SOLUTIONS FOR SUSTAINABLE DEVELOPMENT

Edited by
Klára Szita Tóthné, Károly Jármai and Katalin Voith

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Solutions for Sustainable Development

Editors

Klára Szita Tóthné, Károly Jármai & Katalin Voith

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Possibilities for adopting the circular economy principles in the EU steel industry

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ABSTRACT: The global economy has to face several challenges due to the scarce resources and environmental impact of economic activities. The introduction of circular economy as a business model can reduce environmental damage. In our study, we introduce the potentials the steel economy has in the transition to circular economy. Steel is the most commonly used raw material, it is essential in all fields of life. Based on the strategic documents, workpapers and reports of relevant organizations of the sector we introduce in our model the advantages and possibilities the steel industry has to engage to the circular approach. We found that the sector can be one of the drivers in transition. The raw material and energy consumption can be reduced, besides the GHG emissions, while cost efficiency and competitiveness increases. The developments have spillover effects in other sectors using steel of higher quality or through the by-product reuse and have an impact on social well-being as well.

1 INTRODUCTION

Despite of the rapid economic development, the past and present trends of using our material resources lead to the scarcity of environmental resources, volatile prices, high level of pollution and acceleration of climate change. The well-known definition of the Brundtland Report says that the sustainable development is a "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, p.41), but today's patterns of production and consumption risk the fair access to scarce resources. According to Li et al. (2011), a 1% increase in real GDP per capita results in a 0.48-0.50% increase in energy consumption and therefore increases carbon dioxide emissions by about 0.41-0.43% (Li et al. 2011). Circular economy as a strategy of sustainable development receives increasing attention both in political, strategic and scientific platforms as it involves the efficient use of resources and minimization of waste. It contributes to a sustainable, low carbon and more competitive economy, while increases the level of employment by creating local jobs at all skills levels. Due to the transition to circular economy in Europe resource productivity could grow by 3%, resulting in a primary resource benefit of 600 million EUR per year by 2030 and could generate 1200 million EUR non-resource and externality benefits. The GDP increase could reach about 7 percentage points relative to the current development scenario. (Ellen MacArthur Foundation 2015).

Concerning the European Union, it can be connected to the main strategic and operational EU policy aims and priorities like jobs and growth, investments, climate and energy, innovation and sustainable development. The Action Plan "Closing the Loop" focuses on the use of finite, abiotic resources, through five priority areas, such as plastics, food waste, critical raw materials, construction and demolition waste and biomass and bio-based products. Also contains recommendations on innovation and investment, and on monitoring the process. (European Commission 2015) The European Union provides the economic actors with a wide range of financial support to accelerate the transition to the circular economy (e.g. Horizon 2020, Cohesion Policy, LIFE Program), the total sum exceeds 10 billion Euros over the 2016–2020 period. (European Commission 2019) Although the circular economy concept gains growing attention today, implementation is limited, our world is only 9% circular, meaning 9% of minerals, fossil fuels, metals and biomass that enter the economy are re-used. (PACE 2019).

The first aim of this study is to give a brief summary on what circular economy means. Afterwards, we introduce what possibilities an energy-intensive industry, the steel industry, has in transition to circular economy.

2 THE CIRCULAR ECONOMY

2.1 *The concept*

It is often emphasized that in a circular economy, there is no waste, as products of today can serve as resources for the future. However it is more than just recycling, it is rather a new model of production and consumption overarching the supply chain and sectors, being able to increase the efficiency of resource use and competitiveness, to decrease costs, to drive innovation and to contribute to sustainable development.

The concept itself is not a new one. According to the latest studies (Murray et al. 2017, Kirchherr et al. 2018) basic idea of circular economy was first mentioned in 1848, in 1966 by Boulding and was further discussed in the last 40 years by e.g. Stahel and Ready-Mulvey, Pearce and Turner. Currently, more than 100 definitions are identified with a wide range of meanings. (Kirchherr et al. 2017) As the circular economy gained importance in Europe since in 2015 the European Commission announced its package to support the EU's transition to a circular economy, we accept the definition of the European Parliament and the European Commission. Circular economy is "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible" (European Parliament) "and the generation of waste minimized" (European Commission 2015).

2.2 *Benefits and enabling factors*

The circular economy compared to the linear uses less input and natural resources, while the share of renewable and recyclable resources increases. The value of products, components and materials are kept as long in the economy as possible, resulting in reduced emissions and fewer material losses. (EEA 2016) Benefits are connected to the following four areas, including the 3 pillars of sustainable development:

- Resource benefits: demand for primary raw materials decreases, so does the dependency on imports
- Environmental benefits: environmental impact of economic activities decreases due to the higher resource-efficiency, thus externality costs decrease.
- Economic benefits: it fosters innovation and economic growth.
- Social benefits: creates jobs and through a more sustainable consumer behavior it can contribute to human health and safety. (EEA 2016)

Circular economy is a systemic shift that requires changes in current production and consumption patterns. Firstly new, innovative technologies must be developed and introduced (eco-innovation and eco-design). Besides the technological innovation, social and organizational innovation is inevitable. Secondly, the actors must change their interplay by giving repair, refurbishment, remanufacture and recycling higher importance. All these changes cannot be done if not supported by regulation (such as rethinking incentives, providing a suitable set of international environmental rules) and cultural shift in changing the manner of both consumers and producers. (Kirchherr et al. 2018, EEA 2016) Among the enabling factors, we would like to highlight the industrial symbiosis as a new business model, a local or global partnership where companies of different sectors collaborate to make one's waste or by-product a resource for another. By providing, sharing and reusing resources industrial symbiosis can create loops of technical or biological materials and minimize waste. (PwC 2018, EEA 2016).

In the next part of the study, we examine what potential the steel industry has in the transition to circular economy. As an explanation of our choice we cite the Director General of the World Steel Association Dr Edwin Basson:

"As steel is everywhere in our lives and is at the heart of our sustainable future, our industry is an integral part of the global circular economy." (World Steel Association 2015, 3.).

3 THE STEEL INDUSTRY IN THE CIRCULAR ECONOMY

3.1 *The status of the European steel industry concerning the EU climate policy*

3.1.1 *Steel industry of the European Union – overview of the current situation*

Steel is the second most commonly used raw material, its significance is unquestionable in our daily lives. The global steel consumption excluding net indirect exports in 2016 was 1,425,732 thousand tonnes in finished steel equivalent and has increased steadily in recent years. China ranks first in the world in terms of true steel use with 43 percent of total. It is followed by the EU with about 10.5 percent, and by the US with about 8 percent. (World Steel Association 2018a, 115–116.).

