originally the term *Industry 4.0* (I40) first appeared in the German High Tech 2020 Strategy launched in 2011 (EC 2017). In addition, the European steel industry deals with digitalisation and Industry 4.0 in several ways. Initiatives include the ESTEP Working Group *Integrated Intelligent Manufacturing (I^2M)* founded in 2008 or the Working Group *Industrie 4.0* of Steelinstitute VDEh from 2014 (Peters 2016). While in the latter initiative steelmakers from German speaking countries and the research institution of the Steelinstitute VDEh are members of this group[1], the ESTEP working group covers a broader range of stakeholders. Next to European or multinational steelmakers, this group also consists of plant manufactures and several European universities and R&D institutions.[2]

However, literature is rare on what is actually behind Industry 4.0 in the European steel industry and what concrete activities are going on in this. Besides few presentations e.g. by Peters (e.g. Peters 2016, Peters 2017) or Sube (2017) that give slight insights, Hecht (2017) described rather in detail what Industry 4.0 means to Dillinger, a German steel company. He extends the definition of Industry 4.0 by the Platform Industry 4.0 (2018) (horizontal integration, vertical integration, digital conform engineering, and the human being as the *conductor* of value added) by four further aspects (data gathering & data processing, generation & supply of information, definition of & compliance with standards, assurance of autonomy). He summarizes that industry 4.0 is a holistic approach to connect business

1. ThyssenKrupp Steel Europe, Salzgitter Flachstahl, Hüttenwerke Krupp Mannesmann, Arcelor Mittal Ruhrort & Bremen, Dillinger, Voestalpine, Stahlwerke Thüringen, Stahlinstitut VDEh, VDEh-Betriebsforschungsinstitut BFI.

2. Arcelor Mittal, Tata Steel, ThyssenKrupp Steel Europe, Voestalpine, Ilva, Primetals, Danieli, VDEh-Betriebsfoschungsinstitut BFI, Centro Sviluppo Materiali, *Centre d'Excellence en Technologies de l'Information et de la Communication*, Scuela Superiore Sant Anna, Lulea University.

processes in a functional way. Hecht (2017) also describes three examples of industry 4.0 at Dillinger (functional connection between BOF and slab adjustment; functional connection between BOF and laboratory; digital conform engineering along the process chain).

Even though Hecht (2017) puts forward a rather clear strategy towards industry 4.0, others are more reserved about clear future strategies. For instance, Qin et al. (2016) state that the technology roadmap of accomplishing Industry 4.0 is still not clear in industry nor in academia.

This paper aims at shedding some light on what are the activities behind digitalisation and industry 4.0 in the European steel industry, how policy supports them, and what impact on energy efficiency we can expect.

Since there is no clear definition of industry 4.0 so far, this paper also considers projects that cover necessary pre-steps towards industry 4.0. Thus, we additionally include digitalisation and advanced automation, e.g. by using new IT-developments such as new sensors, optical measurements that can be applied (in future) in real-time (online). We understand Industry 4.0 as measures that are directed to online through-process control in real-tine, i.e. that several processes of a process chain can be controlled in real-time and decentralised e.g. by wireless technologies. On the other hand, industry 4.0 can be applied to a single plant if further parameters such as the raw materials or customer requests can be considered in real-time and, again, decentralised.

In section 2 the methods are given. Section 3 presents our findings on policy activities to support digitalisation and industry 4.0 in the European steel industry, on research and other activities, and finally on patents in this field. The paper ends with discussion and conclusion.

Methods

ANALYSING POLICY ACTIVITIES

Public support for industry 4.0 in Europe is given by R&D support, by initiatives to facilitate knowledge transfer, and by activities to coordinate standards. This study focuses on the European level and skips policy activities on the national level. We analyse European initiatives on knowledge transfer by desktop research.

DATABASE ON R&D PROJECTS

Within Europe, typically either European or national research programmes fund R&D projects in the steel industry. European programs include the Research Fund for Coal and Steel, RFCS, which is a key funding institution for the steel industry with an annual budget of about 55 Mio. Euro (RFCS 2018). The European Union maintains its own research and innovation-funding programme. In the period from 2007–2013 it was referred to as the Seventh Framework Programme, FP7, and nowadays, its successor Horizon 2020 is in place for the period 2014–2020 (EC 2018a). Another European initiative is EUREKA, a pan-European network for market-oriented, industrial R&D (Eureka 2018a). Finally, SPIRE is a public private partnership under the Horizon 2020 programme for the most important European process industries, among these the steel industry. SPIRE stands for Sustainable Process Industry through Resource and Energy Efficiency (EC 2018b).

Additionally, each country may hold its own research and development programmes, e.g. Ministries for Economic Affair and Technology or Innovations Agencies. Examples are the German Ministry for Economic Affairs, the German Ministry for Education and Research, the NL Ministerie van Economische Zaken, or the Swedish Innovation Agency Vinnova.

Available databases for the identified R&D programmes such as Eureka were scanned for relevant R&D projects (Table 1). The results were complemented with searches on the internet.

