Low-carbon transition in the steel industry: a comparative study of Iran and Sweden

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Keywords

technological innovation system, sustainability, low carbon technologies

Abstract

The challenges of the new era about being more sustainable have been increasing in recent decades. Most of the studies have focused on investigating the sustainability transition in clean-tech industries of emerging economies. Meanwhile, the role of scale-based industries like the steel industry in the transition to sustainability has been neglected, specifically in emerging economies and developing countries. The iron and steel industry has a share of one-third of global industrial emissions all over the world, which can make a stronger argument to get more attention. The pressure on the industry shift to more sustainable ways of production is currently undergoing in the Swedish steel industry within the HYBRID project that aims to transition towards a hydrogen-based steel making. Hydrogen Direct Reduction (H-DR) is taken as a case study in order to compare with the steel of Iran in terms of sustainability transition. Considering the advantages of Iran like the availability of renewable energy (solar), of iron ore, a growing steel industry, and well-skilled people, the main question is how Iran as a latecomer, can make a collaboration with Sweden in order to develop the sustainability transition in this industry. Here, the experiences of Sweden shall be taken into account to identify the features and conditions in Iran. We apply a Multi-Level Perspective (MLP) in this study.

Introduction

Economic growth raises living standards around the world, but such growth can also put increasing pressure on ecosystems that lead to irreparable consequences in the future (Fagerberg 2017). Neoclassical economists emphasize the important role of technology development in order to succeed in the economic development of countries. While its apparent aim was to bring economic equality and convergence in different countries, in practice, it polarized and divided the world economy into two parts, the rich north, and the poor south, which led to social and economic inequalities (Idowu et al. 2020). However, this approach is criticized since it is purely economic and destroys the biological balance of the world. In this regard, Fagerberg (2017) states that to reduce the ineffective consequences of economic development, countries should become more innovative in the transition to sustainability. Therefore, subsequent studies attempt to focus on socio-technical systems in order to answer the question of how these systems can shift towards a sustainability transition (Markard et al. 2012). The Paris Agreement from (2015) and the United Nations Framework Convention on Climate Change (UNFCCC) goals to reduce Greenhouse Gas (GHG) emissions all over the world have been effective in shaping sustainability transition studies. Most studies have focused on the development of sustainable technologies for transition in clean or emerging industries. In contrast, the energy-intensive industries such as steel, cement, aluminum should be further explored because these industries, which are often based on natural resources, have a high share of CO2 emissions worldwide (Wesseling et al. 2017). Appropriate measures have been taken to reduce carbon emissions and increase energy efficiency in some countries such as Sweden or China. Such efforts have navigated studies on clean technologies used to help reduce carbon emissions in energy-intensity industries (Karakaya et al. 2018, Kushnir et al. 2020).

However, the growth rate of developing countries relies more on the development of energy-intensive industries with mass production. Hence, most of them focus on increasing production for economic development, while in many cases, sustainable development goals have not been addressed (Idowu et al. 2020). Given the importance of sustainable transition debates in recent years, therefore, low-carbon technological changes and socio-technical changes are prerequisites for the development of many countries in the present age. Most studies of low-carbon technology in the steel industry are in one country (Karakaya et al. 2018; Kushnir et al. 2020; Arens et al. 2017) and few studies have examined several nations at transnational level (Zhao et al. 2019). Given the issues discussed above, the present study investigates sustainability transition in the steel industry. We choose a case study approach in two countries, Iran and Sweden, as we seek to respond to the following questions: *Where are the Iran's and Sweden's steel industry placed in the transition process, and what factors have an impact on their success or failure?*

The paper aims at responding to the questions by applying the MLP method. The paper is structured as follows: Section 1 gives an overview of literature. Section 2 reviews the global iron and steel sector. Section 3 presents the methodological details. Section 4 presents the case studies and their findings. The last sections provide discussions, conclusions and make suggestions for industry, and policymakers.

Sustainability transitions

In recent years, sustainable transitions have been taken into account by many researchers. Sustainability transitions are long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption (Markard et al. 2012). However, it is an intriguing question of how these transitions to a new system take place. To answer this question, the MLP has been applied (Geels 2006). The MLP is based on the logic that the transition would happen through interaction within and among three analytical levels: niches (local innovations), socio-technical regimes (established actors, technology, practices, and rules in the system and in fact) and a socio-technical landscape (Bilali 2019). Socio-technical regimes coordinate the activities of actors and social groups that force creates, lock-in, and path dependence in existing systems. So the transformation in the socio-technical regime is incremental.

Changes in industrial leadership in the world iron and steel industry

Nowadays, the steel industry around the world has witnessed technological changes, starting with Open-Hearth Furnace (OHF) technology, then the emergence of Blast Oxygen Furnace (BOF), and Electric Arc Furnace (EAF) technologies. Now it is on the verge of a new generation of technological transition (Ahman et al. 2018). For centuries, the adoption of such emerging technologies has become one of the most important challenges in different countries. Soma studies have introduced countries' capabilities to attract new technologies in the context of industrial leadership changes (Kang & Song 2017, Giachetti and Marchi 2017, Lee and Malerba 2016, Lee and Ki 2017). Windows of opportunities are a reason to catch up cycles that include demand shifts, regulations and technology development (Lee and Ki, 2017). In this Part, technological catch up is introducing based on which circumstances and by which technologies countries could catch up in the steel industry.