Steel production is a material- and energy-intensive process with high level of CO2 emissions. Thus, the sector is very sensitive to the changes in the commodity market and in the energy sector (like primarily access to resources or price volatility) as well as to the stringer environmental regulations.

In addition, the EU steel industry had to face further challenges over the past decades. The majority of the steel industry's products are investment goods which results in high level of cyclical sensitivity. (Barta and Poszmik 1997) After a significant (42 percent) fall in demand in 2008 as a result of the global economic crisis, steel use in the EU increased to three quarters of the pre-crisis level by 2017. (World Steel Association 2018a, 115–116.) Crude steel production followed this trend too when from 2008 to 2009 fell by 30 percent. By 2017, crude steel production increased by about 21 percent compared to the year 2009, but the pre-crisis level was far not achieved. The global crude steel production was 1,690,479 thousand tonnes in 2017 of which China accounts for 49 percent, the EU ranked second with a share of about 10 percent (168,305 thousand tonnes), followed by Japan, India and CIS with a share of around 6 percent. The share of the US share in global production is about 4.8 percent. (World Steel Association 2018a, 1–2.).

The EU steel industry is facing difficulties in maintaining its position in the international competition dominated by the growing production of emerging countries, mainly China, India, CIS and Brazil. While in 2008, the EU ruled 14.8 percent of global production, its share fell below 10 percent by 2017. (World Steel Association 2018a, 1–2.) The situation is further worsened by the overcapacity of the worldwide steelmakers. This encourages the export of steel products, increasing competition for EU steel companies and thus the likelihood of market loss within the EU. The commercial policy measures applied by the competitors (such as the introduction of subsidies for their steel sector or import duties) also have a negative impact on the competitiveness of the European steel industry.

Continuous innovation can be an effective solution to these challenges. The introduction of low-carbon, less energy-intensive technologies, the development of high-quality, tailor-made products and the exploitation of the potentials of industrial symbiosis are key to the competitiveness of the EU steel industry. In this regard, the circular economy concept can provide an effective solution for the industry.

3.1.2 *Characteristics of the steel production*

When presenting the characteristics of the steel production, we place the emphasis on the technological solutions of steel production, raw materials used in production, energy use, and CO2 emissions, as well as the effects of related environmental regulations. Although we acknowledge the importance of those factors, we do not cover the analysis of labor intensity and employment of the sector.

Two main technologies exist in steel production. In the basic oxygen furnace (BOF) within an integrated steel mill, molten iron from the blast furnace is changed into liquid steel. (Ecorys 2008) This is also known as oxygen-blown converter (OBC) technology. The main raw materials in this case are iron ore, coke, limestone and little amount of steel scrap. As energy resource predominantly coal is used. Annual capacity of over 2 million tonnes can make production viable. Introduction of the so called EAF route is a technological improvement. An electric arc furnace (EAF) is a furnace that heats charged material by means of an electric arc. (Ecorys 2008) In this technology, the raw material is primarily steel scrap, while it mainly uses electricity as energy resource. The technology applied highly depends on the type of the product and on the quality requirements. The BOF route compared to the EAF technology is characterized by higher cost of capital, higher fixed costs as well as higher energy cost. Overall, the EAF technology is a more expensive process (Ecorys 2008, 62.) Commonly the most important cost factors are cost of raw materials, energy costs and transport costs. Connected to the development of technology, the introduction of continuous casting should be mentioned as revolutionary. Improving productivity and cost-efficiency, nowadays it is predominant, 96.3% of global production applies continuous casting. (World Steel Association 2018a, 5-6.) The implementation of DRI and HBI as scrap substitutes also was of high importance. Due to the continuous technological innovation, the sector achieved lower cost of capital, economic viability at small scale, lower operational costs, higher flexibility in raw material and significant environmental benefits. (Ecorys 2008)

Access to raw materials and long-term insurance of that must receive strategic attention from the EU. Although there is no shortage of raw materials in the long run, rising demand from emerging countries puts pressure on the supply of raw materials. Thus raw material prices are rising while import dependency of the EU is high and growing steadily.

The steel industry is one of the energy-intensive sectors, its emission is constantly in the center of attention. Energy consumption of the EU steel industry in 2016 was 49 Mtoe. It is important to emphasize that this represents a 40.7 percent reduction compared to 1990 energy consumption. According to 2016 data, 47.2 percent of energy was from coal, 30.2 percent from natural gas, and 20.2 percent from electricity. The rest is made up of other energy resources. The share of electricity in the 1990s shows an increase of about 7.5 percentage points due to the spread of EAF technology. Energy consumption per tonnes of crude steel in 2016 was 0.3021 toe/t. Compared to 1990, this represents a decrease of 27.2 percent. Energy intensity of primary metals, at purchasing power parities calculated as Final consumption/Value added) at 0.7353 koe/€in2010. The value of the indicator also showed a significant decrease of about 42 percent compared to the 1995 value. (1.27675). (Enerdata-Odyssee database)

The sector is very sensitive to changes in energy prices due to its energy demand. Energy prices today increases constantly and dramatically concerning electricity, natural gas, coal and oil. Significant territorial differences exist in the development of prices, which means prices show a significant variation within the EU and the situation is even more unfavorable compared to non-EU states. For example, the advantage of the US concerning energy prices has been significant in recent years. One of the reasons for the large differences in the price was the shale gas revolution in the US, but the effects caused by the diversity of taxation of energy products are significant as well. The EU is applying stricter environmental rules, such as higher tax burdens, resulting in higher energy prices. This is certainly disadvantageous for energy-intensive industries.

In 2015, CO2 emissions from the iron and steel industry were 102.2 Mt in the EU. This represents a 41.5 percent decrease compared to 1990 levels. CO2 emission per tonne of crude steel in 2015 was 0.6172 tCO2/t, representing a 30.3 percent reduction compared to 1990 levels. (Enerdata-Odyssee database). EU environmental legislation put a significant burden on steel industry. The EU has introduced much stricter rules (e.g. EU ETS, IPPC standards) than most non-EU countries. This is a major competitive disadvantage for EU steel companies. In the period up to 2030, the rules for producers were further tightened. A 40 percent reduction in CO2 emissions and a further 27 percent improvement in energy efficiency must be reached. High expectations will enhance carbon trading, resulting in higher carbon credit prices. In 2018, the price of carbon credit increased by 4-5 times, which contributed significantly to the rise in electricity prices. According to Róbert Móger, Director of the Hungarian Iron and Steel Association, "the expectations set by the EU are not realistic, because there is currently no technology that can be operated economically on an industrial scale to ensure the achievement of these goals." (Viland 2018, 2.).