Those projects were transferred to the database that were rated as relevant by the authors understanding of the project content after having read the title and abstract and considering the definition of Industry 4.0 given in the induction.

The established database contains the acronym of the project, the project title, the abstract, the year in which the project started and ended (or ends), total budget of the project, the participants, the source of this information and further information, if available.

FRAMING OF THE PATENT ANALYSIS

Since no patent classification for Industry 4.0 exists, a search strategy combining keywords and classification codes was chosen. As listed below, keywords describing industry 4.0 relevance and CPC classification narrowing down the results on production and processing of iron and steel were used to match relevant patents.

Table 1. Sources for information on R&D projects.

RFCS	Research Fund for Coal and Steel	2003–2014	Summaries of RFCS Projects: 2003-2014	RFCS 2003–2014
RFCS	Research Fund for Coal and Steel	2015–2016	Synopsis of the RFCS projects 2015-2016	RFCS 2015–2016
FP7	European Union Framework Programme 7	2003–2014	Community Research and Development Information Service, CORDIS database	EC 2018c
H2020	European Union Horizon 2020	2015–2020	Community Research and Development Information Service, CORDIS database	EC 2018c
EUREKA	EUREKA	1985–2018	Eureka projects	Eureka 2018b
SPIRE	Sustainable Process Industry through Resource and Energy efficiency	2015–2020	Community Research and Development Information Service, CORDIS database	EC 2018c

Keywords describing industry 4.0 and digitization aspects (also similar words): *machine learning, intelligent, smart, tracking, Internet of Things, artificial intelligence, customer integration, vertical integration, horizontal integration, cloud, big data, massive data, machine communication, RFID, autonomous, embedded system, predictive, deterministic, data driven, data handling, wireless, database, cyber, cognitive, logistics.*

CPC codes classifying iron and steel production, casting and rolling (also sub-codes were used): *B21B (Rolling of metal), B21C (Manufacture of metal sheets, wire, rods, tubes or profiles), B22D11 (Continuous casting of metals), C21B (Manufacture of iron and steel), C21C (Processing of pig iron), C21D8 (Modifying the physical properties by deformation combined with, or followed by, heat treatment, e.g. hot or cold rolling), C22B (Production and refining of metals).*

Only applications to European patent offices or WO patents and patents with a priority date after 2011/01/01 were reviewed. The search strategy was implemented using the STN International database (FIZ Karlsruhe). Patent abstracts were retrieved using the google patents database.

The search strategy based on keywords does not collect all industry 4.0 relevant patents, since the basic concept of digitization, automation and process integration might be part of an invention, but is not expressed in terms of typical keywords. To evaluate the search strategy, a manual screening of patents was done for some European steel producers. Since 2011, the following numbers of patents (families) were applied for to European patent offices or the WIPO using the CPC codes given above: Assignee: ArcelorMittal 54, ThyssenKrupp Steel 66, European sections of TataSteel 55, Voestalpine 22, Salzgitter 29, Saarstahl 2, Dillinger 1. Similarly to the method for screening relevant research projects (see above), industry 4.0 relevant patents were selected by analyzing the abstracts and descriptions of these 229 patents or patent families. Industry 4.0 relevance was assessed based on the authors expertise and the above given criteria. Compared to the search strategy based on keywords, a similar number (±1) of industry 4.0 relevant patents was found for each of the companies. We hence conclude, that our search strategy catches the correct order of magnitude for relevant patents. Similarly, selecting patents by steel-related CPC codes neglects certain inventions, which might be utilized for steel production processes, but have no exclusive reference to the procedure itself (e.g. sensors, algorithms).

Results

POLICY ACTIVITIES TO SUPPORT INDUSTRY 4.0 IN EUROPE

Public support for Industry 4.0 in Europe can be grouped into three areas: support of R&D to develop and implement specific I4.0 technologies, initiatives to facilitate knowledge transfer from I4.0 research to small and medium sized enterprises (SMEs), and activities to coordinate standards and build up I4.0 skills. Although the governments of almost all European Member States have already developed own initiatives, measures, and activities, our study concentrates on the European level.

Concerning R&D support for Industry 4.0, Horizon 2020, the current research framework of the European Commission, focusses on the development and exemplary implementation of Industry 4.0 technologies in different contexts, predominantly in the manufacturing area. In addition, we find relevant Industry 4.0 projects carried out in the context of the Research Fund for Coal and Steel (RFCS), a programme managed by the European Commission. In its report of 2016, the RFCS documents its activities in the area of Industry 4.0 and similarly puts them into the context of modernizing the steel industry and making it more efficient and eco-friendly (RFCS 2016).