Lee and Ki (2017) have taken this framework to analyze the process of industrial leadership change in the steel industry. They claim that the US was the industrial leadership in steel until the first half of the 20th century, then the emergence of new technologies (BOF, continuous casting (CC)) in 1960 was an exogenous window of opportunity for Japanese firms to adopt and create their own path. However, Japan also failed to sustain its position, and South Korea could benefit from reduced cost worldwide by importing mature and cheap technologies in 1970 and enhancement of in-house R&D in the development of CC technology gradually. However, South Korea also like the US, and Japan could not sustain its leadership position. With the financial crisis of 2008–2009, demand for steel declined again, and countries faced excess production capacity and oversupply of imports, which put high pressure on steel prices, and lowered the profitability of the industry. Under such circumstances, each country was seeking to reduce its imports and maintain its local market by adopting policies and laws. In this situation China's iron and steel industry can adopt suitable measures quickly, and became world leader in EAF technology production (Madias, 2014). At the same time, many environmental challenges and constraints increased, and the steel industry forced to adopt some of the most stringent environmental standards that would virtually reduce steel production and increase the circular economy. Thus, the global steel community attempted to balance excess steel capacity and ensure the sustainability of the carbon steel industry through efficient and cost-effective production routes (Joon Min, 2016). Different countries have tried to introduce sustainable technology to meet the balance mentioned above and also to meet the 2050 GHG emission target all over the world. These transitions not only are involved the technologies, but they are also included how the countries respond to the opportunities. Before developing the sustainability transition goals, all of the windows of opportunities were exogenous and latecomer countries should respond them actively (Lee and Malerba, 2017). However, in the transition era, indigenous windows of opportunity should be opened by managing a broad set of activities to develop socio-technical system to respond proactively (Kwak and Yoon, 2020, Yap and Truffer, 2019). Table 1[1] presents the emergence technologies in the steel industry.

1. In Table 1, "R" refers to more complex innovations that do not significantly change existing production structures; "RR" implies new technologies that require change in production facilities and systems, "RRR" refers to innovations at very early stages of development that would radically change the production system.

Table 1. Overview of low carbon innovations in Iron and Steel (Wesseling et al. 2017).

Technology	Type of Innovation	Description	Bottlenecks of diffusion of the innovation
Recirculating Blast Furnace and Carbon Capture and Storage (CCS)	R	Currently under R&D (ULCOS project) needs high integration into existing plants which might need significant changes in plant/sites	High energy demand, costs, infrastructure, acceptance by the local public, CCS as a precondition
Smelt reduction and CCS	RR	Makes obsolete coke ovens, Blast Furnace (BF) & BOF of conventional steel factories	Costs, infrastructure, acceptance, CCS as a precondition
Direct reduction with H_2	RR	Make obsolete coke ovens, BF &BOF of conventional steel factories, but is combined with electric arc furnace, needs H_2 supply infrastructure	Costs, infrastructure and Technology
Electrowinning	RRR	Makes obsolete coke ovens, BF & BOF of conventional steel factories, needs large electricity supply; technology only on lab scale available	Only available in lab; low coal/CO_2-prices and high electricity prices

Table 2. Lists of interviews conducted in Iran and Sweden's steel industry.

Interviewee in Sweden	Interviewee in Iran
Assistant professor of KTH Royal Institute of Technology	Member of the board of Middle East Meyare Sanat Engineering Company
Assistant professor of KTH Royal Institute of Technology	Director of planning and research at National Iranian Steel Company
Professor of Faculty of Engineering (LTH), Lund University	R&D manager of Isfahan Steel Company
Professor of Faculty of Engineering (LTH), Lund University	Vice President of Research Management, Technology, and Localization of ESCO
Technical Director of Swedish steel producers' Association (Jernkontoret)	Manager of Pershia Metal Espadana Investment Company
Senior Advisor (environmental issues) and Research Manager Swedish steel producers' Association	Technology Manager of Isfahan's Mobarakeh steel company
Chief Technology Officer of SSAB AB	The executive director of Iran's steel producers association
Researcher and assistant professor	Professor at Sharif University of Technology
Expert in Stockholm environmental institute	Deputy of Planning and capability building of Iranian Mines and Mining Industries Development and Renovation Organization (IMIDRO)
Energy and environment director	CEO of Iranian Fartak Research and Innovation company
Researcher at CIRCLE	Expert in related to technology development in Steel in Vice-presidency for Science and Technology

Methodology

This paper aims to investigate the factors that are essential to developing a Technological Innovation System (TIS) in the steel industry. To this, a multiple case study has been used (Yin 2003). In a multiple case study, the researcher studies multiple cases to understand the similarities and differences between the cases. The multiple case study is studied with a comprehensive view by either one or several methods. The Multiple-Level Perspective has been used as an analytical method in the multiple case study framework of this paper (Gustafsson 2017). The case studies focus on the situation of sustainability transition, and hydrogen direct reduction technology in particular, in Iran and Sweden.