3.2 *Steel industry as an engine of circular economy*

Steel production plays a major role in the global concept of the circular economy. All the elements of the 4R framework (Reduce, Reuse, Remanufacture, Recycle) of the circular economy model can be identified. Life cycle thinking is essential to the successful transition to the circular economy. The raw material and energy consumption, emissions and waste generated must be taken into consideration at all stages of the product's life cycle from design, production of raw materials, production and use to reuse or disposal. The total impact of a product on the environment can be determined only if a full life cycle approach is applied. (World Steel Association 2015).

The extremely favorable properties of steel can make it one of the drivers of the circular economy and gives several advantages over other materials (e.g. aluminum, magnesium, plastic). Steel can be recycled 100% and many times while maintaining its original properties. Through recycling, a wide range of new steels can be produced from any type of steel waste. For example, a lower value steel scrap can be used to produce higher value steel using appropriate technology. Due to its magnetic properties, steel products can be recovered from waste streams. The high value of steel scrap makes the recycling economically viable. On one hand the excellent durability of steel results in less steel is needed to maintain everyday life, while on the other hand it means that steel scrap is available in limited amount.

Material efficiency index of the steel industry (meaning percent of materials converted to products and by-products) is around 97 percent (World Steel Association 2018b), which is quite high compared to other sectors. It means 66 percent of the raw materials and steel scrap used in production becomes new steel, 31percent is by-products and only 3 percent waste is produced. Thus, it can be said that steel production is an almost closed-loop system, the future goal is to reach 100 percent. (Eurofer 2015).

The integration of the steel industry into the global circular economy is illustrated by our model.

As Figure 1 shows involvement in the circular economy can be realized through potentials within the steel industry and by exploiting the potential of industrial symbiosis. As a result, they can reduce raw material and energy consumption, reduce CO2 emissions, increase cost

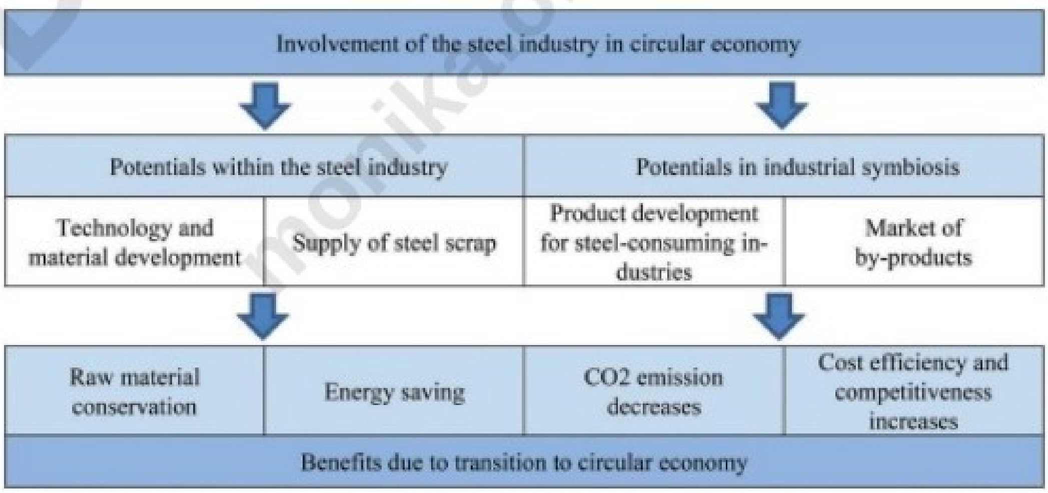

Figure 1. Model of the involvement of steel industry into the circular economy.
Source: own elaboration.

efficiency, and thus competitiveness. And most importantly, these positive effects do not only occur in the steel industry, but also in sectors that use steel or its by-products, and ultimately at social level.

3.2.1 *Potentials within the steel industry*

3.2.1.1 TECHNOLOGY AND MATERIAL DEVELOPMENT

In the previous chapter, we introduced the main features of the 2 main steel production routes. According to data from 2017, the BOF accounts for 71.6 percent of the global crude steel production, while 28 percent is produced by EAF. (The remaining 0.4 percent means other technological solutions, such as the open-hearth furnace technology.) However, the share of technologies of steel production varies significantly across regions. In the EU, the share of the BOF route is only 59.7 percent, while the more advanced EAF technology has a 40.3 percent share. In the US, the focus was even more shifted to the EAF technology (68.4%), while in China, BOF technology accounts for 90.7 percent of total production. (World Steel Association 2018a, 17-18.) The growth of electro-steel production is projected in the medium term, e.g. China has already begun to transform several oxygen-blown steel plant to change to the electro steel production process. (Krause 2019) Besides the technological milestones described, currently, carbon capture and storage technologies are also developed. In addition to reducing CO2 emissions, the reduction of other greenhouse gases and harmful substances (NO_x, SO_x, dust) is among the objectives.

3.2.1.2 SUPPLY OF STEEL SCRAP

There are 3 main sources of steel scraps. The internal by-products from the steel mills that are the industry's own circular scrap from steelworks and foundaries. Due to the constant improvements of technology, this type of scraps shows a downward trend. The second source is the new scrap from steel-processing industries that is together with the previous type is also referred to as pre-consumer steel scrap. It is 100 percent collected and recycled in steel production. The third source is the so-called post-consumer steel scrap, like used cars and other end products. The latter is the most common type of waste. (Ecorys 2008) While in BOF technology steel scrap is used up to 35 percent, in the case of the EAF this rate can be 100 percent. The supply of steel scrap is limited by the durability of steel. We distinguish products with short (e.g. small boxes), average (e.g. caring machines, cars) and long (e.g. buildings, bridges) service life. The latter serves up to 100 years. (Eurofer 2015) The 75 percent of the steel ever produced is still in use. Therefore, the development of scrap substitutes is also a key issue. Steel is the most frequently recycled material in the world, about 650 million tonnes of steel scrap is recycled annually. The recovery rate is not the same in different sectors, is 98% for industrial and commercial buildings and over 90% for machine manufacturing, while 50% for smaller electronic equipment. About 20 percent of steel scrap of the EU is exported, thus the EU is a net exporter in the international steel scrap market.

3.2.2 *Potentials in the industrial symbiosis*

3.2.2.1 PRODUCT DEVELOPMENT FOR STEEL-CONSUMING INDUSTRIES

Analysis of the share of total finished steel demand in the EU shows that the largest steel-consuming sector is construction (35%), automotive (19%), mechanical engineering (15%), metalware (14%) and tubes (11%) are also significant, while domestic appliances, other transport and the miscellaneous both have a 2% share. (Eurofer 2018) Technological development has also led to improvements in the quality of steel. High quality steel is a prerequisite for manufacturing high value added products. The EU's competitiveness in the production of high-quality, tailor-made steels is the highest.

The sector is characterized by permanent material and product innovation, as it has to meet the constantly changing needs of the main steel-consuming industries. In all sectors, steel meets different basic requirements, e.g. in the automotive industry the development of advanced high-strength steels (AHSS) is needed to be lightweight but also rigid components for the transport sector. It contributes to a decrease in weight of vehicles, while safety and quality increases, fuel consumption and emission decreases. (Ecorys 2008) According to a research cited by the World Steel Association 2015 study, vehicles manufactured using AHSS were slightly worse in the use cycle in emissions reduction than the aluminum, magnesium, plastic and steel based Super Light Cars (SLC). However, applying the lifecycle thinking, including the raw material production and the automotive industry GHG emissions as well, the use of AHSS was less harmful. Stronger and lighter steel is also demanded in the energy sector, e.g. the production of wind turbines from lighter steel significantly reduced CO2 emissions and emissions from its transport and assembly. Using high grade steel in the construction industry, the construction of higher buildings is more efficient, the amount of steel used reduces, so does transportation cost. The construction time of plants has also decreased, and the thinner buildings allow for space utilization. Modular reinforced concrete elements can be reused, that provides with cheaper solutions than producing new items from raw materials. Reducing the thickness of steel used in the packaging industry, such as food and beverage cans, has resulted in positive environmental impacts concerning the whole life cycle. Despite of the increase in energy use of production, the total energy use, GHG emission and transportation cost decreased as less steel is needed.

3.2.2.2 MARKET OF BY-PRODUCTS

In the circular economy framework finding market to the by-products is inevitable. The steel industry is outstanding in it. One of the main by-products of iron and steelmaking is slags. In 2016 in Europe a total of 41 million tonnes slags was used, out of it 46.8 percent in the cement industry. This significantly reduces the environmental impact of cement production. (up to 59 percent CO2 and 42 percent energy savings). The 29.8 percent of the slag was used as aggregates in road construction, metallurgical use was 6.8 percent but it could be used in crop fertilizer production (1.2%) The 5.7 percent of the slag was placed in landfill sites. Another important by-product are the process gases, which are utilized in electricity and heat production. Dust and sludge are reused in alloys, the petrochemicals are input materials for the chemical industry. (World Steel Association 2018c).

4 CONCLUSIONS

The world's environmental resources are scarce, while the amount used in production is increasing. Business models need to find sustainable solutions for preserving raw materials and decreasing the environmental impact of economic activities. The circular economy model is a new approach in practice, where maximum value is created with minimum waste by closing the loops. Transition to the circular economy became a priority in the European Union to gain competitive advantage. It is very important to take steps towards transition to all actors of the economy in all sectors and it is supported financially.

The steel industry has made considerable efforts and shows significant progress over the past decades to reduce raw material and energy consumption and greenhouse gas emission. Technology development is in the center of attention, although the efforts are partly driven by the stricter environmental regulations the steel industry and the steel-consuming sectors have to face.

The steel industry fit into the circular approach taking advantage of potentials within the sector and potentials in the industrial symbiosis. Thanks to the transition to the circular economy steel industry can reduce raw material and energy consumption, reduce GHG emissions, increase cost efficiency, while it becomes more competitive. The positive effects do not only occur in the steel industry, but also in sectors that use steel or its by-products, and at social level as well. While emphasizing the environmental and economic advantages we cannot go along the fact that innovative technologies need skilled and medium skilled workforce. Besides its sectoral advantages, the transition to circular economy can contribute to better well-being of people.

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REFERENCES

Barta, Gy. & Poszmik, E. 1997. A vas- és acélipar versenyképességét befolyásoló tényezők. "Versenyben a világgal" kutatási program, műhelytanulmány - Budapesti Közgazdaságtudományi Egyetem, Budapest Available at: thttp://edok.lib.uni-corvinus.hu/211/1/MT_15_Barta_Poszmik.pdf (Retrieved: 30 May 2019).

Ecorys 2008: Study on the Competitiveness of the European Steel Sector. Within the Framework Contract of Sectoral Competitiveness Studies – ENTR/06/054, Final report, August 2008. ECORYS Nederland BV, Rotterdam Available at: https://ec.europa.eu/growth/content/study-competitiveness-european-steel-sector-0_en (Retrieved: 30 May 2019).

EEA – European Environment Agency 2016. Circular economy in Europe Developing the knowledge base. EEA Report No 2/2016 Available at: https://www.eea.europa.eu/publications/circular-economy-in-europe (Retrieved: 30 May 2019).

Ellen MacArthur Foundation 2015. Growth within: A Circular Economy Vision for a Competitive Europe. Available at: https://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe (Retrieved: 30 May 2019).

Enerdata-Odyssee database.

Eurofer 2015. Steel and the Circular Economy. The European Steel Association (EUROFER), Brussels. Available at: http://www.eurofer.eu/News&Events/PublicationsLinksList/20151016_CircularEconomyA4.pdf (Retrieved: 30 May 2019).

Eurofer 2018. European Steel in Figure 2018. The European Steel Association (EUROFER) Available at: http://www.eurofer.org/News%26Events/News/European%20Steel%20in%20Figures%202018.fhtml (Retrieved: 30 May 2019).

European Commission 2015. Closing the loop -An EU action plan for the Circular Economy, COM (2015) 614 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614 (Retrieved: 30 May 2019).

European Commission 2019. Report on the implementation of the Circular Economy Action Plan., COM(2019) 190 Final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:190:FIN (Retrieved: 30 May 2019).

European Parliament. Circular Economy 2019. Available at: http://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html Retrieved: 30 May 2019.

Kirchherr, J. et al. 2017. Conceptualizing the circular economy: an analysis of 114 definitions. *Resources, Conservations and Recycling*, Vol 127: 221–232.

Kirchherr, J. et al. 2018. Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecological Economics* 150: 24–272.

Krause, G. 2019. Acél- és alumíniumhulladék-piaci trendek. Főnixmadárként születik újjá az értékes nyersanyag az olvadékból. Available at: http://www.autogyar.hu/auto-vilag-piac/acel-es-aluminiumhulladek-piaci-trendek-20190222 (Retrieved: 30 May 2019).

Li et al. 2011. Energy Consumption-Economic Growth Relationship and Carbon Dioxide Emissions in China. *Energy Policy* 39(2): 568–574.

Murray, A. et al. 2017. The circular economy: an interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics* Vol 140: 369–380.

PACE – Platform for Accelerating the Circular Economy 2019. The Circularity Gap Report. Available at: (Retrieved: 30 May 2019).

PwC 2018. Ha a kör bezárul – a körforgásos gazdaság jelentősége és lehetőségei. Available at: https://www.pwc.com/hu/hu/sajtoszoba/2018/korforgasos_gazdasag.html (Retrieved: 30 May 2019).

our world is only 9% circular, meaning 9% of minerals, fossil fuels, metals and biomass that enter the economy are re-used. (PACE 2019).

The first aim of this study is to give a brief summary on what circular economy means. Afterwards, we introduce what possibilities an energy-intensive industry, the steel industry, has in transition to circular economy.

2 THE CIRCULAR ECONOMY

2.1 *The concept*

It is often emphasized that in a circular economy, there is no waste, as products of today can serve as resources for the future. However it is more than just recycling, it is rather a new model of production and consumption overarching the supply chain and sectors, being able to increase the efficiency of resource use and competitiveness, to decrease costs, to drive innovation and to contribute to sustainable development.

The concept itself is not a new one. According to the latest studies (Murray et al. 2017, Kirchherr et al. 2018) basic idea of circular economy was first mentioned in 1848, in 1966 by Boulding and was further discussed in the last 40 years by e.g. Stahel and Ready-Mulvey, Pearce and Turner. Currently, more than 100 definitions are identified with a wide range of meanings. (Kirchherr et al. 2017) As the circular economy gained importance in Europe since in 2015 the European Commission announced its package to support the EU's transition to a circular economy, we accept the definition of the European Parliament and the European Commission. Circular economy is "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible" (European Parliament) "and the generation of waste minimized" (European Commission 2015).

2.2 *Benefits and enabling factors*

The circular economy compared to the linear uses less input and natural resources, while the share of renewable and recyclable resources increases. The value of products, components and materials are kept as long in the economy as possible, resulting in reduced emissions and fewer material losses. (EEA 2016) Benefits are connected to the following four areas, including the 3 pillars of sustainable development:

- Resource benefits: demand for primary raw materials decreases, so does the dependency on imports
- Environmental benefits: environmental impact of economic activities decreases due to the higher resource-efficiency, thus externality costs decrease.
- Economic benefits: it fosters innovation and economic growth.
- Social benefits: creates jobs and through a more sustainable consumer behavior it can contribute to human health and safety. (EEA 2016)

Circular economy is a systemic shift that requires changes in current production and consumption patterns. Firstly new, innovative technologies must be developed and introduced (eco-innovation and eco-design). Besides the technological innovation, social and organizational innovation is inevitable. Secondly, the actors must change their interplay by giving repair, refurbishment, remanufacture and recycling higher importance. All these changes cannot be done if not supported by regulation (such as rethinking incentives, providing a suitable set of international environmental rules) and cultural shift in changing the manner of both consumers and producers. (Kirchherr et al. 2018, EEA 2016) Among the enabling factors, we would like to highlight the industrial symbiosis as a new business model, a local or global partnership where companies of different sectors collaborate to make one's waste or by-product a resource for another. By providing, sharing and reusing resources industrial symbiosis can create loops of technical or biological materials and minimize waste. (PwC 2018, EEA 2016).

In the next part of the study, we examine what potential the steel industry has in the transition to circular economy. As an explanation of our choice we cite the Director General of the World Steel Association Dr Edwin Basson:

"As steel is everywhere in our lives and is at the heart of our sustainable future, our industry is an integral part of the global circular economy." (World Steel Association 2015, 3.).

3 THE STEEL INDUSTRY IN THE CIRCULAR ECONOMY

3.1 *The status of the European steel industry concerning the EU climate policy*

3.1.1 *Steel industry of the European Union – overview of the current situation*

Steel is the second most commonly used raw material, its significance is unquestionable in our daily lives. The global steel consumption excluding net indirect exports in 2016 was 1,425,732 thousand tonnes in finished steel equivalent and has increased steadily in recent years. China ranks first in the world in terms of true steel use with 43 percent of total. It is followed by the EU with about 10.5 percent, and by the US with about 8 percent. (World Steel Association 2018a, 115–116.).

Steel production is a material- and energy-intensive process with high level of CO2 emissions. Thus, the sector is very sensitive to the changes in the commodity market and in the energy sector (like primarily access to resources or price volatility) as well as to the stringer environmental regulations.

In addition, the EU steel industry had to face further challenges over the past decades. The majority of the steel industry's products are investment goods which results in high level of cyclical sensitivity. (Barta and Poszmik 1997) After a significant (42 percent) fall in demand in 2008 as a result of the global economic crisis, steel use in the EU increased to three quarters of the pre-crisis level by 2017. (World Steel Association 2018a, 115–116.) Crude steel production followed this trend too when from 2008 to 2009 fell by 30 percent. By 2017, crude steel production increased by about 21 percent compared to the year 2009, but the pre-crisis level was far not achieved. The global crude steel production was 1,690,479 thousand tonnes in 2017 of which China accounts for 49 percent, the EU ranked second with a share of about 10 percent (168,305 thousand tonnes), followed by Japan, India and CIS with a share of around 6 percent. The share of the US share in global production is about 4.8 percent. (World Steel Association 2018a, 1–2.).

The EU steel industry is facing difficulties in maintaining its position in the international competition dominated by the growing production of emerging countries, mainly China, India, CIS and Brazil. While in 2008, the EU ruled 14.8 percent of global production, its share fell below 10 percent by 2017. (World Steel Association 2018a, 1–2.) The situation is further worsened by the overcapacity of the worldwide steelmakers. This encourages the export of steel products, increasing competition for EU steel companies and thus the likelihood of market loss within the EU. The commercial policy measures applied by the competitors (such as the introduction of subsidies for their steel sector or import duties) also have a negative impact on the competitiveness of the European steel industry.

Continuous innovation can be an effective solution to these challenges. The introduction of low-carbon, less energy-intensive technologies, the development of high-quality, tailor-made products and the exploitation of the potentials of industrial symbiosis are key to the competitiveness of the EU steel industry. In this regard, the circular economy concept can provide an effective solution for the industry.

3.1.2 *Characteristics of the steel production*

When presenting the characteristics of the steel production, we place the emphasis on the technological solutions of steel production, raw materials used in production, energy use, and CO2 emissions, as well as the effects of related environmental regulations. Although we acknowledge the importance of those factors, we do not cover the analysis of labor intensity and employment of the sector.

Two main technologies exist in steel production. In the basic oxygen furnace (BOF) within an integrated steel mill, molten iron from the blast furnace is changed into liquid steel. (Ecorys 2008) This is also known as oxygen-blown converter (OBC) technology. The main raw materials in this case are iron ore, coke, limestone and little amount of steel scrap. As energy resource predominantly coal is used. Annual capacity of over 2 million tonnes can make production viable. Introduction of the so called EAF route is a technological improvement. An electric arc furnace (EAF) is a furnace that heats charged material by means of an electric arc. (Ecorys 2008) In this technology, the raw material is primarily steel scrap, while it mainly uses electricity as energy resource. The technology applied highly depends on the type of the product and on the quality requirements. The BOF route compared to the EAF technology is characterized by higher cost of capital, higher fixed costs as well as higher energy cost. Overall, the EAF technology is a more expensive process (Ecorys 2008, 62.) Commonly the most important cost factors are cost of raw materials, energy costs and transport costs. Connected to the development of technology, the introduction of continuous casting should be mentioned as revolutionary. Improving productivity and cost-efficiency, nowadays it is predominant, 96.3% of global production applies continuous casting. (World Steel Association 2018a, 5-6.) The implementation of DRI and HBI as scrap substitutes also was of high importance. Due to the continuous technological innovation, the sector achieved lower cost of capital, economic viability at small scale, lower operational costs, higher flexibility in raw material and significant environmental benefits. (Ecorys 2008)

Access to raw materials and long-term insurance of that must receive strategic attention from the EU. Although there is no shortage of raw materials in the long run, rising demand from emerging countries puts pressure on the supply of raw materials. Thus raw material prices are rising while import dependency of the EU is high and growing steadily.

The steel industry is one of the energy-intensive sectors, its emission is constantly in the center of attention. Energy consumption of the EU steel industry in 2016 was 49 Mtoe. It is important to emphasize that this represents a 40.7 percent reduction compared to 1990 energy consumption. According to 2016 data, 47.2 percent of energy was from coal, 30.2 percent from natural gas, and 20.2 percent from electricity. The rest is made up of other energy resources. The share of electricity in the 1990s shows an increase of about 7.5 percentage points due to the spread of EAF technology. Energy consumption per tonnes of crude steel in 2016 was 0.3021 toe/t. Compared to 1990, this represents a decrease of 27.2 percent. Energy intensity of primary metals, at purchasing power parities calculated as Final consumption/Value added) at 0.7353 koe/€in2010. The value of the indicator also showed a significant decrease of about 42 percent compared to the 1995 value. (1.27675). (Enerdata-Odyssee database)

The sector is very sensitive to changes in energy prices due to its energy demand. Energy prices today increases constantly and dramatically concerning electricity, natural gas, coal and oil. Significant territorial differences exist in the development of prices, which means prices show a significant variation within the EU and the situation is even more unfavorable compared to non-EU states. For example, the advantage of the US concerning energy prices has been significant in recent years. One of the reasons for the large differences in the price was the shale gas revolution in the US, but the effects caused by the diversity of taxation of energy products are significant as well. The EU is applying stricter environmental rules, such as higher tax burdens, resulting in higher energy prices. This is certainly disadvantageous for energy-intensive industries.

In 2015, CO2 emissions from the iron and steel industry were 102.2 Mt in the EU. This represents a 41.5 percent decrease compared to 1990 levels. CO2 emission per tonne of crude steel in 2015 was 0.6172 tCO2/t, representing a 30.3 percent reduction compared to 1990 levels. (Enerdata-Odyssee database). EU environmental legislation put a significant burden on steel industry. The EU has introduced much stricter rules (e.g. EU ETS, IPPC standards) than most non-EU countries. This is a major competitive disadvantage for EU steel companies. In the period up to 2030, the rules for producers were further tightened. A 40 percent reduction in CO2 emissions and a further 27 percent improvement in energy efficiency must be reached. High expectations will enhance carbon trading, resulting in higher carbon credit prices. In 2018, the price of carbon credit increased by 4-5 times, which contributed significantly to the rise in electricity prices. According to Róbert Móger, Director of the Hungarian Iron and Steel Association, "the expectations set by the EU are not realistic, because there is currently no technology that can be operated economically on an industrial scale to ensure the achievement of these goals." (Viland 2018, 2.).

3.2 *Steel industry as an engine of circular economy*

Steel production plays a major role in the global concept of the circular economy. All the elements of the 4R framework (Reduce, Reuse, Remanufacture, Recycle) of the circular economy model can be identified. Life cycle thinking is essential to the successful transition to the circular economy. The raw material and energy consumption, emissions and waste generated must be taken into consideration at all stages of the product's life cycle from design, production of raw materials, production and use to reuse or disposal. The total impact of a product on the environment can be determined only if a full life cycle approach is applied. (World Steel Association 2015).

The extremely favorable properties of steel can make it one of the drivers of the circular economy and gives several advantages over other materials (e.g. aluminum, magnesium, plastic). Steel can be recycled 100% and many times while maintaining its original properties. Through recycling, a wide range of new steels can be produced from any type of steel waste. For example, a lower value steel scrap can be used to produce higher value steel using appropriate technology. Due to its magnetic properties, steel products can be recovered from waste streams. The high value of steel scrap makes the recycling economically viable. On one hand the excellent durability of steel results in less steel is needed to maintain everyday life, while on the other hand it means that steel scrap is available in limited amount.

Material efficiency index of the steel industry (meaning percent of materials converted to products and by-products) is around 97 percent (World Steel Association 2018b), which is quite high compared to other sectors. It means 66 percent of the raw materials and steel scrap used in production becomes new steel, 31percent is by-products and only 3 percent waste is produced. Thus, it can be said that steel production is an almost closed-loop system, the future goal is to reach 100 percent. (Eurofer 2015).

The integration of the steel industry into the global circular economy is illustrated by our model.