Another goal of the European Commission is to facilitate knowledge transfer from Industry 4.0 research carried out in research and technology developing organisations into real-life SME production contexts. For that matter, the EU has been supporting more than 50 so called Digital Innovation Hubs (DIH) which are testing and experimentation facilities located across Europe. The DIHs are knowledge-transfer platforms and education centres that specialize in certain topics like new business models for manufacturing companies, IT-security aspects in networked production contexts or implementing smart sensors in manufacturing. Although listed within the EU initiative *Digitising European Industry* (see below), the Digital Innovation Hubs are financed through the Horizon 2020 programme in a project called I4MS (http://i4ms.eu). In fact, several digital innovation hubs have been set up by national governments before this EU initiative. The EU Digital Innovation Hubs are in addition to existing ones on national levels and shall complement the topical range of Industry 4.0 in the respective areas.

Whereas the main aim of the EU Digital Innovation hubs is to provide a platform, where research institutes and SMEs share know-how and experiences and learn from each other, the initiative is only indirectly relevant for the steel industry since there is no specific measure or focus on this sector in any of the Hubs.

Finally, the EU supports the Industry 4.0 development with its umbrella initiative *Digitising European Industry* which is intended to coordinate the activities of the Member states, help establishing standards and build up specific Industry 4.0 skills in Europe. The list of instruments to achieve this is quite long and ranges from coordination activities, regulatory measures and R&D projects. The official budget for the initiative is said to be 50 billion Euros. However, this figure comprises all expenses of Member States for their own Industry 4.0 activities, includes all related Horizon 2020 projects, expected leverage effects as well as budgets from related initiatives like the European Cloud Initiative. In fact, additional budget for the Digitising European Industry-initiative can be expected to be about 6 million Euros, mainly allocated to coordination activities and the Digital Innovation Hubs mentioned above.

Again, for the steel industry, the Digitising European Industry-initiative is relevant only in an indirect way because no specific activities addressing the sector are foreseen. On the other hand, steel-making companies may profit from those initiatives either by taking over new technologies and processes developed in other sectors or by actively participating in R&D projects and transfer measures supported by the European Commission.

CURRENT R&D ACTIVITIES

Projects funded by the Research Fund for Coal and Steel

The Research Fund for Coal and Steel is according to the findings of this study the most important programme for technology development in the European iron and steel industry and thus

also in the field of digitizing this industry. Two documents list the projects, one for the years 2003–2014 and another for the years 2015–2017 (RFCS 2003–2014, RFCS 2015–2017). Given are the title, budget, year in that the project started and is likely to end, an abstract, and partners. In addition, the chapters list the projects according to their process step (e.g. ore agglomeration and ironmaking, steelmaking process, casting, factory-wide control). The title and abstract give insights whether the projects cover aspects of digitizing the steel industry, but it is hardly possible to identify whether the projects belong to industry 4.0 or if they only include aspects of digitalization. Thus, this contribution covers on a broad range activities on digitizing the European steel industry in order to surely include activities on industry 4.0.

In total, this study identified 145 RFCS-projects that involve aspects of digitization and industry 4.0, e.g. adaptive online control; through-process optimization; through-process synchronization of data; zero-defect manufacturing; traceability; intelligent and integrated manufacturing. The total budget of the identified projects is 250.1 Mio. Euro resulting in an average budget by project of 1.7 Mio Euro. An overview of the acronyms of the identified RFCS-projects gives Table A1 in the appendix.

From the title of the category *Factory-wide control, social and environmental issues* we expect it to be the core category for digitalisation and industry 4.0 projects. Indeed 60.2 % of the projects cover aspects of digitalization, which is the highest share of all RFCS-categories (Figure 1). However, the categories *Steelmaking processes* and *Casting* show high rates of digitalization projects, too (55.4 %, 47.5 %). Even in the remaining categories still about one third of the projects show elements of digitalisation (Ore agglomeration and ironmaking: 35.3 %; Hot and cold rolling: 32.8 %; Finishing and coating: 27.3 %).

Among all identified projects, the categories *Factory-wide control* and *Steelmaking processes* represent more than half of the projects that cover digitalisation elements (34.5 %, 21.4 %). The other categories have shares between 8.3 % and 14.5 % (Figure 1).

Projects funded by the Research Fund for Coal and Steel can include as many as ten project partners. Indeed, there is an extent amount of research institutions, steel making companies and plant manufacturers or IT-providers. In total, more than 170 actors are incorporated in the identified projects, but 90 of them are only participating in one project and 47 actors in two or three projects. However, two actors stand out (Figure 2). The first is the VDEh-Betriebsforschungsinstitut BFI (in short: BFI), a German based research institution with close ties to the Steelinstitute VDEh. According to this study, the BFI is

Table 2. Descriptive statistics of the identified R&D projects funded by the Research Fund for Coal and Steel.