The MLP approach has been applied to grasp fundamental factors that lead to success or failure of this type of transition in both countries through analysing the transition process at three levels, namely niche, existing socio-technical system, and landscape. Both primary and secondary data have been applied in the paper. As primary data, some semi-structured interviews were conducted among Swedish and Iranian experts in the steel industry during 2018–2019. The secondary data consist of academic papers, documents from companies, governmental documents, reports, and statistics of some agencies.

STATUS QUO OF IRAN'S AND SWEDEN'S STEEL INDUSTRY

In this section, Iran's and Sweden's steel industry are compared. They have a different history, steel production amount, raw material, energy consumption, and technology used. The Swedish iron and steel industry has a long history beginning in the middle ages (Jernkontoret, 2018). But the first attempts for domestic steel production in Iran in 1884 and 1937 failed. The most important measure in Iran's iron and steel was the construction of the Esfahan Steel company in 1965, which was put into operation in 1972. After the Iran's Islamic Revolution of 1979, the development of the industry flourished (Attarpour et al., 2018). A comparison of steel production in these two countries shows that Iran has 84.05 % of the total production of the two countries (Figure 1). Iran's vision is to have 55 million tons production by 2025, and crude steel production in Iran increased by 30 % in 2019 that has transcended its ranking from 13th to 10th as a world steel producer. In 2019, Iran produced 31.9 million tons (MT) steel (World Steel Association 2019). In Iran, the largest share of production is in the three major manufacturing companies, Isfahan, Mobarakeh, and Khouzestan steel company (about 17.8 MT out of a total of 21.8 MT in 2017) that most of them are ore-based reduction plants (Iran's Steel Master Plan 2018).

However, according to the World Steel Association, this amount was not significant for Sweden. The total production of crude steel in 2018 was 4.7 million tons, which shows a 5 % reduction compared to 2017. It should be noted that the quality and variety of steel industry products in Sweden is much higher and better than Iran because the production is based on specialty and highly finished products that are mainly exported. In Sweden, steel production is at thirteen plants. The majority of the steelworkers are found in Bergslagen. Ten production plants are scrap-based, and one of them is an ore-based reduction plant (Jernkontoret 2019).

From the energy consumption point of view, the large part of the energy consumed in Sweden's steel industry is based on coal, while in Iran, it is natural gas because Iran has second in the world in terms of natural gas reserves (Middle East Bank, 2015). Based on the energy consumed, the type of technology used in each country is determined. In Sweden, the critical technology in steel production is oxygen Blown Converters (OBC), which is based on coal consumption with 62.5 % usage in 2017. In contrast, the largest share of steel production is based on a direct reduction in (EAF) that accounts for 89.5 % in 2017 (World Steel Association, 2018). According to Midrex statistics (2016), Iran has the most massive production of natural gas using plants and is the number one gas-based Direct Reduction Iron (DRI) producer (Figure 1).

The amount of CO_2 emissions in Sweden was 5,691.4 Kt in 2018 that has experienced an 0.08 % reduction compared to the previous year (Swedish Environmental Protection Agency, 2019). There is no exact information on the amount of CO_2 emissions in the Iran's steel industry. However, they can be estimated based on emission factors of the technologies. The emission factors for the OBC and EAF of Iran's steel industry are 1.46 and 0.78 (ton CO_2/ton steel) respectively. It shall be considered that about 20 percent of electric arc furnace volume is filled with recycled steel scrap (with emission factor equal to 0.08 ton/ton steel) that is combined with pig iron (Third national communication to UNFCCC, 2017). Then in total, Iran's steel industry CO_2 emissions can be estimated at about 17,542 Kt for 24,520,000 tons' steel production. Compared to Sweden, it is less than 5,691.4 Kt CO_2 emissions of 4,654,000 tons of steel production in Sweden (Swedish Environmental Protection Agency, 2019).

Comparison of raw material illustrates that Sweden is one of the largest sources of iron ore in Europe, with approximately 92 % of Europe's iron and 5 % of the world's iron reserves. Currently, Sweden's mines produce 80 million tons of ore in Sweden per year, mostly from Kiruna Mine, which in 2008 produced 27.5 million tons of iron. LKAB is a *Swedish* mining company that is wholly owned by the *Swedish* state and is the largest mining company in Sweden. It is located at Kiruna and Malmberget in northern *Sweden*. LKAB produced 27.2 Mt of iron ore products during 2019 (LKAB 2019).

Iran also has abundant reserves of iron ore. About 40 % of Iran's iron ore reserves are located in the GolGohar area of Sirjan in Kerman province, and the largest iron ore producer is GolGohar Mining and Industrial Company, which is under IMIDRO supervision. The company produced approximately 14 million tons of iron ore in 2019. Iran also has a competitive advantage in terms of sponge iron production worldwide. In 2019, Iran's sponge iron reached 27.73 MT, an increase of 7.7 % over the same period in 2018, and took the second place after India (producing 36.8 MT) in the world (Steel master plan 2018). Nevertheless, Iran has 66.95 % of the total iron ore production of the two countries (Figure 1).