As Figure 1 shows involvement in the circular economy can be realized through potentials within the steel industry and by exploiting the potential of industrial symbiosis. As a result, they can reduce raw material and energy consumption, reduce CO2 emissions, increase cost

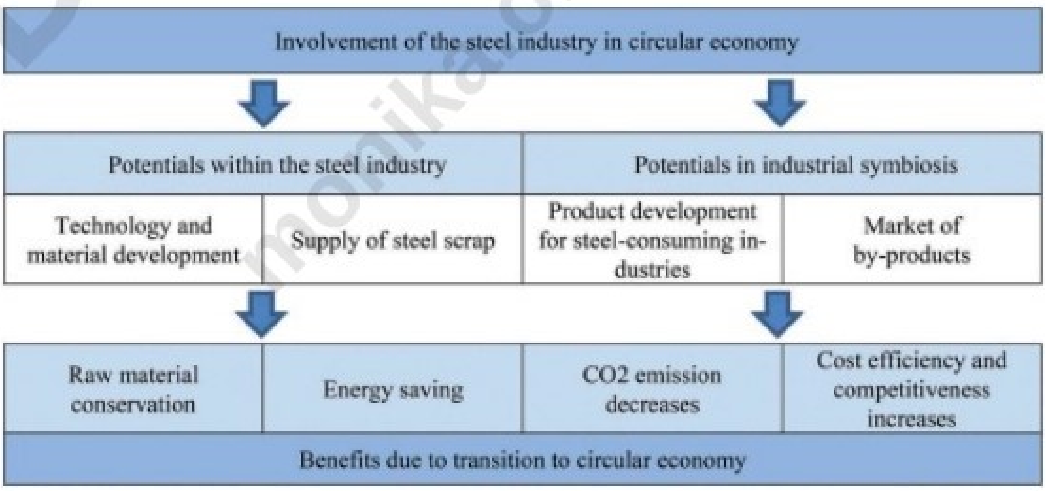

Figure 1. Model of the involvement of steel industry into the circular economy.
Source: own elaboration.

efficiency, and thus competitiveness. And most importantly, these positive effects do not only occur in the steel industry, but also in sectors that use steel or its by-products, and ultimately at social level.

3.2.1 *Potentials within the steel industry*

3.2.1.1 TECHNOLOGY AND MATERIAL DEVELOPMENT

In the previous chapter, we introduced the main features of the 2 main steel production routes. According to data from 2017, the BOF accounts for 71.6 percent of the global crude steel production, while 28 percent is produced by EAF. (The remaining 0.4 percent means other technological solutions, such as the open-hearth furnace technology.) However, the share of technologies of steel production varies significantly across regions. In the EU, the share of the BOF route is only 59.7 percent, while the more advanced EAF technology has a 40.3 percent share. In the US, the focus was even more shifted to the EAF technology (68.4%), while in China, BOF technology accounts for 90.7 percent of total production. (World Steel Association 2018a, 17-18.) The growth of electro-steel production is projected in the medium term, e.g. China has already begun to transform several oxygen-blown steel plant to change to the electro steel production process. (Krause 2019) Besides the technological milestones described, currently, carbon capture and storage technologies are also developed. In addition to reducing CO2 emissions, the reduction of other greenhouse gases and harmful substances (NO_x, SO_x, dust) is among the objectives.

3.2.1.2 SUPPLY OF STEEL SCRAP

There are 3 main sources of steel scraps. The internal by-products from the steel mills that are the industry's own circular scrap from steelworks and foundaries. Due to the constant improvements of technology, this type of scraps shows a downward trend. The second source is the new scrap from steel-processing industries that is together with the previous type is also referred to as pre-consumer steel scrap. It is 100 percent collected and recycled in steel production. The third source is the so-called post-consumer steel scrap, like used cars and other end products. The latter is the most common type of waste. (Ecorys 2008) While in BOF technology steel scrap is used up to 35 percent, in the case of the EAF this rate can be 100 percent. The supply of steel scrap is limited by the durability of steel. We distinguish products with short (e.g. small boxes), average (e.g. caring machines, cars) and long (e.g. buildings, bridges) service life. The latter serves up to 100 years. (Eurofer 2015) The 75 percent of the steel ever produced is still in use. Therefore, the development of scrap substitutes is also a key issue. Steel is the most frequently recycled material in the world, about 650 million tonnes of steel scrap is recycled annually. The recovery rate is not the same in different sectors, is 98% for industrial and commercial buildings and over 90% for machine manufacturing, while 50% for smaller electronic equipment. About 20 percent of steel scrap of the EU is exported, thus the EU is a net exporter in the international steel scrap market.

3.2.2 *Potentials in the industrial symbiosis*

3.2.2.1 PRODUCT DEVELOPMENT FOR STEEL-CONSUMING INDUSTRIES

Analysis of the share of total finished steel demand in the EU shows that the largest steel-consuming sector is construction (35%), automotive (19%), mechanical engineering (15%), metalware (14%) and tubes (11%) are also significant, while domestic appliances, other transport and the miscellaneous both have a 2% share. (Eurofer 2018) Technological development has also led to improvements in the quality of steel. High quality steel is a prerequisite for manufacturing high value added products. The EU's competitiveness in the production of high-quality, tailor-made steels is the highest.

The sector is characterized by permanent material and product innovation, as it has to meet the constantly changing needs of the main steel-consuming industries. In all sectors, steel meets different basic requirements, e.g. in the automotive industry the development of advanced high-strength steels (AHSS) is needed to be lightweight but also rigid components for the transport sector. It contributes to a decrease in weight of vehicles, while safety and quality increases, fuel consumption and emission decreases. (Ecorys 2008) According to a research cited by the World Steel Association 2015 study, vehicles manufactured using AHSS were slightly worse in the use cycle in emissions reduction than the aluminum, magnesium, plastic and steel based Super Light Cars (SLC). However, applying the lifecycle thinking, including the raw material production and the automotive industry GHG emissions as well, the use of AHSS was less harmful. Stronger and lighter steel is also demanded in the energy sector, e.g. the production of wind turbines from lighter steel significantly reduced CO2 emissions and emissions from its transport and assembly. Using high grade steel in the construction industry, the construction of higher buildings is more efficient, the amount of steel used reduces, so does transportation cost. The construction time of plants has also decreased, and the thinner buildings allow for space utilization. Modular reinforced concrete elements can be reused, that provides with cheaper solutions than producing new items from raw materials. Reducing the thickness of steel used in the packaging industry, such as food and beverage cans, has resulted in positive environmental impacts concerning the whole life cycle. Despite of the increase in energy use of production, the total energy use, GHG emission and transportation cost decreased as less steel is needed.

3.2.2.2 MARKET OF BY-PRODUCTS

In the circular economy framework finding market to the by-products is inevitable. The steel industry is outstanding in it. One of the main by-products of iron and steelmaking is slags. In 2016 in Europe a total of 41 million tonnes slags was used, out of it 46.8 percent in the cement industry. This significantly reduces the environmental impact of cement production. (up to 59 percent CO2 and 42 percent energy savings). The 29.8 percent of the slag was used as aggregates in road construction, metallurgical use was 6.8 percent but it could be used in crop fertilizer production (1.2%) The 5.7 percent of the slag was placed in landfill sites. Another important by-product are the process gases, which are utilized in electricity and heat production. Dust and sludge are reused in alloys, the petrochemicals are input materials for the chemical industry. (World Steel Association 2018c).

4 CONCLUSIONS

The world's environmental resources are scarce, while the amount used in production is increasing. Business models need to find sustainable solutions for preserving raw materials and decreasing the environmental impact of economic activities. The circular economy model is a new approach in practice, where maximum value is created with minimum waste by closing the loops. Transition to the circular economy became a priority in the European Union to gain competitive advantage. It is very important to take steps towards transition to all actors of the economy in all sectors and it is supported financially.

The steel industry has made considerable efforts and shows significant progress over the past decades to reduce raw material and energy consumption and greenhouse gas emission. Technology development is in the center of attention, although the efforts are partly driven by the stricter environmental regulations the steel industry and the steel-consuming sectors have to face.

The steel industry fit into the circular approach taking advantage of potentials within the sector and potentials in the industrial symbiosis. Thanks to the transition to the circular economy steel industry can reduce raw material and energy consumption, reduce GHG emissions, increase cost efficiency, while it becomes more competitive. The positive effects do not only occur in the steel industry, but also in sectors that use steel or its by-products, and at social level as well. While emphasizing the environmental and economic advantages we cannot go along the fact that innovative technologies need skilled and medium skilled workforce. Besides its sectoral advantages, the transition to circular economy can contribute to better well-being of people.

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REFERENCES

Barta, Gy. & Poszmik, E. 1997. A vas- és acélipar versenyképességét befolyásoló tényezők. "Versenyben a világgal" kutatási program, műhelytanulmány - Budapesti Közgazdaságtudományi Egyetem, Budapest Available at: thttp://edok.lib.uni-corvinus.hu/211/1/MT_15_Barta_Poszmik.pdf (Retrieved: 30 May 2019).

Ecorys 2008: Study on the Competitiveness of the European Steel Sector. Within the Framework Contract of Sectoral Competitiveness Studies – ENTR/06/054, Final report, August 2008. ECORYS Nederland BV, Rotterdam Available at: https://ec.europa.eu/growth/content/study-competitiveness-european-steel-sector-0_en (Retrieved: 30 May 2019).

EEA – European Environment Agency 2016. Circular economy in Europe Developing the knowledge base. EEA Report No 2/2016 Available at: https://www.eea.europa.eu/publications/circular-economy-in-europe (Retrieved: 30 May 2019).

Ellen MacArthur Foundation 2015. Growth within: A Circular Economy Vision for a Competitive Europe. Available at: https://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe (Retrieved: 30 May 2019).

Enerdata-Odyssee database.

Eurofer 2015. Steel and the Circular Economy. The European Steel Association (EUROFER), Brussels. Available at: http://www.eurofer.eu/News&Events/PublicationsLinksList/20151016_CircularEconomyA4.pdf (Retrieved: 30 May 2019).

Eurofer 2018. European Steel in Figure 2018. The European Steel Association (EUROFER) Available at: http://www.eurofer.org/News%26Events/News/European%20Steel%20in%20Figures%202018.fhtml (Retrieved: 30 May 2019).

European Commission 2015. Closing the loop -An EU action plan for the Circular Economy, COM (2015) 614 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614 (Retrieved: 30 May 2019).

European Commission 2019. Report on the implementation of the Circular Economy Action Plan., COM(2019) 190 Final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:190:FIN (Retrieved: 30 May 2019).

European Parliament. Circular Economy 2019. Available at: http://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html Retrieved: 30 May 2019.

Kirchherr, J. et al. 2017. Conceptualizing the circular economy: an analysis of 114 definitions. *Resources, Conservations and Recycling*, Vol 127: 221–232.

Kirchherr, J. et al. 2018. Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecological Economics* 150: 24–272.

Krause, G. 2019. Acél- és alumíniumhulladék-piaci trendek. Főnixmadárként születik újjá az értékes nyersanyag az olvadékból. Available at: http://www.autogyar.hu/auto-vilag-piac/acel-es-aluminiumhulladek-piaci-trendek-20190222 (Retrieved: 30 May 2019).

Li et al. 2011. Energy Consumption-Economic Growth Relationship and Carbon Dioxide Emissions in China. *Energy Policy* 39(2): 568–574.

Murray, A. et al. 2017. The circular economy: an interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics* Vol 140: 369–380.

PACE – Platform for Accelerating the Circular Economy 2019. The Circularity Gap Report. Available at: (Retrieved: 30 May 2019).

PwC 2018. Ha a kör bezárul – a körforgásos gazdaság jelentősége és lehetőségei. Available at: https://www.pwc.com/hu/hu/sajtoszoba/2018/korforgasos_gazdasag.html (Retrieved: 30 May 2019).

Viland, G. 2018. Az acélipar fejlődése számos más üzleti területre is hatással van. *Magyar Hírlap*. 2018. október15. Available at: https://www.magyarhirlap.hu/gazdasag/Az_acelipar_fejlodese_szamos_mas_uzleti_teruletre_is_hatassal_van_

WCED - World Commission on Environment and Development 1987. Our Common Future; http://www.un-documents.net/our-common-future.pdf (Retrieved: 30 May 2019).

World Steel Association 2015. Steel in the Circular Economy. A life cycle perspective Available at: https://www.worldsteel.org/en/dam/jcr:00892d89-551e-42d9-ae68-abdbd3b507a1/Steel+in+the+circular+economy+-+A+life+cycle+perspective.pdf.

World Steel Association 2018a: Steel Statistical Yearbook 2018. Brussels, Belgium. Available at: https://www.worldsteel.org/en/dam/jcr:e5a8eda5-4b46-4892-856b-00908b5ab492/SSY_2018.pdf (Retrieved: 30 May 2019).

World Steel Association 2018b: Sustainability Indicators 2003–2017. Brussels, Belgium. Available at: https://www.worldsteel.org/en/dam/jcr:6315d64c-c3a9-460b-8f80-dcbeaeaac5c4/Indicator%2520data%25202003%2520to%25202017%2520and%2520relevance.pdf (Retrieved: 30 May 2019).

World Steel Association 2018c: Steel Industry Co-Products worldsteel position paper. Brussels, Belgium. Available at: https://www.worldsteel.org/media-centre/press-releases/2018/steel-industry-co-products—worldsteel-position-paper.html (Retrieved: 30 May 2019).