Transitions Pathways and Risk Analysis for Climate Change Mitigation and Adaptation Strategies

D3.2 Context of 15 case studies:

Austria: Steel & Iron Sector and Energy Production

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1 COUNTRY CASE STUDIES OF THE HUMAN INNOVATION SYSTEM (HIS): THE ENABLING ENVIRONMENT FOR SUSTAINABILITY

The focus sectors for the Austrian case study are the steel & iron industry and energy supply.

These sectors comprise nearly half of Austrian greenhouse gas (GHG) emissions (ETS and non ETS), and contribute 16% to the Austrian real gross domestic product (GDP.) In the Austrian industrial sector, steel and iron form 45% of the sector's GHG emissions and contribute 18% of the sector's real GDP share (EEA, 2016, Statistics Austria, 2016b).

Among the industrial sectors we have chosen the steel sector not only due to its high share of GHGs but also due to possible high risks associated with a low carbon transition. For the steel industry there is little scope for significantly reducing carbon emissions while remaining with the current production method. An electrification of the pig iron (and steel) production could reduce the carbon emissions substantially. But it would involve, for instance, financial risks for this industry and would lead to an enormous increase of electricity demand from renewables. With respect to CO_2-emission reductions, another less promising pathway would be a switch from coal to natural gas in the production process (for reducing the iron ore). These different technological options would imply a big challenge for the energy supply sector in Austria, thus leading to feedback effects to all other sectors. Furthermore, all other sectors' transitions have impacts on the energy demand and thus energy supply. While such a fundamental change in technology poses high possible risks, in addition a low carbon transition could result in new business activities, potentially leading to a system change, in which steel (e.g. demand for buildings and mobility) might be partly or totally replaced by advanced materials (e.g. polymers).

The case study will therefore analyse the impacts as well as risks and uncertainties for different transition pathways for Austria. It will focus on the steel and iron sector and the energy sector, but with an overall view due to the interdependencies (energy and economic) of all sectors. Stakeholder engagement forms the core part of this case study. Using their input we will explore transition pathways and the key branching points along them, with the aim of formulating pathways that are technically realisable and acceptable to industry and the general public. This work will form part of the case study deliverable 3.3.

1.1 Research questions for the Austrian case study

Steel and Iron Industry:

a) Supply side changes: What emission reduction potential is feasible by technological changes within the steel and iron sector?

b) Demand side changes: What are the prerequisites for replacing steel and metal products by other materials/composites?

c) What will these switches imply in terms of changes in GHG emissions and energy demand and supply?

d) How long will the respective investment and restructuring periods take?

Energy Supply Sector:

e) How can primary energy demand be reduced in absolute terms (by all sectors)?

f) Detailed analysis for the Steel and Iron Industry

g) Rough estimates for the remaining sectors

h) How can the remaining energy demand be covered by renewables?

i) Which kind of renewables are feasible at which levels?

j) What kind of system requirements are necessary?

Both:

k) What are the costs and benefits, as well as risks and opportunities, associated with different low carbon transition pathways and respective policy-options for the focus sectors (e.g. economic, social and environmental impacts)?

l) CGE, E3ME: economic and environmental impacts

m) TIAM: energy system modelling

1.2 Introduction to the general context)

1.2.1 Policy overview

The EU has set itself a long-term goal of reducing greenhouse gas emissions by 80-95% compared to 1990 levels by 2050, with a reduction of 80% to be achieved domestically, as laid down in the EU roadmap (European Commission, 2011) for moving to a competitive low-carbon economy in 2050. To achieve this long-term target cost-efficiently, the EU should aim to reduce its domestic emissions by 40% and 60% by 2030 and 2040 respectively. The target for 2030 is part of the Energy and Climate Package for 2030 and was adopted in 2014 by the European Council (European Council, 2014). Austria is part of the EU and therefore is obliged to adopt the European targets, at least in the medium term. Adopting the EU 2020 targets means a reduction of 21% until 2020 relative to 2005 GHG emission levels for the ETS sectors and 16% for the non-ETS sectors (APCC, 2014) and the 2030 targets will be minus 43% for the ETS sectors, and a reduction of 36% for the Austrian Non-ETS sectors (European Commission, 2016).

Reduction targets for the steel and iron industry, as they are foreseen for the total industry within the EU roadmap, would not be feasible within conventional production routes due to process emissions. Energy efficiency measures have already been introduced and no substantial additional gains are expected (Mueller et al., 2012). Only a structural change with innovative process technologies can lead to substantial reductions of emissions.