Number of identified projects	145
Period	2003–2017
Total amount of mentioned budget	250.1 Mio Euro
Average budget by project	1.7 Mio Euro

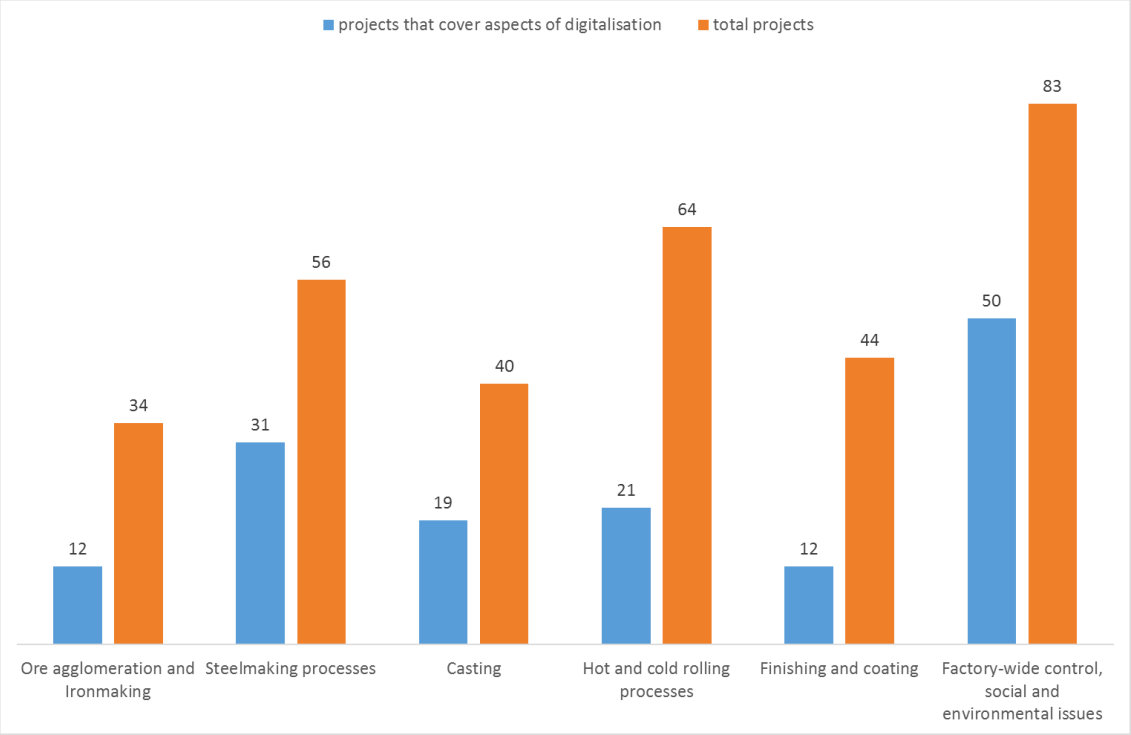

Figure 1. Number of projects that cover aspects of digitalization by RFCS-categories vs. total projects in these categories.