Findings

ANALYSIS OF MULTIPLE LEVEL PERSPECTIVE

Based on the Multiple-level perspective (MLP) framework, the sustainability transition of Iran's and Sweden's steel industry has been analysed. We, then, provide the extracted factors with some examples of the interviews' text that are given as phrases inside the text.

Driver factors of sustainability transition in Sweden's steel industry

Socio-technical landscape

Sweden has the target of emission reduction in different sectors. Over the last years, the steel industry, like other sectors, has been under severe pressure due to global overcapacities, some practices, energy costs, and policies at the national and international stage. The EU commission signed the Kyoto protocol in 1998 and then set up its emission trading scheme under the Emission Trading System (ETS) in 2005. By 2020, it cuts its Greenhouse Gases (GHG) emissions by 20 %, and that can make the challenges for energy-intensive industries like the steel industry in the long-term.

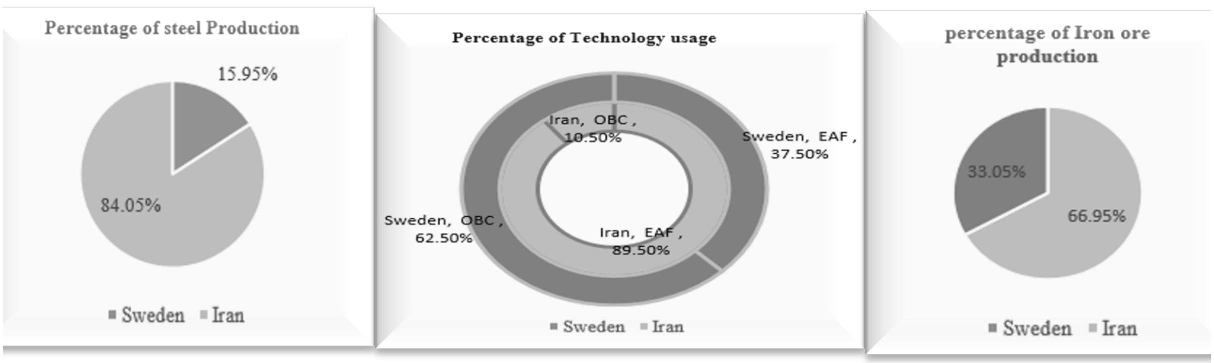

Figure 1. Steel production (2018), technology usage, iron ore production (2017) of Iran's and Sweden's steel industry (World steel association).

> For industries that are in the international market, there are some allowances for emission-free. It is only for 2020, and then this amount of free allowances would be much lower than before. It will be problematic for industries that do not have other technologies today, and they cannot decrease emissions. So they have to pay for them. Another problem is that the steel industry in Europe is costly because no steel industry outside Europe has this price. This is an important legislation problem we have. So, to stay safe from the disadvantages, we need to think about technology development.

To solve the legislation issue, some considerations about Sweden's vision started in 2011, after the financial crisis of 2008–2009 that sustainable issues became highlighted. The vision was drawn up by Jernkontoret's project group, together with representatives from the steel industry, and Jernkontoret's Council adopted this in March 2013 (Jernkontoret, 2019). With this vision, the Swedish steel industry intended to contribute to the ongoing shift to a sustainable society and with a greater responsibility towards people and the environment.

> Starting the discussions at Jernkontoret, we figured out two important needs for the steel industry, one was an improvement of the steel industry's image, and another one is speaking with one voice in the steel industry to move towards sustainability. In 2015–2016, the steel industry and Stockholm Environment Institute (SEI) provided the action plans to bring the Swedish steel industry closer to its 2050 vision.

Then the Paris Agreement in 2016 was signed and released as an agreement within the United Nations Framework Convention on Climate Change, dealing with greenhouse-gas-emissions mitigation, adaptation, and finance. The countries have committed to pursue climate policy in order to reduce or mitigate CO_2 emissions. In June 2017, Sweden's Riksdag decided by a large political majority to introduce a climate policy framework with a climate act for Sweden. This framework is the most important climate reform in Sweden's history and sets out the implementation of the Paris Agreement in Sweden. In this regard, by 2045, Sweden is to have zero net emissions of greenhouse gases into the atmosphere (Carlesson 2018). As it has mentioned by Geels (2006), the macro-level in MLP perspective is formed by the socio-technical landscape, which refers to aspects of the wider exogenous environment, which affect socio-technical development (for example globalization, environmental problems, cultural changes).

The cultural changes can also affect the existing socio-technical system to change by formulating suitable cultural policies that can sustain cultural practices and rights. For instance, the green operations and impacts of cultural organizations and industries raise awareness and catalyse actions about sustainability and climate change, and foster 'ecological citizenship' (Dexbury et al. 2016).

> One of the most important preconditions to move towards sustainability is public support. The government has to change the mindset through the right policies like cultural policies. I think the Swedish government could do that better than other countries.