The European steel industry is under extreme pressure due to slower economic growth after the global financial crisis and the poorly-performing Chinese economy resulting in a worldwide overcapacity of steel. The Head of the World Steel Association proposes to halve European production capacity within the next 15 years (Tovey, 2015).

Currently, the steel and iron sector, as well as the energy sector, are mainly governed by the ETS at least up to 2030. Increasing overcapacity of steel, especially in China, due to the economic crisis and the controversial interpretation of the WTO Accession Protocol for China's Market Economy Status (after 15 years in December 2016) leads to further uncertainty within the steel production sector.

Austria has a long tradition of high quality steel production with an outstanding international role (under top 15 companies based on revenues). Companies have considered outsourcing their production to a large degree, but it has not happened so far. In order to understand why this has not yet happened, we will raise several questions during the stakeholder engagement process including:

- In the face of climate targets, why do Austrian Steel companies threaten to outsource their production to lower income countries, but still remain in the country?
- Which context factors or combinations thereof are important for companies to accept certain risks and uncertainties? Not only current but also perceived context factors? (Here, risks and uncertainties are defined following the conceptual framework of WP 5.1 mainly as exogenous risks, functioning as a barrier of successful implementation of policies, e.g. economic risks, technological risks, social risks, regulatory risks?)

In the pre-interviews that have been conducted so far (see section 1.5), companies stated that they are well aware of long-range consequences of their current decisions and that they recognise the need to act now if climate targets are accepted. Still, there is a trade-off between competitiveness and low carbon technology. There might be a first mover advantage that leads to increased competitiveness in the long term but there are risks and uncertainties concerning the policy framework as well as the industrial and policy institutions.

1.2.2 Natural resources and environmental priorities

Energy resources and use

Austrian primary energy production was stagnate during the period from 1970 to 1995 but this intermediary period was followed by a strong increase until 2014, primarily due to production increases in other renewables like biofuels or fuelwood (Figure 1; data base of Statistics Austria, 2016a). At the same time primary production of fossil fuels clearly declined. Overall, Austria produced about 366.21 petajoule of primary energy in 1970 of which 66.27% was made up of fossil fuels. In 2014, despite the massive drop in the share of fossil fuels to about 16.42%, primary production increased to 512.84 petajoule. However, dependence on imports of energy expressed as quotient of net imports to gross domestic consumption remains high. With about 1,180 petajoule imported and about 269 petajoule exported, the share of domestic consumption was 65.94% in 2014 (range of 61.53-72.87% with median 68.49% in period 1970-2014). This perspective necessitates to complement the perspective with a consumption based inquiry.

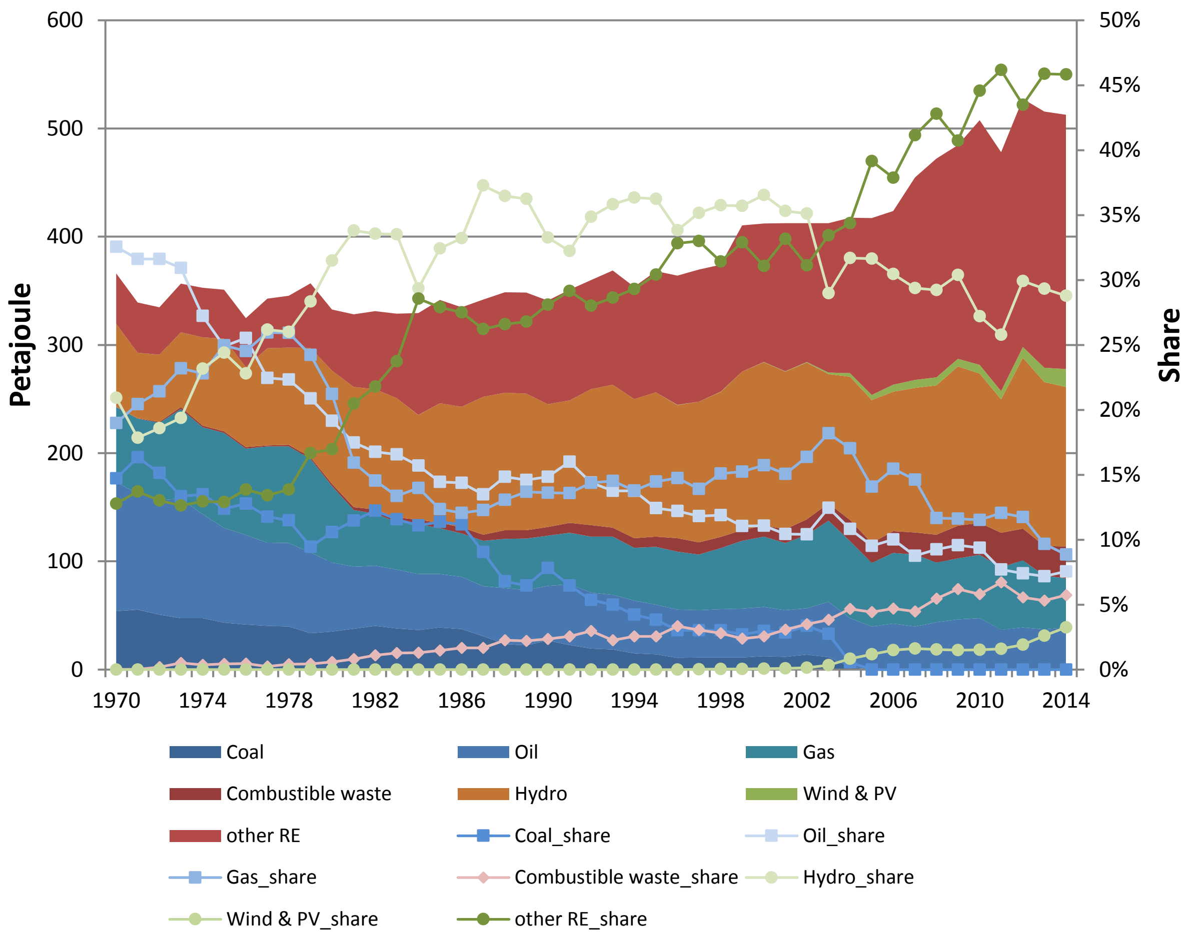

Figure 1: Primary production of energy in petajoule (left) and as share (right) by energy sources for Austria in period 1970-2014; own calculation and representation.

Source: Statistik Austria (2016a).

The most salient historical development in gross domestic consumption of energy in Austria is the declining share of coal and oil which is compensated by an increase of the share of gas and, especially, 'other renewables' (Figure 2; data base of Statistics Austria, 2016a; see also Haas et al., 2014). In fact, total fossil fuel consumption rose from 692.46 petajoule in 1970 (86.9%) to a long term high of 1,119.89 petajoule in 2005 (77.4%) and then declined to 901.42 petajoule in 2014 (68.3%). Moreover, since 2005, gross domestic energy consumption has been relatively stagnant. From a sectoral perspective Transport (34.5%) and Production (29.7%) together made up more than half of the Austrian energy-end use, followed by Private households (22.3%), Public and Private Services (11.4%) and Agriculture (2.1%) in 2014. Furthermore, Austria changed its status from a net exporting country of electricity to a net importing one due to higher electricity demand. Increasing electricity demand is also reflected by the fact that gross domestic consumption of energy increasingly comprises electricity from hydropower, wind and photovoltaics in absolute terms – the respective relative shares are rather trendless.

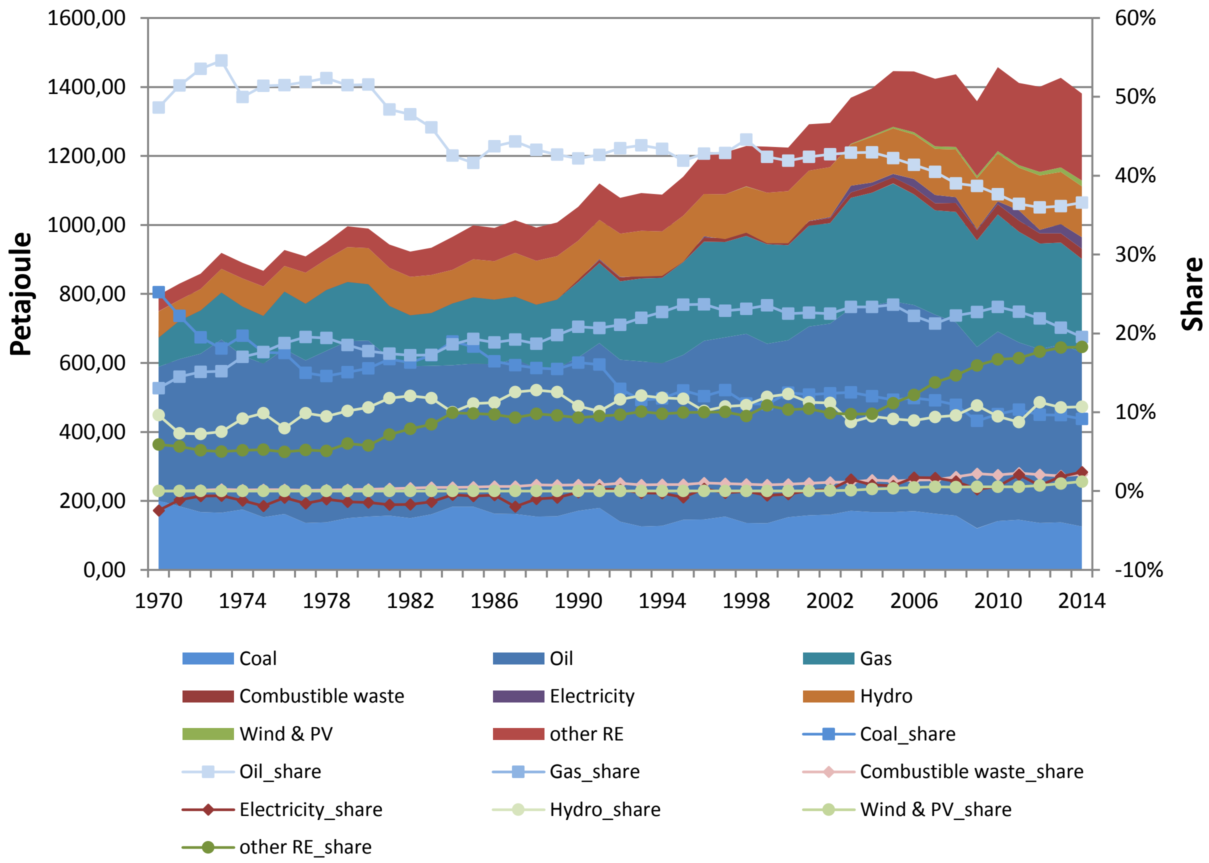

Figure 2: Gross domestic consumption of energy in petajoule (left) and as share (right) by energy sources for Austria in period 1970-2014 which equals the sum of primary production, stocks, recycling and net imports; own calculation and representation.

Source: Statistics Austria (2016).

From an electricity market perspective, hydropower clearly dominates the composition (Figure 3; data base of Statistics Austria, 2016a). Also electricity generated from biogenic fuels and, to a greater extent, from gas experienced noteworthy growth rates. All-in-all, gross electricity generation in Austria increased from about 29,500 GWh in 1970 to a peak of 68,700 GWh in 2009, before declining to 61,600 GWh in 2014. In 2014 about two thirds of gross electricity generation is attributable to hydropower whereas fossil fuels comprise about 18%. The remaining share is made up of wind (6.2%), photovoltaics (1.3%) and geothermal (<1‰), biogenic fuels (7.4%) and combustible wastes from industry and private households (1.2%).

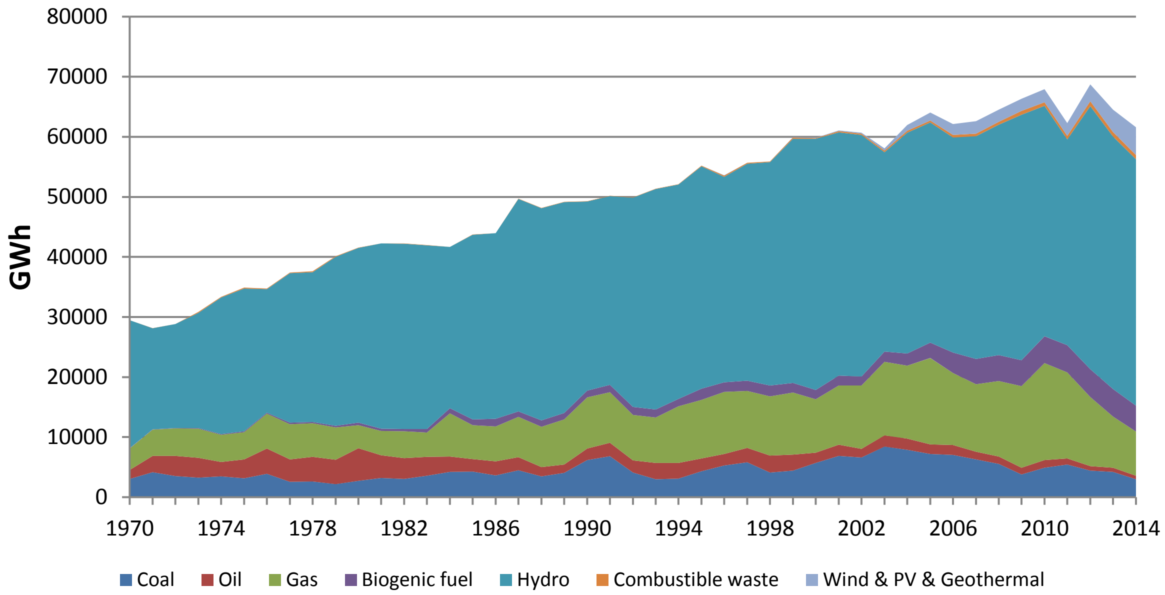

Figure 3: Gross electricity generation for Austria in period 1970-2014 by energy sources; own calculation and representation.

Source: Statistics Austria (2016a).

Excepting the sharp decline in final consumption of energy during the 1980s, due to a global overcapacities crisis in leading steel producing countries, total energy consumption in the sector has remained relatively constant since 1970, with 39.11 petajoule compared to 36.28 petajoule in 2014 (Figure 4). However, the production process of iron and steel making is crucially affected by reorganisation with regards to different techniques, inputs and side products, particularly due to economic rationales (Haas et al., 2014). Coal and oil is largely substituted by electricity and gas from third parties, but also by gas derived from internal process and combustion emissions which is used then in company owned facilities for heat and electricity reconversion. The remaining usage of coal relates to its essential character in processing iron to steel (reduction of iron ore). It can be seen from Figure 4 that potential mitigation of GHG emissions in the aftermath of the steel crisis could not relate to sustained cutbacks in energy usage. If anything, GHG emission abatement efforts are reflected by the switch to less GHG intensive energy carriers.

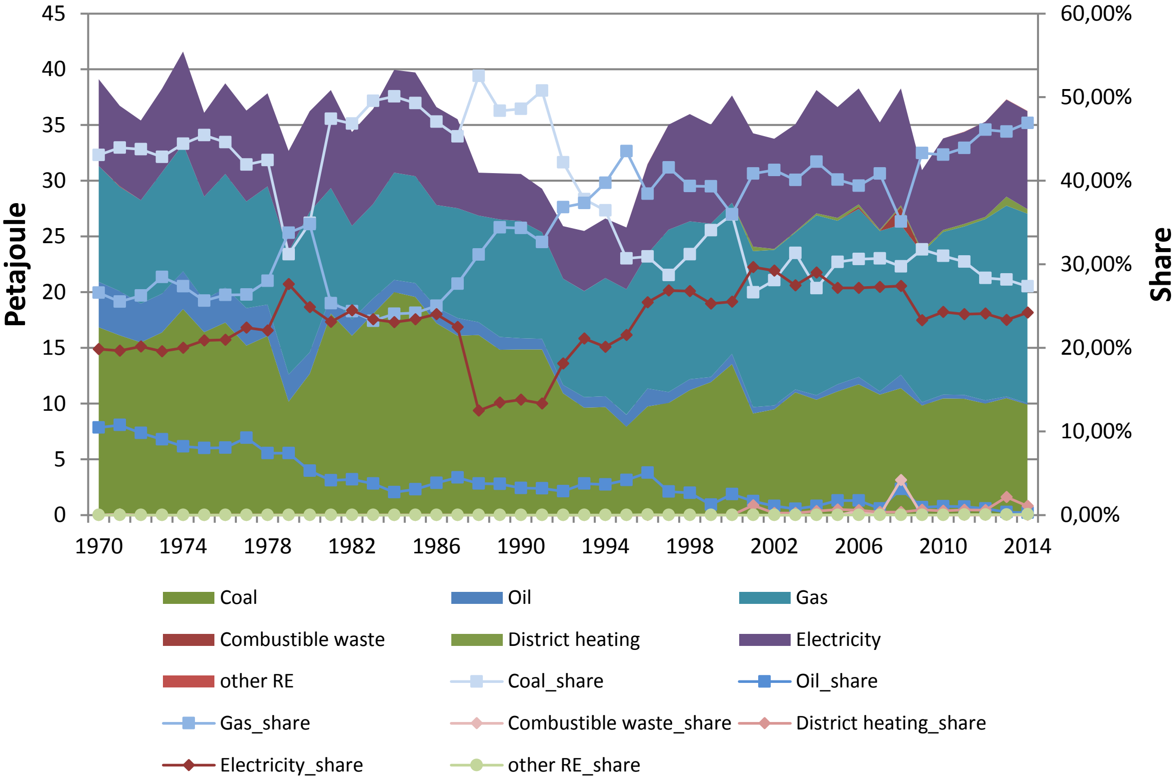

Figure 4: Final consumption of energy by the Austrian iron and steel sector in petajoule (left) and as relative shares (right); own calculation and representation.

Source. Statistics Austria (2016a).

The reduction in overall consumption, and the switch to less GHG intensive energy carriers, reflect two of the three options of how to physically mitigate GHG emissions (Haas et al., 2014). The potential to reduce GHGs lies in two areas: to increase technological efficiency in the iron and steel sector in terms of output per unit of energy used; or, vice versa, decreasing the energy intensity per unit of derived services. Historical data from the World Steel Association (2016) clearly indicate that total output of pig iron and crude steel in Austria increased from about 2.9 mio. metric tonnes in 1970 to 6.0 mio. metric tonnes in 2014 for the former and from about 4.1 mio. metric tonnes to 7.9 mio. metric tonnes, respectively, for the latter (Figure 5). These facts, in combination with the final energy consumption time series presented in Figure 4, show the Austrian iron and steel sector improved its efficiency, represented as output per unit of energy used.

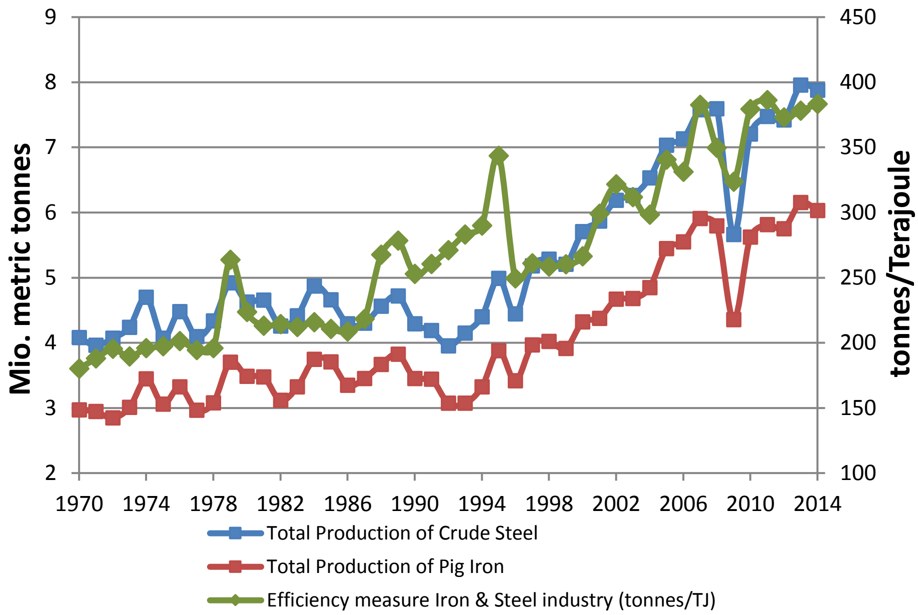

Figure 5: Total output (in mio. metric tonnes - left) and efficiency measure (tonnes/Terajoule - right) of the Austrian iron and steel sector; own calculation and representation.

Source: World Steel Association (2016), Statistics Austria (2016a).

However, the most crucial aspect with respect to GHG mitigation is not efficiency measured alone, but also the distributrion among energy carriers as argued previously. A classical rebound effect took place in the sector: efficiency improved but GHG emissions did not fall, instead stagnating at a high level due to increasing output. With this in mind it is traceable why the Austrian iron and steel sector continues to remain GHG intensive and a major contributor to the national GHG inventory - 13.4% of total national GHG emissions in 2010, according to Anderl et al. (2012). By using updated data from EEA (2016), the development of the Austrian GHG emissions looks as follows.

Without accounting for indirect GHG emissions which arise from foreign exchange (see, for example, Muñoz and Steininger, 2010) and refraining from carbon sinks related to land use, land use change and forestry (LULUCF), total Austrian GHG emissions totaled 76.33 Mio. tonnes CO_2-equivalents in 2014 (Figure 6; data base of EEA, 2016). This correponds to a range of 8.97-10.26 tonnes per capita emissions (median 11.36 tonnes p.c.) in period 1990-2014. The displayed sectoral distribution verifies that the largest shares in 2014 are to GHG emissions from the Energy industry (12,7%) and industrial and manufacturing activities (34.9%). However, the most salient development is the rise in transport related GHG emissions with a share of 17.7% in 1990 rising to 29.0% in 2014. Additionally, Figure 6 reveals that in aggregate terms LULUCF measures compensated for about 28.45 Mio. tonnes CO_2-equivalent in the period of 1990-2014, which represents a remarkable share of 13.7%. This is represented by the area between total GHG emissions without LULUCF measures and the blue line depicting total emissions with LULUCF measures in Figure 6.

Breaking down aggregate GHG emissions to the context of the Austrian Case Study, Figure 4 already demonstrated the almost stable final energy consumption by the iron and steel sector in the past decades, with recent rearrangment of energy carriers as inputs to energy conversion and to processing of materials. This rearrangment is particularly depicted by the steadily relative rise of GHG emissions related to processes (Figure 7), mainly due to the already mentioned essential character of the conversion of coal to coke (reduction of iron ore), reaching 85.5% in 2014. Although the Austrian iron and steel sector improved in terms of GHG intensitiy (expressed as ratio output/emissions in Figure 7), the previously mentioned rearrangment was not sufficient to drive total GHG emissions down. The sectors share of total GHG emissions in Austria (without LULUCF and without indirect CO_2) increased from 11.0% in 1990 to 15.6% in 2014 (with median of 11.6% in the corresponding period).

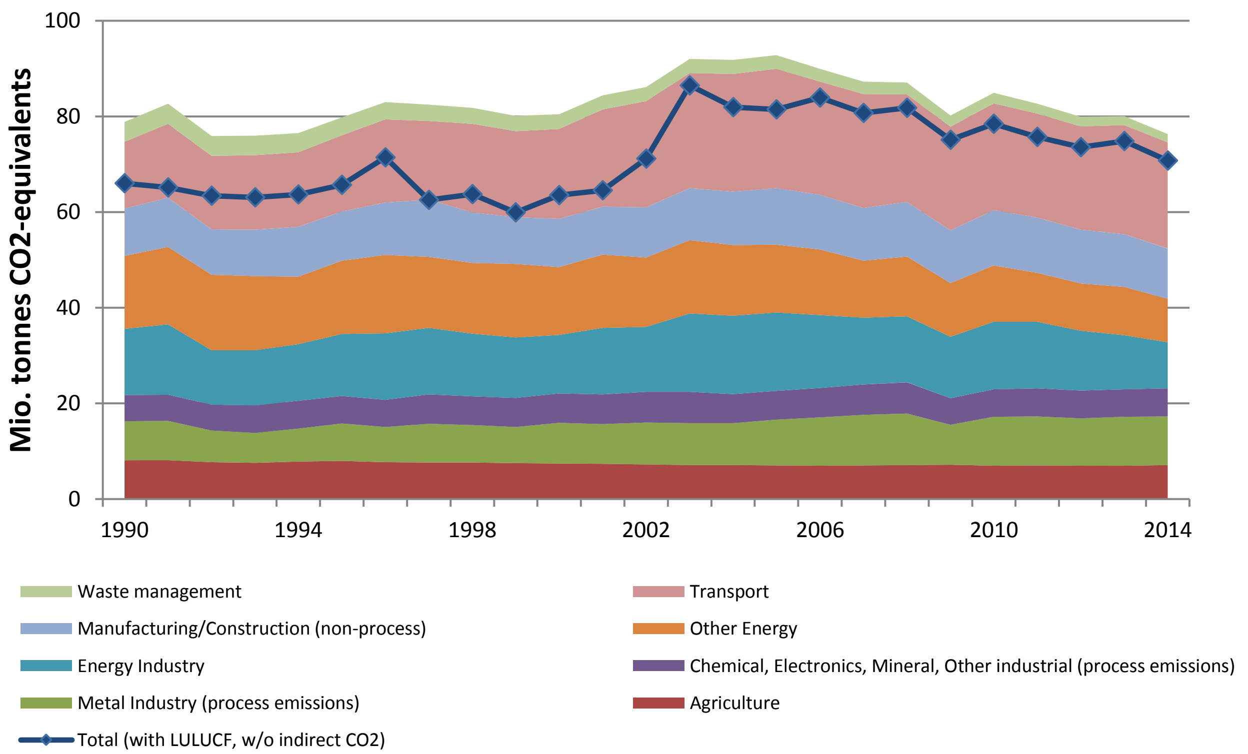

Figure 6: Austrian economy-wide GHG emissions in Mio. tonnes CO_2-equivalents; own calculation and representation.

Source: EEA (2016).

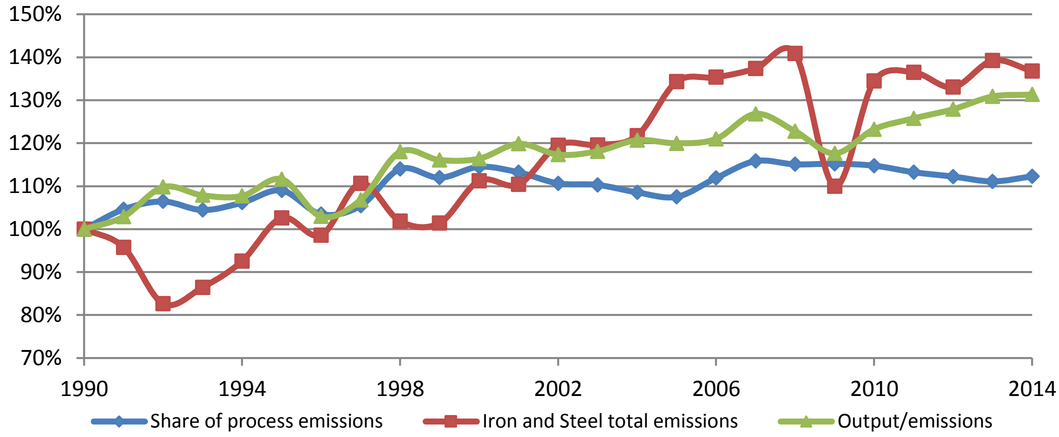

Figure 7: CO_2-equivalent emissions in the Austrian Iron and Steel sector; indexed in 1990 showing the development of total GHG emissions, the ratio of process related GHG emissions and output (iron-steel-aggregate) per GHG emissions; own calculation and representation.

Source: EEA (2016); World Steel Association (2016).

Other environmentally related issues

The most frequent natural hazards in Austria include floods, avalanches, storms, snow pressure and hail. Earthquakes are a rare occurrence (Sinabell & Url, 2008). Natural hazards affect the transport and energy infrastructure and therefore basically have indirect effects on the energy and steel and iron sector, as transport of goods and energy transfer is interrupted. Water scarcity is not usually a serious concern in Austria and is only an issue during hot and dry summers where there may be locally a scarcity of water, especially in the Southern regions. In climate change models the Alps are considered as a dividing range between the north with increasing precipitation and decreasing in the South, leading to decreasing low flows until 2050 (APCC, 2014).

1.2.3 Economic priorities

According to the Austrian Economic Report 2016 of the Federal Ministry of Science, Research and Economy (BMWFW, 2016), current economic policy discussion is predominantly about strengthening the current modest economic growth, re-establishing the lost top position in terms of low unemployment rates and further driving bureaucracy in all areas down (start-ups, SMEs, export-oriented industry). In spite of a record-breaking number of 55,000 exporting companies (supported by the ‘go international’ initiative), as well as a doubling of the R&D investment per GDP ratio in the last two decades (amounting to 3% in 2016), Austrian growth rates (Figure 8) have been far from other EU member or Eurozone states in the last two years.

The global political debate about the causes of the post-crisis economic stagnation is also highly controversial in Austria (since 2007 the Government in Austria is headed by the social democrats with Christian democrats being junior partner). A common agreement is that private consumption and investments are insufficiently low despite record-breaking low interest rates. It is acknowledged that some countercyclical public investments are needed to back domestic demand. