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The European Steel Technology Platform Faces Resource Efficiency in its Strategic Research Agenda

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Abstract

Steel is an fundamental material for a circular economy, as it is essential for the daily life and to the welfare of the society. It has therefore been recognized as a Key Enabling Technology. Steel can be found everywhere: most of the artifacts are partly or entirely made of steel or are manufactured from machines and tools made of steel. Such as most materials, its production involves significant consumptions of resources, energy, raw materials and logistics. However, it is fully recyclable, thus the steel which is produced today will be used also by future generations.

Resource efficiency is an important topic for the European steel industry: it naturally lies in the operating practice of the standard production cycle, due to the recyclability of steel, the significant quantities of raw materials required for its production, the large volumes of by-products and the effort to reduce the energy consumption, to re-use by-product gases from the coke oven, blast furnace and basic oxygen furnace and to recovery the waste heat saving fossil fuel resources.. Further efforts and innovative approaches are demanded to improve resource efficiency. This paper presents how the Strategic Research Agenda of the European Steel Technology Platform addresses the different aspects of resource efficiency and highlights the challenges that the sector faces in terms of Research and Innovation fostering a sustainable steel production.

1. Introduction

The European Steel Technology Platform (ESTEP) is a European 2020 ETP (European Technology Platform) that is a kind of association meeting criteria set by the European Commission. ESTEP is thus a free association, without formal legal status beyond an informal contract binding its members together. ESTEP represents the whole European Steel sector, its value chain, upstream and downstream operations from its core activities, the research and academic institutions which develop intensive research activities related to steel production and usage, as well as some other stakeholders. ESTEP was funded in 2004 from a joint effort of the whole European steel community and in this decade acted as think tank, generating a foresight vision of what Steel is to become in the medium and long term and of how it can get there. This vision is presented in the ESTEP's Strategic Research Agenda (SRA), an extensive document that is periodically revised and updated according to the most recent trends and results of the research in the field. The most recent version of the SRA has been published in 2013 [1].

Steel is everywhere: it can be found in a multitude of different tools, equipment, machines, transportation means and infrastructure which form the basis of our daily life, although they often remains invisible underneath decorative, protective or functional layers of other materials. The reason for this extensive presence lies in the fact that steel is directly linked to human activities, as attested by the relevant steel consumption intensity per capita (185.2 kg per capita in the world and 368.1 kg per capita in the EU in 2014 [2]). Noticeably the importance of steel in social life and organization grows with population, standard of living and quality of life.

The core business of the steel industry is to organize the recovery of iron from natural or anthropogenic resources, in order to make possible the construction and the maintenance of the structure of the anthroposphere (technosphere) and of its artifacts. To this aim, significant amounts of primary and secondary raw materials (32/68 % BOF/EAF routes, close to the virgin iron/scrap ratio), of energy (18.5 GJ/t steel) and of logistics (more than 2 t of raw materials per ton of produced steel in an integrated steel mill) are marshalled in complex and professional ways, literally on a global scale. In fact 60% of the iron ore consumption and 80% of the coal are traded internationally. This also requires the contribution of millions of people (2 million jobs, worldwide) and creates a GDP footprint that extends far beyond that of the steel sector (2%), and along the value chain and the life cycle of steel (20%).

Steel is thus deeply and subtly interconnected with the environment, the whole planet and society, and the steel industry is committed not only to simply comply with the environmental regulation, but also to cooperate with the whole anthroposphere of the human society in the promotion of sustainable

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development as the only way to couple welfare and progress to respect and protect the natural environment [3]. ESTEP's SRA explores how to manage this cooperation as smoothly as possible in its section devoted to environmental issues [4, 5].

Resource efficiency has a key role in sustainable development and the SRA touches several topics directly or indirectly connected to resource efficiency. The present paper depicts how the ESTEP's SRA addresses the different aspects of resource efficiency in order to highlight the challenges that the sector faces in terms of Research and Innovation fostering a sustainable steel production. Clearly the final aim is the reduction of the environmental footprint of steel production. This must lead to steel solutions that can only be achieved by reducing the resource consumption, fostering the use of secondary raw materials and, consequently, promoting the establishment of a more closed-loop economy, as well as by implementing energy efficiency, saving exergy, implementing process integration and eco-design approaches.

The paper is organized as follows: Sec. 2 provides an overview of the structure of the ESTEP's SRA, Sec. 3 introduces the topic of the sustainable production of steel, Sec. 4 depicts in details the main issues that the European steel industry is facing related to supply of energy and raw materials. Sec. 5 depicts the efforts spent to move toward a closed loop economy. Sec. 6 outlines some main limitations of current Life Cycle Assessment and the efforts spent in order to overcome them. Finally Sec. 7 depicts the future trends of the related research activities for the steel industry and Sec. 8 provides some concluding remarks.

2. Structure of the SRA

The European Steel industry identifies in the SRA four main pillars for its sustainable growth:

- **Planet** dealing with innovative technologies, including breakthroughs, which help to meet environmental requirements, promote sustainable steel production and develop Life Cycle Thinking and Life Cycle Assessment;
- **Profit** ensuring profit-making through innovation and new technologies within the production processes;
- **Partners** responding to the demands and needs of the society by working with the partners of the steel sector for proposing innovative steel products and steel solutions in the sectors of transport, construction and infrastructure, and energy.
- **People** attracting and securing human resources and skills in a dynamic way by optimizing the deployment of the human resources and becoming a worldwide reference for health and safety at work.

Seven working groups corresponding to the above listed pillars have been set up. They have developed the following three industrial programs with large societal impacts each of them encompassing several R&D themes and research areas:

- Sustainable steel production
- safe, cost-effective and lower capital intensive technologies
- appealing steel solutions for end users

The importance of ICT, Industry 4.0 and BigData was reason to establish the task force **Integrated Intelligent Manufacturing** (I2M) as an independent working group. The impact of I2M [6] is strongly related to the scope of all other working groups of ESTEP so that it represents a fifth pillar of the sustainable development.

A transversal objective regarding human resources has also been added, namely:

- attracting and securing qualified people to help meet the steel sector's ambition

Figure 1 depicts the connection between the four pillars and the identified industrial programs with large societal impacts based on a sustainability approach.

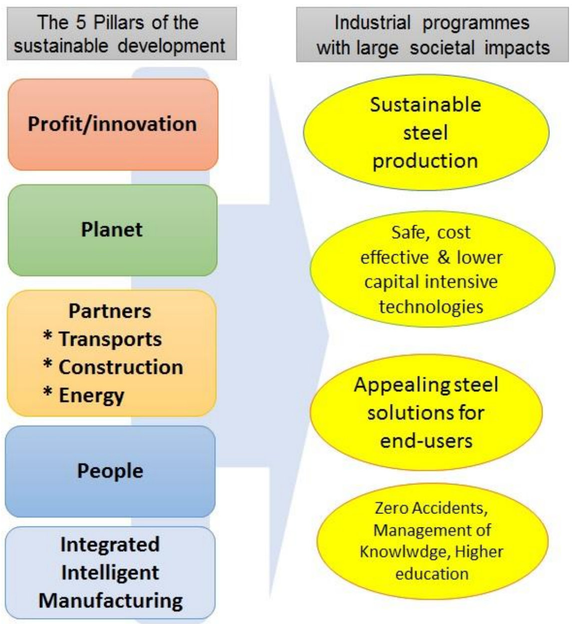

Figure 1. Connection between the 4P's and the 3 industrial programmes

3. Sustainable Steel Production

Meeting environmental regulation is part of the daily business of the European steel industry and any remaining challenge in this area lies in making steel production processes change incrementally in ways that ensure that they meet both economic and environmental targets in a synergic way. This task involves incremental process modifications that are

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mostly handled by incremental research, thus it falls within the duties of one ESTEP Working Group which is devoted to process **innovation**.

On the other hand, the European steel industry Index of energy consumption and specific CO2 emissions compared to 1960 (=100) [will take the sector further in the direction of sustainable production than ever before. Therefore another ESTEP Working Group named "Planet" tackles more holistic and prospective issues which are not only incremental but also extend into the medium-long term. Such issues can be summarized as follows:

- Resource issues due to energy and raw materials supply
- Moving smoothly into a closed-loop economy
- Synergies with neighboring communities
- Synergies with nature
- Life Cycle Assessment (LCA) and Life Cycle Thinking (LCT)
- Steel and new energy frontiers
- C-lean steelmaking
- Global threats and future environmental demands

Of the above-listed topics, the first three ones can be directly connected in a straightforward way to resource efficiency and such a connection will be depicted in the next three sections. LCA and its evolution represents a basic tool to implement resource efficiency globally (not just for specific industries) as discussed in [7] and so Sec. VII will overview also this topic.

4. Resource issues due to energy and raw materials supply

4.1. Energy

Energy Intensive Industries (EII), a concept used by various governments and regional organizations such as the European Union, the US and Japan. The iron and steel sector plays a key role in Europe's energy consumption ranking second, with 18%, belongs to the EII family, such as highlighted in [8]

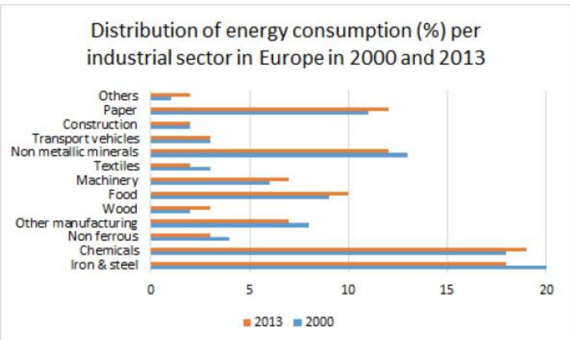

Figure 2. Change in the energy consumption by industrial branch (source [8])

The high requirement of energy in the steel sector has an economic consequence both on production cost (the energy amounts to 20-25% of operating costs) than on the environment (GHG emissions). This is the reason why the continuous search for process optimization to conjugate the low OPEX with the reduction of environmental impact. Such powerful drivers, has made possible to cut consumption of the steel sector by large amounts at the end of the 20th century, such as illustrated by EUROFER in its recent study [9] and depicted in Figure 3.

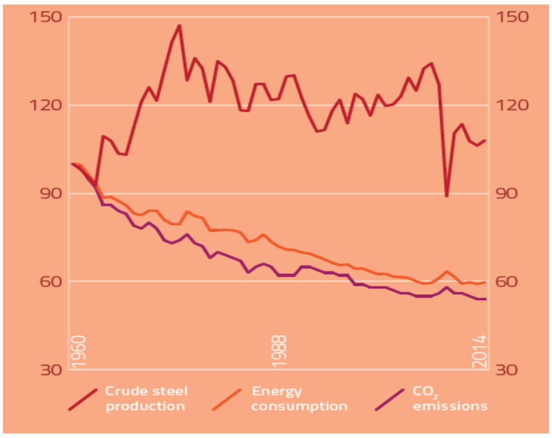

Figure 3. Index of energy consumption and specific CO_2 emissions compared to 1960 (=100) [9]

The steel sector continues to be virtuous, also with respect to other sectors in the new century in spite of recession and the fact that factories do not operate at full capacity and are thus less efficient.

Information regarding energy intensity of steel mills is collected by surveys conducted regularly by international organizations, steel associations or inside large companies. Some of the best publicly available documents in this class have been produced by Worldsteel association [10] and by Eurofer and ESTEP [11].

The ESTEP considers for each step of production the direct energy (the process energy for the step of production) and the total energy (cumulated energy, including the upstream part).

Reference values for total energy, based on the first quartile data of the European plants, are 20 GJ/t of hot rolled product for the integrated steel mills and 9.5 GJ/t for the EAF/scrap based mini-mills, limited to the "hot mill"-, in coherence with previous and parallel efforts.

The ESTEP-Eurofer study [11] announces "a potential of improvement in energy efficiency of 8%. The level of accessible improvement was defined as the gap between the collected values and the benchmark. It was further "estimated that this figure might raise to 10-12%": the mills used in the study have been selected on the best-in-class side and

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Western Europe that is probably doing better than the world in terms of energy efficiency.

From an overall standpoint, this kind of analysis show a relatively high spread of data collected by operating plant, that indicate that working on align everyone with best practices is one of the most powerful levers short term action to reduce the sector's energy footprint. In the future new technology will become one of the few remaining levers of improvement. The ESTEP study, therefore, provides a list of technologies that can help to improve efficiency: existing technologies, which could be used more widely, new concepts, either already mature (for instance at demonstrator scale, Technology Readiness Level (TRL) 7 or more, or simply at a conceptual level (TRL ~ 4).

Related to the energy efficiency improvement, also the amounts of CO_2 generated by the production from steel have been reduced (see Figure 3). While, there are alternatives to fossil fuels for producing electricity (nuclear power and renewables), there is no alternative to coal and coke in the blast furnace. By-product gases from the coke oven, blast furnace and basic oxygen furnace are already fully reused, saving additional fossil fuel resources. They typically contribute 60% to total energy and are used either as a direct fuel substitute or for the internal generation of electricity. Alternatively, gases can also be sold for power generation.

In the early 2000s, the steel sector explored different options for cutting emissions of 50%. The largest program was entitled “Ultra Low CO2 Steelmaking” (ULCOS), and has been supported by the EU between 2004 and 2012 through FP7 and RFCS projects.

Low-carbon steelmaking is achieved, either by replacing carbon by other reducing agents, like hydrogen, directly or through methane reforming, or electrons, through electrolysis of iron anions, or by capturing and storing CO_2 through technologies for CO_2 Capture and Storage (CCS). Room was provided for biomass-sourced carbon, if it is properly generated and thus in effect ensures carbon neutrality. The role of scrap and its substitute in the EAF route was also analyzed and discussed.

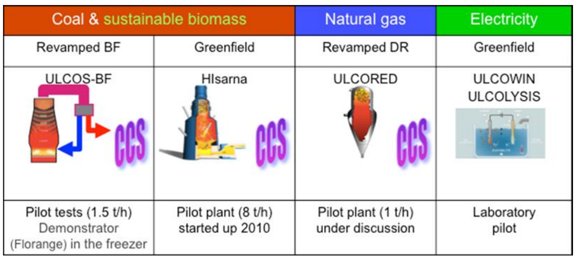

Figure 4. The 4 solutios developed within ULCOS [12]

The outcome of this extensive work [12], which started from the analysis of 80 process routes, which became 53 at a later stage, was the selection of 4 ULCOS solutions which are summarized in Figure 4.

The sector, however, is not only using energy: energy system needs steel, from coal mines, oil and gas fields, power generation, renewable energy to power transmission and distribution. The present energy system is built around steel. This has been true in the last century, it is true today and it will remain true in the future. The energy generation technologies based on renewables, due to the smaller scale with respect to traditional power plants, are several times more material intensive, including the steel among the required materials.

4.2. Raw Materials

Indeed Europe is not the richest mining region in the world, as it imports most of the primary raw materials which are needed for its industrial production. This fact is very relevant to the European steel industry, as most of its virgin material comes from outside Europe. For this reason the Steel model has been one of globalization since the 1980s, with very large capsize vessels and sourcing from Brazil and Australia of very high grade iron ore and coals.

On the other hand, the lack of primary raw materials in Europe, together with the consideration that also at the global levels these kind of resources are finite and not renewable (and both fossil resources and renewable ones are also bound by the competition for land), raises many issues related to access to resources, security of supply, scarcity, criticality, sustainability of material-based activities and simple economic and logistical issues. The European Commission is well aware of the underlying threats and launched a large initiative, framed as a European Innovation Partnership (EIP), the EIP on Raw Materials [13].

The approach focuses on the finiteness of the ecosphere and on the need to preserve its resources for future generations. But this does not apply only to those resources which are intrinsically scarce. Although many resources will remain abundant in the long period, the growth of demand related to population growth and urbanization may have a faster kinetics with respect to the supply capability provided by the economy. This could create tension and volatility on prices and an unbalanced situation of the market which could also affect the competitiveness of the European steel industry.

Therefore the need arises to develop a leaner economy, based on higher energy and raw materials efficiencies, as this represents an acceleration of the pace at which the economy will be relying on close-loop operation. The Circular Economy is a contemporary and popular concept that describes how materials and resources should be handled in the future: the European Commission has recently published a communication setting the relevant

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policy trends [14]. The major enabler, which the Commission proposes in order to enforce these principles, is the encouragement and further development of a circular economy, based on reduction, reuse, recycling, and recovery of waste.

A recent paper from J.P. Birat discusses some of these issues, proposing an analysis of what the concept means from the standpoint of materials stakeholders [15] while a EUROFER publish the point of view of steel industry on The Parliament Magazine [16].

In order to improve resource efficiency within its production cycle and in the whole society, the European steel industry is already applying Process integration (PI) [17] for integrating technologies which enhance the use as resources of by-products, discharged water and off-gases at overall plant level. For instance in [18] a PI solution has been explored to improve the exploitation of process off-gases while reducing the CO_2 emissions, in [19] PI-based solutions for recovery of steel scrap through environmental-friendly technologies are investigates. In [20] PI is applied to optimal design of industrial waters management, while in [21] PI-based solutions are analyzed aimed at the recovery and reuse of low temperature heat.

However there is indeed an increasing demand for industrial ecology solution and synergies between industries, cities and communities, as well as for a reinforcement of reuse and recycling. Industrial ecology is a multidisciplinary research field which investigates the material and energy flows within industrial systems often to the aim of analyzing (and possibly reducing) the impacts that industrial activities have on the environment, due to the exploitation of natural resources and the generation and disposal of wastes. According to [22] the term “industrial ecology” derives from and analogy with natural systems that should be used to help to understand how to design sustainable industrial systems. Industrial ecology thus can represent a further step toward a true cross-sectoral and global approach to the problem.

The idea of resource preservation by increasing energy and material efficiency includes the recycling of steel in particular and recycling of the all the large volume of by-products generated by the steel sector both inside and outside the steel production cycle. Steel has been recycled at a high level estimated around 85%. Steel mills are moving towards "zero residues" (zero waste) in a credible way: their energy use is one of the most efficient among Energy Intensive Industries (EII). The steel sector is committed to progress further and to imagine solutions for turning into an even leaner sector. Furthermore, transversal, through-process issues are essential to acknowledge in a holistic approach, as well as the quick integration of new technologies developed outside of the sector and cooperation with other economic players.

However, such as pointed out in [15], large amounts of research were conducted to develop concept into viable industrial solutions, but the death rate was enormous due to low return on investment and/or high operating costs. Thus a system of subsidies would have had to be implemented, like it is done for renewable energy and many other examples. There are many examples of processes in the metal sector, where industrial ecology principles have been applied, sometimes before that discipline was invented, such as, for instance, the use of Blast furnace slag for cement making as a clinker substitute, or of slag for road construction, or of EAF dust as a feedstock for the zinc industry mainly through the Waelz process. How large this part of residue handling actually is in a sector like steel is demonstrated by the material efficiency indicator of the WorldSteel Association which is at the level of 98% [23].

5. Moving smoothly into a closed loop economy

Steel is correctly stated to be the most recycled material in the world and this is often interpreted to mean that steel is part of a closed-loop economy. This is a subtle and complex concept, as an economy can be close-looped for some material and not for others and it can be partially or totally closed (namely the term “closed” can be interpreted in a weak and strong meaning). Steel today is indeed part of a partial closed-loop economy related to the generation and reuse of scrap but also to the reuse of steel without re-melting it, as is commonly practiced for rails or pile sheets.

This practice will be as essential in the future, as it was essential in the past. The steel sector is organized with specialized steelworks, where the production cycle is based on the Electric Arc Furnace (EAF), where the steel scrap is melted to produce new steel products. Moreover, the collection of scrap and its treatment to turn it into a true secondary raw material is mostly a profitable, value-creating business: this is actually why steel is recycled to such a high level. In the future, the fraction of scrap vs iron ore is expected to increase, as the steel produced in the past and especially since the explosion of production, which has taken place since 2000, will be coming back in the economy as scrap. This will raise delicate issues of adjusting the balance between integrated and scrap process routes, for instance in China, which has invested heavily in integrated mills.

This fact will also generate the need for new technologies to sort scrap more effectively and to purify it after sorting, as well as for taking care of the environmental aspects related to recovery and pre-

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treatment of scrap [19]. In fact, although the EAF-based steel production route shows important environmental advantages, being less energy intensive (and less CO_2 insensitive), the limited availability of scrap means that not all steel demand can be met by recycling. This means that it is not interchangeable but complimentary to the production cycle that produces steel by melting virgin materials (mainly iron ore and carbon) in the Blast Furnace (BF), i.e. the so-called "BF route". The major limitation in steel recycling is represented by tramp elements which can concentrate in the iron and decrease its properties; therefore there are some steel qualities and products that currently can only be produced through the BF route and secondary resources containing high amounts of impurity elements can only be used for lower qualities of steel. Different types of scrap or scrap and virgin ore can be mixed in order to achieve the required specifications making possible to obtain a virtually closed cycle without a drop of quality. However, it has to be pointed out that all tramp elements are irreversibly fed to the iron cycle. As global recycling rates will further increase (up to 80%) the issue of tramp elements will become more important in the future and need to be addressed by the research in the steel field in order promote resource efficiency at global level, which also encompass an efficient exploitation of available secondary raw material.

Finally it must be underlined that the technologies fostering the reuse of the by-products generated by the steel production cycle in other industrial sectors or activities are also an integral part of this effort toward a closed-loop economy. Some examples are still available (see for instance [25]) but the application of Industrial ecology solutions, such as already mentioned in the Sec. 4 needs to be further investigated.

6. Synergies with neighboring communities

The Steel sector is immersed in the economy and society, in various ways: the value chain and the life-cycle dimensions have already been stressed, but various other synergies are at play and operate in a cross-sectorial manner. A steel mill is at the center of a huge logistical hub, where more than 10 tons of matter and scores of energy are handled, transformed, exchanged and sometimes dissipated or landfilled per ton of steel. This puts large demands on logistics, which ought to be considered as a resource akin to raw materials, except that it is a more abstract one, based on seaways, harbors, rail tracks, roads and bridges on the one hand and on ships, cranes, trains and trucks on the other hand.

The steelworks are also connected with other economic sectors and with local communities in a horizontal manner, i.e. not through the logics of the value chain but with that of industrial ecology. Indeed, waste heat and residues can be used elsewhere and the steelworks itself can, in principle, use those of neighboring industrial sites. This is usually a mesoscale effect, as opposed to the macro-scale of international trade. This field is not virgin, as supplying heat to city districts has been practiced for decades (some interesting examples are depicted in [25-26]). Similarly, much of blast furnace slag is used as raw material for the cement industry, the rest being turned into roadbed material. The expectation today is that more can be done in the future to save energy and raw materials globally, across value chains, thus increasing energy and material savings.

The cooperation with other industrial sectors, such as illustrated in Figure 5, has a large potential to promote the reuse of by-products (slag, dust and sludge) as secondary raw materials. It can also recover valuable metals (e.g. zinc, tin, major alloying elements present in steels and iron from non-ferrous metallurgy residues).

Figure 5. Cross-sectorial approach to foster by-products reuse.

These are beneficial for reducing the environmental footprint of steel production and improving competitiveness. Process Integration is an important means to implement industrial symbiosis by promoting resource efficiency: The European steel industry through the Research Fund for Coal and Steel (RFCS) is promoting pilot projects exploring this direction, such as the following projects

- "Development of tools for reduction of energy demand and CO_2-emissions within the iron and steel industry based on energy register, CO_2-monitoringand waste heat power generation" (ENCOP) [18];
- "Processes and technologies for environmentally friendly recovery and treatment of scrap" PROTECT [19];
- "Efficient use of resources in steel plants through process integration" REFFIPLANT [20, 27-28];

Such a cross-sectoral approach can be extended to improve efficient management and reuse of secondary but fundamental resources, such as water and off-gas.

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The European Steel sector has been a founding stakeholder of the European Public Private Partnership (PPP) named SPIRE (Sustainable Process Industry through Resource and Energy efficiency). The SPIRE association developed its own roadmap [29], which includes also concepts and principles that were already present in the ESTEP roadmap.

7. Overcoming current Life Cycle Assessment

LCA is nowadays a consolidated and widely exploited technique to assess environmental impacts associated with all the stages of the life of a product from cradle to grave [30].

The present most common kind of LCA is named *attributional LCA*. A different method, describing more closely how the real world operates, is the so-called *consequential LCA*, but it is still rarely used. More forward looking methodologies are being developed, such as *foresight LCA*, *dynamic LCA*, *social LCA*, *Life Cycle Costing (LCC)*, introduction of end-of-life and recycling into LCA [5].

Nonetheless there are important areas where LCA is not yet properly used or not adopted at all: This is, for instance, the case of EU rules and regulations for cars, which favor a concept called "recycled content" rather than a recycling ratio. Another example is provided by the use of tail pipe emissions to rank the performance of commercial vehicles, without considering the life cycle emissions instead. As a consequence, the importance of light weighting is overestimated, which is not always a worthy objective when pursuing low Green House Gases emissions. Moreover, this fact gives a predominant importance to climate change without considering other issues and may thus be creating difficulties elsewhere.

Life Cycle Thinking (LCT), the approach behind LCA, is worldwide recognized as beneficial to society and the European steel industry wishes to promote it. However the present methodology is still not perfect and other methodologies are needed to complement it.

To move away from the micro-economic description of the economy related to choosing the functional unit as the central concept of LCA, one should open the scope to macro-economic thinking with Material Flow Analysis (MFA) [30] or Energy Flow Analysis, which lie at the core of the analysis of recycling, a major issue for steel and metals in general and many other materials

This might be insufficient to deal with the main open issues and challenges: thus, more ambitious methodologies, going beyond LCA and MFA have to be developed, or, rather, their development has to be further encouraged. In the steel and structural material sectors, this corresponds to the SOVAMAT initiative [32], which puts forward the concept of "social value", which is close to a more holistic definition of sustainability. The LCA Community is exploring the idea of functionality, beyond that of functional unit, etc. The steel sector needs to be at the forefront of methodological innovation in this area, in order to create a dynamics that would open up to interdisciplinary cooperation, from sociology, socio-economics to scientific ecology by encompassing the various communities of LCA, MFA, economic global modelers, etc.

In order to overcome the current limitations of LCA in the context of process industry, the European Research Framework Program Horizon 2020 (H2020) is currently supporting the following three international research projects running under the umbrella of SPIRE:

1. *STYLE - Sustainability Toolkit for Easy Life Cycle Evaluation* aims at developing a practical toolkit to be used by EU projects and industry in order to assess the value of new technologies and process modifications focused on improving resource and energy efficiency.
2. *MEASURE - Harmonised cross-sectorial sustainability assessment in the European process industries*, aims at developing a roadmap providing recommendations for standards and best-practice methods and tools for life cycle-based evaluation approaches in process industries and sustainable process design.
3. *SAMT - Sustainability assessment methods and tools to support decision-making in the process industries* aims at reviewing and making recommendations on the most suitable methods to evaluate sustainability in the process industry, focusing especially on energy and resource efficiency.

The three projects are linked with each other and several steel industries are partners of the first two above-listed project, by thus accomplishing part of the actions planned in the ESTEP's SRA.

8. Future research directions

The ESTEP is committed to stimulate the research in the steel field in order to provide the European steel industry with all the suitable means to face the future challenges at technological, economical and societal levels. This will lead also to gradually broadening the dimension and scope of the investigations and to enlarge the number of potential partners in the research activities. While in the past (roughly until the end of the nineties) the research was focused mostly on mitigation of the environmental risk at the specific site level, current short term research activities are addressed toward the reduction of the environmental impact of the

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production cycle in both the surrounding areas and in general at a wider level. Resource efficiency lies in this dimension but it is also a far more global topic. In fact, as depicted in the previous section, the global perspective for an effective resource efficiency strategy must be related to the profitable steel production, competitiveness of European steel industry and creation of new jobs opportunities. The real target for medium-long term research activities and initiatives is aimed at decreasing the "social footprint" of the steel industry targeting at high level technical challengers:

- maintaining continuous improvement in product performance: e.g. high strength - development of both new products and the capability to make them
- Extend service life – through new product development and use of more efficient coatings, the recycling of coatings, closing the loop within manufacturing
- Education and communication – influencing public perceptions of steel in general, also for customers and markets
- Product data tracking, maintaining steel identity (source/batch/history information) through manufacture, supply chain, use and EOL
- Increase re-use – demonstrate the benefits with new business models (technology)
- Improving carbon and energy efficiency of steel plant operation
- Improving process yield and through supply chain yield – new process routes such as additive manufacturing, or optimize products to meet supply chain
- Best use of information technology to balance supply and demand – operational plant IT systems, stock control, flexible manufacturing, response and delivery times
- Using LCA/SATs to demonstrate value of steel in circular economy against alternative materials – social aspects such as flood defense, affordable housing, and agriculture and food production

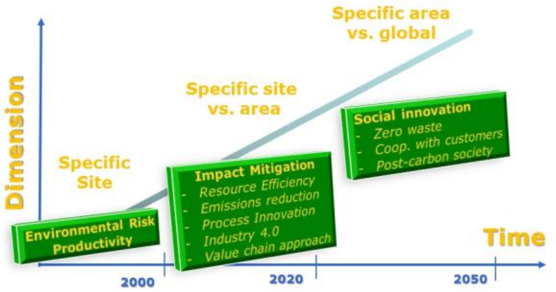

Figure 6. Foreseen dimension and time evolution of the R&D activities

In this frame the cross-sectorial approach and the cooperation with society and stakeholders is also essential. The above-depicted foreseen evolution is summarized in Figure 6.

9. Conclusions

The paper presented an analysis of the ESTEP's SRA concerning the topics which are directly related to resource efficiency. The SRA vision is one of smooth cooperation between the anthroposphere and the bio/ecosphere and to enforce a balanced respect for both. This raises challenges that the sector faces in terms of R&I in relation to sustainable steel production. The focus is on reducing the environmental footprint of steel production and steel solutions by reducing resource consumption, fostering the use of secondary raw materials and thus accelerating the move towards a more closed-loop economy, as well as by implementing energy efficiency, saving exergy, implementing process integration and eco-design approaches.

Environmental topics, constraints and commitments that have long been considered as external to the economy, business and metallurgy, are no more simple boundary conditions expressed by bother-some regulations, but an integral part of an holistic system, where nature and society, geo-, bio and anthropospheres interact at a complex level.

Holistic, transverse, cross-cultural and cross-sector approaches are the standard ways to move forward. Steel is not starting from a clean slate, as these issues have been embedded in its practice and culture for a long time (recycling, energy efficiency, zero waste, carbon-lean steel production processes, steel as an enabler of a leaner economy, etc.), but the pace of change should not slacken and it might even have to accelerate, as the world is becoming ever more populated, more compact and more demanding.

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