Socio-technical regime

Government support for Research and Development (R&D)
Investment in R&D is costly and risky by itself. If a government has financial restrictions, public investment and innovation will decrease. Thus, well-designed policies on R&D allocation can play an important role in fostering investment. Sweden has some kinds of support for R&D, one is direct government funding of business R&D, and another is a tax incentive for R&D (OECD, 2019). The European Research Fund is a third type of support for Sweden's steel industry. It allocates about SEK 400 million for steel research at companies, institutes and universities in Sweden annually (Jernkontoret, 2019). In 2017, Sweden was close to the OECD median in total government support to business R&D as a percentage of GDP, at a rate of 0.13% of GDP (OECD, 2019). It demonstrates that the industries in Sweden are well supported financially.

> The steel industry had not any problematic issues on funding the research related to developing Hydrogen based production in Sweden. The feasibility studies and pilot plant building phases were 50 % funded by the government (Swedish energy agency) and 50 % by manufacturers.

Policymaking model of government
As Fagerberg (2017) has noted, the effective policies for sustainability transitions are not based on traditional top-down policies. Reducing emissions of greenhouse-gases to almost zero requires a large number of actors all over the world to transition from producer-oriented to user-oriented mode. According to the ETS system, the Swedish steel association Jernkontoret with other actors, has proactively tried to discuss a fossil-free industry. It tries to convince other actors like the government and other organizations that the fossil-free steel industry is important and also has advantages in the long run. They could influence the visions and government's expectations that lead to the formulation of the policies afterward.

> Looking for possible solutions to decrease or eliminate the emissions in the steel industry, we had some meetings with a group of government officials to bring them with ourselves. Thus, in 2013 the vision and 2017 the climate policies provided the support in practice.

Well established collaboration among actors
Transition is a *multi-actor* process that entails interactions between social groups (Geels and Schot 2010), meaning the more actors collaborate, the more successful transition to a sustainable environment will happen. In Sweden's steel industry, the actors and especially producers have well-established relationships. Additionally, Karakaya et al. (2018) have argued that the culture of the companies is to be special in niche markets that have no competition. In other words, the companies have focused on the production of special steels, and these products are aimed at customers within various market niches. In line with the Jernkontoret report (2018), the reason is that the Swedish steel industry has undergone a process of significant restructuring since the mid-20th century. And this has led to a specialization in fewer products. The major part of the special steel produced in Sweden is exported to 140 recipient coun-

tries in 2014 (Jernkontoret, 2018). So, building a shared vision among actors based on their collaboration and transition from the current socio-technical system to a new one is simpler than the relationships based on the competition.

> One of the distinctions of this industry in Sweden, compared to other countries, is the lack of competition between the actors because Sweden's steel industry is working on different products. As an example, there is an outstanding collaboration among three major actors namely SSAB (a major producer and incumbent company in the Swedish steel industry that is not a state-owned company but it has some cross-ownership with LKAB), LKAB (the State-owned Swedish mining company) and Vattenfall (the state-owned Swedish multinational power company) in the HYBRIT project.

Of course, this cooperation is not limited to the national level; the Swedish steel industry also has some international collaborations by joining and attending international networks like the European or the World Steel Association (EUROFER and Worldsteel). For instance, SSAB has some plants in other countries like SSAB's production plants in Sweden, Finland, and the US. This company also can process and finish various steel products in China, Brazil, and many other countries. Nonetheless, the company is the frontier of knowledge by recruiting skilled labour and experts from different countries and using the potential of other countries. SSAB also helps the industry to be aware of the transformations that would happen in the industry globally and discover windows of opportunity earlier than other countries (SSAB, 2020).

> Today, we are strong in the global presence by having a high amount of professionals in approximately 50 countries.

The Swedish steel industry also has relationships with the research centers and universities at national and international levels. The primary role of the research centers is to bridging the gap between university, industry, and government. Indeed, the R&D structure operates in a coherent and integrated way that provides a coherent orientation for all actors.

> We have good research centers that provide research issues about different sectors. So the universities and governmental agencies can see these issues, which is partly funded by this center, and apply for them by submitting their proposal. The HYBRIT project is an example in which Mistra, as a Swedish research foundation, could build bridges between academia and the business sector.

Public awareness

The development of new technologies requires radical changes in the culture of consumerism. Cultural acceptance is created through training and involving people in relevant issues like the environment. The concept of sustainable development is well-known in Sweden, and therefore, it facilitates public support for transformations in different sectors. The climate change effect is also a familiar and popular concept among Swedes. The level of awareness among the public had peaked between 2002–2003 because of the information campaign on climate change, as a part of Sweden's climate strategy, by the Swedish Environmental Protection Agency on behalf of the Sweden government (Ministry of sustainable development Sweden, 2005).

> We had many meetings with people in the company and outside (NGOs, Ordinary people, society entities, authorities, politicians, academics …) in the workshops. We tried to listen to everybody.

Niche-innovation

For the sustainability transition, there are different kinds of innovation, of which technological innovation is the most favour by governments (Chang et al. 2015). Referring to the interviews, in 2015–2016, the steel industry, in collaboration with the Stockholm Environmental Institute (SEI) formulated action plans to bring the Swedish steel industry closer to its 2050 vision. In spring of 2016, the Swedish companies LKAB, SSAB, and Vattenfall announced their ambition to develop and implement a fossil-free steel production process in Sweden. This process would replace coal with hydrogen for the direct reduction of iron, combined with an electric arc furnace. It would be almost entirely fossil-free, and if it fully deploys, Sweden will see a 10 % reduction in its GHG emissions. The concept is called Hydrogen Breakthrough Ironmaking Technology, or HYBRIT for short (Ahman et al. 2018). However, this technological innovation is still in a pilot phase and also has some challenges about creating infrastructures in practice.

Barrier factors of sustainability transition in Iran's steel industry

Socio-technical landscape limitations

In 1992, the Iranian government established a National Committee for Sustainable Development (NCSD), and the government completed two national initiatives, the national plan for the protection of the environment, and the national strategy for sustainable development. However, they were not very successful. After the introduction of the Paris Climate Change Agreement (2015) around the world, many of the priorities of various sectors to meet their goals have changed in economic, technological, environmental, political perspective. Iran is also no exception. By submitting an Intended Nationally Determined Contribution (INDC), the Islamic Republic of Iran intended to participate by mitigating its GHGs emissions by 4 % (unconditionally) and 8 % (conditionally) in 2030. However, as shown in Figure 2, CO_2 emissions have not decreased over the last years nationally, and Iranian companies have not imposed any strong climate targets yet.

> We have some policies for sustainable development that mentioned in Fifth and Sixth Five-year Development Plans; however, they are not applicable. They cannot push enough pressure on the sectors.

Moreover, the cultural preferences in Iran maintain the current socio-technical regime; most of the people prefer to purchase the products with low costs, which is in contrast to environmental goods. Ecological goods need higher investments for production, and they might have higher consumption costs too.

> Culturally, our people are not serious about environmental issues because they have not been trained, and the performance of related regulations is not efficient. So people do not pursue a sustainable path.

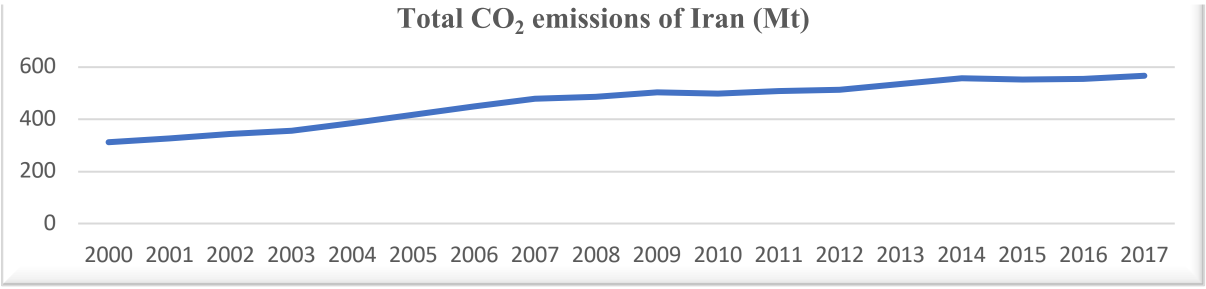

Figure 2. Total CO_2 emissions, Islamic Republic of Iran 2000–2017 (IEA data services).

Socio-technical regime barriers

Low R&D allocation
R&D efforts in the steel industry are driven by the goal of improving the productivity of industrial processes. Iran's internal R&D's resources are not in perfect shape. According to the Budget Act (2019) passed by Iran's Islamic Consultative Assembly, up to 3 % of the budget should be allocated to R&D in different sectors, which have been spending less than expected in the organizations.

> The government has set a tax exemption for corporations that are more in line with the vision 2025. They use this exemption to invest in R&D. However, only a small number of large corporations (one or two of them) can take the advantages of this grant.

Market control by fossil fuel systems
Due to the subsidies provided by policies in Iran, the production (52 %) and consumption (60 %) share of natural gas are significantly high (Safari et al, 2019). Based on the IEA fossil-fuel subsidies database (2019), Iran holds the first place among the world's top countries in terms of the number of subsidies which is allocated to energy consumption. In 2018, Iran had allocated $69 billion of subsidies for various types of energy consumption, including oil ($26.6), natural gas ($26), and electricity ($16.6).

According to Merrill et al. (2017), the current global governments' subsidies to consumers and producers of fossil fuels hold industries back from delivering sustainable development. Huge subsidies and low energy price policies in Iran's energy-intensive industries like the steel industry are a reason to reinforce the existing socio-technical system.

> Subsidizing fossil fuels makes it easier to access, so the manufacturers can make good money through a lower cost, while non-fossil fuels can be costly and risky in this situation that we are under the sanctions.

Another reason is understating the need for change and transitions. Interviews with Iranian steel experts have revealed that the Iranian steel industry is in a better position than other countries in terms of emissions. It can easier transfer to fuel-based sustainability because natural gas can be an important complementary fuel to support renewable energy in short to medium term (Safari et al. 2019). Since natural gas is a clear fuel with lower emissions and CO_2 rates than coke and oil, this socio-technical system may not encourage companies to take advantage of new technologies based on renewable energy to produce the steel.