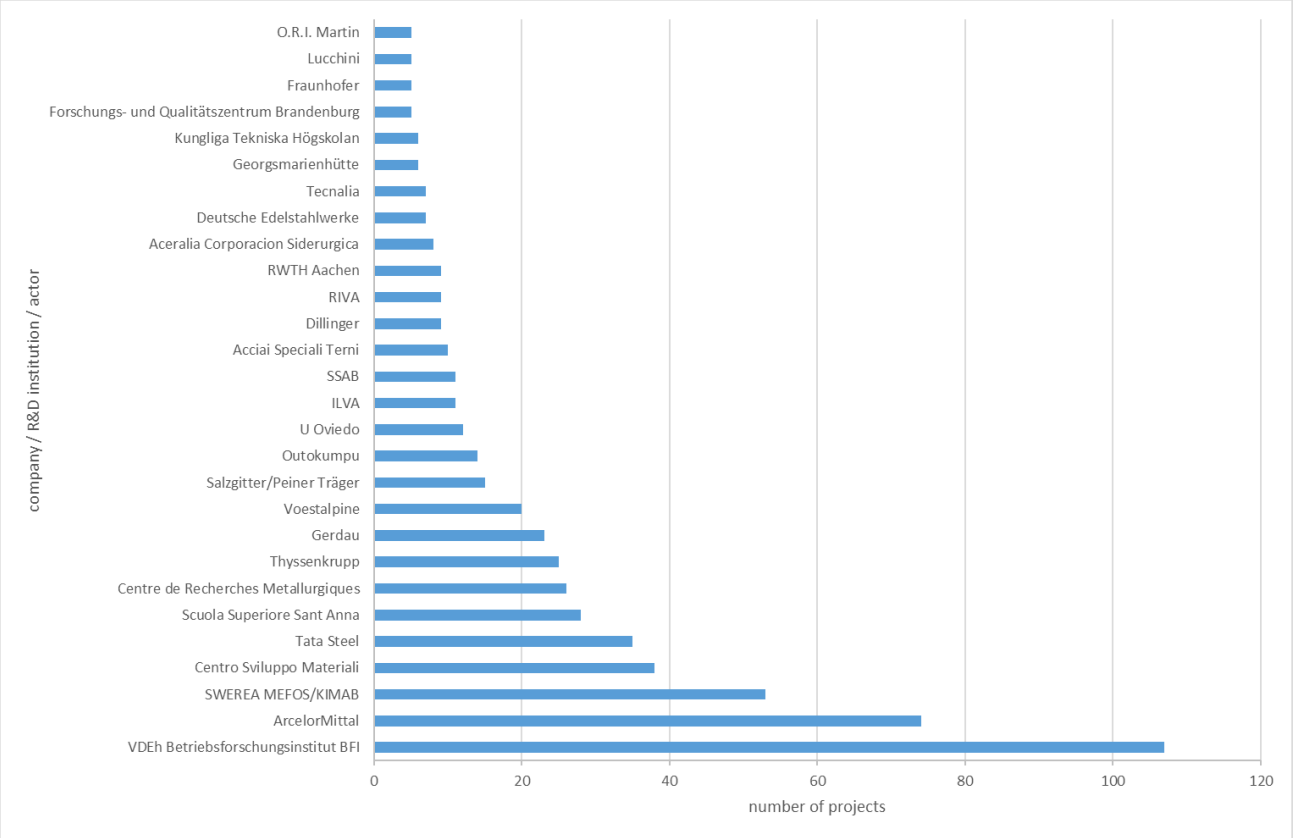

Figure 2. Amount of RFCS-funded projects the institutions/companies are involved (2003–2016).

involved in 73.8 % of the identified projects. ArcelorMittal, the world's largest steel company (Worldsteel 2017) and the second key actor according to this analysis is partner in every second identified project.

A group of four research institutions and four steelmaking companies follows the two outstanding actors. Among these, the most important research institutions are Swerea MEFOS and Swera KIMAB that belong to Swerea, the Swedish Research Institute for Industrial Renewal and Sustainable Growth. The other relevant research institutions are the Centro Sviluppo Materiali and the Scuola Superiore Sant'Anna[3] both based in Italy and the Centre de Recherche Metallurgiques in Belgium. Four steel companies, namely ThyssenKrupp Steel, Tata Steel, Gerdau and Voestalpine, complement the group.

Interestingly, plant manufactures or IT-providers seem only to play a minor role in RFCS projects on digitizing the steel industry. The technology suppliers Siemens and SMS are only partners of three and two projects, respectively, and thus not represented in Figure 2. In addition, Danieli and ABB are only participating each in one of all identified projects.

When comparing the results of this actor analysis with the members of the ESTEP Working Group on *Integrated Intelligent Manufacturing*, we find that both groups coincide largely, except for Swerea MEFOS/KIMAB as well as for the Centre de Recherche Metallurgiques that are not part of this ESTEP Working Group.

3. Scuola Superiore Sant'Anna di Studi Universitari e di Perfezionamento.

Projects funded by European institutions other than by the Research Fund for Coal and Steel

In addition to the projects funded by the Research Fund for Coal and Steel, we also identified 16 projects on digitizing the steel industry from other European funds, i.e. European Commission (FP7, H2020), Eureka and SPIRE. These sixteen projects have a total budget of 85.9 Mio Euro, resulting in an average budget of 5.1 Mio Euro per project compared with only 1.7 Mio Euro of RFCS funded projects. Some of these projects are not restricted to the steel industry, but have a broader scope. The Recoba project, for instance, funded under the H2020 framework also covers the chemical industry. Table A2 in the appendix provides an overview of the acronyms of the identified projects and the respective funding programme.

Two thirds of these projects started between 2014 and 2017. Interestingly, we also identified three projects that started in the early 1990s that cover already aspects of digitising the steel industry, all being funded by EUREKA (OREXPRESS, BRICK, and TAM). These findings support the statement by Hecht (2017) that digitalising the steel industry have long started before calling these activities Industry 4.0.

Analysing the actors of these projects, we find that only five companies are involved in two or more projects. Interestingly, ArcelorMittal again has a leading position in this group of funded projects. It is the only company that is involved in four projects, while the other four companies only participate each in two projects. ThyssenKrupp and Tata Steel are two steelmaking companies that next to these projects also frequently collaborate in RFCS projects.

Table 3. Descriptive statistics of the identified R&D projects funded by other European institutions than the Research Fund for Coal and Steel.

Number of identified projects	16
EUREKA	7
FP7	1
H2020	6
SPIRE	3
Period	1990–2016
Total amount of mentioned budget	85.9 Mio Euro
Average budget by project	5.1 Mio Euro

Table 4. Descriptive statistics of the identified other activities.

Number of identified projects	31
Funded by national ministries or agencies	15
Number of projects the company/institution is involved in	
ThyssenKrupp	6
ArcelorMittal	4
Tata Steel	4
BFI	3
Dillinger	2
Fraunhofer	2
Voestalpine	2

Other activities

Along the data gathering for this study, we also identified a set of activities that are funded by national institutions (e.g. economic ministries), or that are initiated by steel companies without any funding we would know of. Information on these projects is often incomplete since typically companies do not publish the budget of those activities or the year they started working on it. The identified activities and the funding body or the respective company are given in Table A3 in the appendix.

In total, we identified another 31 activities in the field of digitizing the European steel industry. These activities cover a broad range, from proper research projects funded by national ministries or innovation agencies, to one-time events on developing new software on industry 4.0 in rolling processes (e.g. Hack4Steel Belgium) or the announcement to erect the world's most advanced special steel plant that aims at setting the benchmark over the next decades (i.e. Kapfenberg by Voestalpine).

Again, the most relevant actors of this group coincide with those from the above-analyzed groups. ThyssenKrupp is involved in six projects, and ArcelorMittal and TataSteel each in four projects. BFI holds three projects, and Dillinger, Fraunhofer and Voestalpine are involved each in two activities.

Examples of activities on digitizing the European steel industry

The information given in from the identified R&D projects and activities is limited. However, this section reviews some of them to give shed some light on what is behind them. The RFCS-project AdaptEAF (2014–2017) aims at setting up an adaptive online control for the electric arc furnace considering, among others, the properties of the actual charged materials. IConSys (2012–2015) develops a so-called Intelligent Control Station in order to support decision making in rolling and finishing. PlantTemp (2015–2018) develops an operator advisory system covering the electric arc furnace and casting in order to meet the target casting temperature with minimal energy and material consumption. I²MSteel (2012–2015) develops a factory- and company-wide automation and information technology to intelligent and integrated manufacture steel. SoProd (2014–2017) is one RFCS-project that is publically characterized as industry 4.0 (Research Gate, 2018).

The EUREKA-project BRICK that was run from 1990–1993 aimed at reducing downtimes at steel converters by predicting failures. To achieve this aim, vision techniques and tactile sensors were used and flexibles data evaluation systems were applied.

From the identified other activities, two seem especially to be worth mentioning in detail. The first is the project on industry 4.0 at the BOF at Dillinger. It is about the development of a real-time forecasting project for a BOF supposed to be adaptive, i.e. it learns and therefore fine-tunes a production process based on the data it receives from the manufacturing process (SMS 2014). According to the literature, this project is successfully running, self-learning and can make real-time predictions.

The second one is an R&D project on loading steel with knowledge. This project is lead by SSAB, a Swedish steelmaking company. The idea behind this project is to make available information and instructions relating to any steel item, regardless of where it is produced. Each link in the chain can then utilize and accumulate information (SSAB 2017). But even asking by e-mail the responsible project manager how steel could be signed with a unique identity code along the entire value chain, no concrete answer was given.

PATENT ANALYSIS

The analysis of patents can give insights into the technological but also economical importance which assignees attribute to industry 4.0. Compared to R&D projects, patents are one step

further towards commercialization of new technologies and the intellectual property is either considered to be economically valuable in terms of licensing opportunities or applicants intend to gain competitive advantages by securing the developed methods and products for their own use.

Following the strategy described in the methods section, more than 600 industry 4.0 relevant patents or patent families with priority date in or after 2011 were identified (340 applied for by organizations registered in Europe). The collected data shows no significant increase of patenting activities over time, underlining that in contrast to the emergence of "industry 4.0" or "smart production" as umbrella terms, the use of digital methods in iron and steel production has already been pursued for several years.

Figure 3 shows the number of patent applications since 2011 by organization. Only organizations with four or more applications as well as organizations appearing in the R&D projects (section Projects funded by the Research Fund for Coal and Steel) are shown. Two organizations, namely Primetals Technologies and the SMS Group are dominating, both in terms of applications as well as granted patents. Taking into account their predecessor or sub organizations (Siemens VAI, SMS Siemag, SMS Meer), they account for about one third of the patents applied for by organizations registered in Europe.

Other plant manufacturers are also represented, however they play a smaller role. The focus of industry 4.0 patents by plant manufacturers lies in the fields of material tracking, transport and handling and the use of predictive methods in process control.

Compared to the plant manufacturers, European steel producers are by far less active in patenting industry 4.0 relevant inventions. They account for only about 5 % of the identified patents. Among steel producers, ThyssenKrupp Steel Europe has the highest share. Compared to the elevator division of Thyssenkrupp, the patenting activities in the field of industry 4.0 are however significantly less pronounced. The industry 4.0 patents by steel producers mainly focus on process control by image processing, human machine interaction and safety aspects of shared workspaces of humans and machines as well as tracking of metal products throughout the steel mill.

The patent landscape shows a certain contrast to the composition of publicly funded R&D consortia and budget allocation. Steel manufacturers and R&D-organizations only hold a comparably small number of patents. Both types of organizations however showed a strong presence in RFCS and other funding programs.

To some extent, this might reflect the pre-competitive character of many of the analyzed R&D projects. On the other hand, the strong share of intellectual property patented by plant manufacturers might indicate, that industry 4.0 solutions are typically not developed by steel producers themselves.

In practice, the smart linkage of systems and devices or the equipment of production facilities with digital interfaces and sensors will be at the core of industry 4.0 implementation. The development of data driven process control strategies, which then are able to utilize the generated information, does often not lie within the scope and expertise of steel manufacturers since specialized algorithms and software are needed. Hence, inventions are expected to be generated by second or third parties.

Discussion

In this study, we scanned European policy activities, databases and reports on R&D projects. We also searched the internet and relevant literature for other activities and we conducted a patent analysis. Since there is no clear and commonly accepted definition of industry 4.0 the scope of this paper is extended to activities in the field of digitalisation. According to Peters (2017), digitalisation is a pre-condition for industry 4.0.

Consequently, the paper reviews a large amount of activities of which only a minor share might be considered industry 4.0.

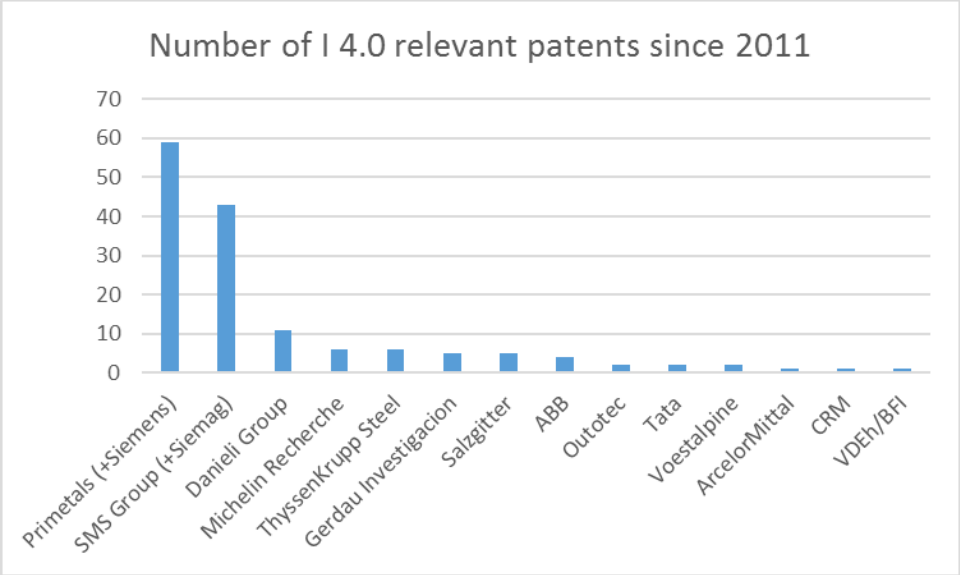

Figure 3. Number of industry 4.0 relevant patents by organization. Only organizations with more than four patents and organizations appearing in public R&D projects are shown.

For instance, we identified over 100 R&D projects in which the VDEh-Betriebsforschungsinstitut BFI is involved. From discussions with experts, we learnt that this institution is only participating in about 20 projects they consider as industry 4.0 projects. One reason is of course, the lack of a strong definition of what industry 4.0 actually is. Also from these expert discussions, we are nevertheless confident that our approach covers those industry 4.0 projects that apply to the definition from the experts' discussion. To further distinguish projects that include digitalisation aspects from industry 4.0 projects, the final reports of the projects would have to be reviewed and complementary experts should be consulted. Based on our analysis and the expert consultations, it can be estimated that there are in total in the range of 30–50 RFCS-projects with a strong focus on industry 4.0 up to 2017.

Conclusions

Our study for the first time tries to assess what activities are behind digitalisation and industry 4.0 in the European steel industry. We identified relevant policies and actors and we collected an extended database on relevant projects and activities as well as on patents.

Our results that all major actors of the European steel industry are active in the field of digitizing this industry. Future research could correlate the amount of identified R&D projects, patents or activities with relevant factors describing the size of the actor (e.g. produced ton of steel for steel companies, number of scientists for research institutions, or turn over for plant manufactures) to identify if some actors are specially active in this field. Our study did not identify any major actors who were previously not associated with the steel industry.

The Research Fund for Coal and Steel is the outstanding fund for R&D projects for digitising the European steel industry. We identified 145 R&D projects with an average budget of 1.7 Mio Euro. Other programs fund larger projects, but not in total to that extend as the RFCS does. The outstanding research institutions are the German VDEh-Betriebsforschungsinstitut BFI, followed the Swedish R&D institution Swerea MEFOS/KIMAB. Two Italian based institutions Centro Sviluppo Materiali and the Scuola Supperiore Sant Anna as well as the Belgian Centre de Recherches Metallurgiques are other key R&D institutions.

The by far most active company among the RFCS-projects is ArcelorMittal. ThyssenKrupp and Tata Steel and to some extend also Gerdau and Voestalpine are relevant actors as well. We found that plant manufacturers rarely participate in R&D projects, but that they are key players when it comes to patents. Primetals and SMS Siemag are the most outstanding plant suppliers in our patent analysis followed with some way behind by Danieli. Research institutions and steel companies only announced a limited number of patents according to our analysis.

Factory-wide control is a key focus to digitising and aspects of industry 4.0 according to our findings. Thus, energy efficiency in the iron and steel industry should be affected positively by digitalisation and industry 4.0, but it is not the core driver for industry 4.0. The word *energy* is part of the title or abstract of 10.6 % of the RFCS projects. However, the holistic resource efficiency approach of Industry 4.0 (Stock and Seliger 2016) or the so-called concept of *zero-waste-production* leads to an increase in energy efficiency.

This paper also gave glimpses on selected projects and activities in digitising the European steel industry. In the future, a systematic review of all identified projects and activities could reveal more detailed information on digitizing the European steel industry, e.g. based on the relevant keywords extracted from the titles and abstracts.

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Appendix

Table A1. Acronyms of identified RFCS-projects.

AdaptEAF	EAFCAMERA	INNOSOLID	OPCONSTAINLESS	SensorControPilot
ADCTEC	EAFDYNCON	INTCLEANCON	OPTCOOLUB	SHAPEHPM
AlCirc	EDDYCAST	IPCDS	OptDeslag	SHELL-THICK
ANALCO	EDGECONTROL	IPRO	OPTHEAT	SimulEAF
AUTOADAPT	ENCOP	IPTINGOT	OPTIBLAFINS	SIMUSTEEL
Autocheck	EnergyDB	KNOWDEC	OPTILUB	Sinter efficiency
Autodiag	Enhanced BF Operations	Lacomore	OptiScrapManage	SISCON
BOFDEDUST	ERAMAC	LADTHERM	OPTISHAMP	SLACON
BOFdePhos	EvalHD	LAREFMON	OPTITUBE	SMARTFIRE
BOFDYN	FACTMON	LCS	ORSC	SOFTDETECT
CASTDESMON	FINALPLATEFLATN.	LINECOP	OSCANEAF	SoProd
CASTINCREM	Flat strip control	LOWCNEAF	OXYMON	SSSSS
CHATTER	FLEXCHARGE	MACO Pilot	PerMonLiSt	StackMonitor
CheckSIS	FLEXPROMUS	MASTERBILLET	Plant Temp	StImprove
CLOGGING	FLOWVIS	MeltCon	PLUGWATCH	SUPERCHARGEEAF
Cognitive Control	FOMTM	Memorace	Predinc	SUPSYSCC
CONOX	FOSUCOR	MICROCONTROL	PRESED	SURFQUALDEV
Consistent BF	GASNET	MicroControl-P.	PRESEG	SUSTAINTAP
Cyber-POS	GLOBALSHAPECONTR.	Modelcor	PUC	TECPLAN
DECFLAQ	Hearth efficiency	MONWIRE	RAMSCI	TOPOMETER
DEFFREE	HIGH-PICK	MULTISAVE	RAPCOAT	TotOptLis
Deprex	HIRODS	NDTCASTING	REFFIPLANT	TRACKOPT
DIRECT DEF.	I2MSteel	NDTSLAB	REMOCOAL	TUNDJUST
DOT Application	IConSys	NEXTEP	ROLLMARK	ULTRAFINE
DroMoSPlan	ICONTENS	Nox-RF	ROLLWITECH	VADPSHEETS
DUMICO	ILORA	O-Chess	Scale Control	VirtROLL
DYNAMO	IMGALVA	OFFGAS	SCRAP PROBE	WAVIMETER
DYNERGYSteel	INCLUSION	OMC	SELSA	WAVISURF
DynStir	INFOMAP	ONDECO	SensoCont	ZINCANA

Table A2. Acronyms of identified other EU-projects.

EUREKA	FP7	H2020	SPIRE
Orexpress	FACTORY-ECOMATION	DECRON	DISIRE
TAM		I-ThERM	EPOS
BRICK		LoCO2Fe	
H2PREDICTOR		COCOP	
HOPLITES		Recoba	
MILLTECH		Intensified by Design	
TOP-RADAR			

Table A3. Acronyms/titles of identified other projects/activities.

Acronym	Funding body/company
Hack4steel Belgium	ArcelorMittal
InDaSpace	BMBF
iProdict	BMBF
RadINSPECT	BMBF
Vertpress	BMBF
Eesel	BMWi
Energieeffiziente dynamische Vakuumbehandlung von Metallschmelzen	BMWi
NEW 4.0 – Norddeutsche Energiewende 4.0	BMWi
Rensodyn	BmWi
TopTemp	Bonnenberg+Drescher
Rationelle Prozessgasnutzung	BWMi
Industry 4.0 at BOF	Dillinger
ELEMET	FIMECC
SitErk	iba AG
Improved Continuous Steel Casting through Electromagnetic Flow Control	NLMEZ
SUPREME	NLMEZ
Towards inline 2D surface topometry by lensless imaging	NLMEZ
COBS	other
REC DC EAF	RFCS
QMS	Salzgitter
BSA	Spinnverse Oy
SIMP	Tammet
Smart Steel Factory Ijmuiden	Tata Steel Europe
b2c	thyssenkrupp
Hot Rolling Mill Hohenlimburg	thyssenkrupp
mes	thyssenkrupp
Odin	thyssenkrupp
Order ready	thyssenkrupp
SSAB smart steel	Vinnova
Additive manufacturing center	Voestalpine
Kapfenberg	Voestalpine