> Iran has the lowest rate of greenhouse gas emissions and is well ahead of the goals of the Paris Agreement! 1.56 % CO_2 is produced per ton of production. We are 1.16 % behind the Paris Agreement for 2050, which is 1.19 %.

Government financial support restrictions
According to Article 44 of the Iranian Constitution, the government is obliged to transfer 80 % of the public sector shares to the private sector. Large steel companies under the supervision of National Iranian Steel Company (NISCO) were also privatized. However, privatization policies are inefficient in Iran's steel industry. The shares of the large steel companies are usually owned by public companies like Iran Social Security Investment Company (SHASTA). Though they are allegedly private, they are still state-owned or public-private ownership. In such a case, because of the transfer of the public share to private, the government does not engage in financial support. Additionally, the units are large because they were initially launched by the government and then privatized. So, the capital is high, and the private sector is not able to provide this amount of investment.

> We are not completely privatized; only our ownership has been different, and now our stocks are in the hands of the Iran Social Security that is a state-owned organization.

Lack of proper cooperation among the actors
According to the literature of innovation system, interactions among the *actors* involved in *technology development* are as important as investments in R&D because they can help to promote the knowledge flows. A high number of actors make it difficult to coordinate and build a collaborative relationship among them. According to the MLP, a socio-technical transition might occur if the socio-technical landscape exerts sufficient pressure on the incumbent technology and if such pressure gets matched by the full development of at least one innovation niche. This pressure has to influence existing norms, visions, and preferences. In this regard, it is harder to create a shared vision, abolish the ruling socio-technical system, and match with an innovation in an industry with a high number of actors than a small number of actors.

> It is a severe competition among companies to have more production for several reasons; first, because of the vision

> 2025[2] that focuses on production. Next, due to the lack of proper government oversight in the companies, and lastly, because of the transfer of a large proportion of the mining companies to the private sector. Many mining companies are seeking to develop their iron and steel production chains, resulting in not shaping the communication and cooperation between suppliers and producers.

Iran's steel industry does not have a specific R&D structure for facilitating the actors' relationships. All of the R&D activities have been done by companies separately in the form of sporadic R&D.

> In Iran's steel industry, when we talk about R&D, everyone thinks we are talking about gradual and small changes. The problem of R&D in Iran's steel industry is that there is no direction.

At the international level, Iran also has important barriers like sanctions and limited access to international markets, customers, technologies and financial resources. Iran's steel industry has no outstanding cooperation with foreign research centers related to environmental issues.

Lack of proper executive policies related to the transition in steel
How policymakers could govern the sustainability transition processes through transformative policy mixes is a challenging issue in recent studies (Rogge et al. 2018, Kivimaa and Kern 2016, Rogge and Reichardt 2016). It has been pointed out that policies should support not only green niches but also target overturning the status quo (Kivimaa and Kern 2016). In Iran, there are not well-established policies affecting the transition to fossil fuels free in the steel industry for two reasons; first the underestimation of fossil fuel issues in the steel industry, next is the lack of cooperation among policymakers from National Steel Company of Iran, IMIDRO, and the Ministry of Industry, Mine, and Trade in formulating convergent policies. Further, the state institutions dominate the company's decisions. They exert strategies without examining the needs of companies.

> There are two legal and governmental entities that work on steel, one is the Ministry of Industry, Mine, and Trade, and another one is IMIDRO. The Ministry of Industry, Mine, and Trade, and IMIDRO have a Mining Deputy position, which is the same position but parallel in both institutions and in that position, they work on the same issue. So they face conflicting interests that would lead to a lack of consistency in decisions.

Lack of public awareness
The awareness of Iranians about the benefits of environmental solutions in various sectors is low due to the competitive culture, lack of social trust, and education about the right environmental policies. Also, there is no support for raising public awareness and intervene for behaviour change among people in the companies.

> Here, people do not feel the need to pay attention to environmental issues. They are in suffer to make enough money, so the importance of self-preservation is a priority over environmental survival.

Discussions

The aim of this study was to compare Iran's and Sweden's steel industry based on interviews conducted with experts of the industry in both countries. Results of the qualitative analysis revealed that the Swedish steel industry has succeeded in the Hydrogen- Direct Reduction (H-DR) technology pilot phase and many factors have supported this transition. As Kushnir et al (2019) stated "this technology changes the current steel production processes and it substitutes with current coal-based steelmaking using coke ovens, sinter plants, blast furnaces, and oxygen blown converters. Hence, the entire liquid phase needed to be replaced and that, requires major investments." As a bridging technology, hydrogen Direct Reduction can also rely on natural gas.

Even though many components of the H-DR/EAF setup have been tested and deployed in industrial settings, the key challenges about the process remain. (Ahman et al. 2018). One of the critical issues in countries like Sweden and Germany is not the technology, but the price of hydrogen plants.

In Iran, the steel industry faces challenges related to status quo resistance that prevent the industry from being sustainable. Some of Iranian experts in the interviews have suggested to move towards sustainability transition in the steel industry through utilizing the potentials of two countries. Iran's steel industry can be one of the major projects in Sweden's H-DR development because of the potentials that Iran has. One of the potentials is that the generation of solar power in Iran has been developed in recent years. Referring to interviews with Swedish experts, Iran also has rich sources of natural gas that is needed for a short time in the H-DR process. Another potential of Iran's steel industry is its infrastructures and skilled people. Iran's steel industry has made advances in both production and the development of technology through Direct Reduction. Initially, Iran was the only importer of technology, and through the technical know-how of foreign partners, it could achieve OBC technology from foreign partners like Russia. Years after, the knowledge of how to work with *MIDREX* direct reduction ironmaking that reduces iron ore using natural gas, came to Iran through Kobe Steel of Japan. With the accumulation of knowledge, the efforts of internal engineers and the increasing demand for domestic steel as well as access to Midrex technology knowledge, the improvement of the Midrex process and the creation of new technology in the reduction process called Persian Reduction (PRED) based on Midrex modification was initiated with the assistance of several Indian experts in Iran (Khalili et al. 2019).

Based on interviews with the Swedish experts, they pointed out that if Iran would want to make low-carbon steel, it has excellent conditions much better than other countries. This can be a kind of cooperation between Iran's and Sweden's steel industry based on different kinds of international flows. How-

2. In a five-year economic development plan in March 2005, the Iranian government issued a document called *Iran's 20-Year Economic Perspective*, outlining a road map for the country's economic, political, social and cultural developments during the next two decades. The Perspective's preamble promised that by 2025, i.e., after the completion of four five-year development plans, Iran would be a fully advanced country, rising to the number-one rank in economic, scientific and technological progress among 28 nations in the Middle East and Southeast Asia.

ever, to make this scenario a reality, some prerequisites need to be addressed to remove or decrease Iran's barriers.

The fundamental precondition to transition towards sustainability is lifting economic sanctions on Iran to make possible the access the financial resources globally. Other necessary conditions that should be noted are reconsidering the destructive policies including regulatory restrictions for dominant technologies like subsidies for fossil fuels. Iran's government has a concern about reducing or removing subsidies because of social discontent. The government in Iran should strive to increase social trust by eliminating the subsidies in favour of increasing social welfare. Also there should be changes in social networks. For instance, the replacement of key actors in stakeholder consultation or empowerment of new entrants in political debates can be followed (Kivimaa and Kern 2016). In Iran's interviews, it has been discovered that some experts disagree with energy subsidies. They are interested in moving towards sustainability, but the pressure of the opposite group prohibit them from attempting. One solution can be creating a network of both advocates of sustainability transition and influential people in selecting environment as a priority.

Conclusion

This paper contributes to the literature in two ways. First, we applied a multiple case study method that has not been surveyed in the recent papers. To do so, we investigated sustainability transition in the steel industry based on a comparison of two developed and developing countries. Second, we deployed the MLP to extract the factors that support the current socio-technical system and help driving sustainability in Sweden and factors against low-carbon transition and resistances of the existing socio-technical system in Iran.

We conclude that Iran has both existing socio-technical system resistances and landscape restrictions to accept sustainable technologies. The main barriers for the sustainability transition of Iran's steel industry are non-operation of policies to put pressure on the sectors, as well as the cultural preferences at the landscape level, low R&D allocation, market control by fossil fuels companies, limitation of government's financial support, lack of proper cooperation among actors, understating the need for transition, lack of proper regulations in the current system, and lack of public awareness at the socio-technical regime level.

In Sweden, we also conclude that the steel industry with government support could put itself in the transition pathway by focusing on fossil-free production based on H-DR. The main supports for the transition are formulating the right policies to force the current system to have transformation at the landscape level and supports of government for R&D, policymaking model of government, well-established collaboration among socio-technical regime's actors, and public awareness at the socio-technical regime level.

Then we demonstrated that mutual collaboration among two countries could contribute to developing the transition in the steel industry based on H-DR. We can learn that based on taking advantage of countries together, it can be possible to achieve inclusive development in the steel industry.

This paper has some limitations like the availability of interview partners because some of them refused to have interviews. Another limitation is that in this paper, only H-DR technology as a technology to achieve sustainability transition has been investigated. As we understood, the current socio-technical system is stabilized in Iran through high investments in fossil fuel-based machinery and infrastructure. So change in these infrastructure requires a long time, taking high risks especially for the technology which has not been commercialized. It may be good to survey the CCS because it can keep the existing processes. Hence, it is low risk, and is rather mature than H-DR technology.

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Acknowledgements

This article was extracted from the PhD dissertation prepared by Soma Rahmani. The authors gratefully thank Iran's Ministry of Science, Research and Technology for the opportunity of the first author to attend Lund university; Professor Cristina Chaminade at the Department of Economic History for her support and guidance; and academics of Lund university in Sweden, Mazandaran university in Iran and assistance of experts in Iran's and Sweden's steel industry.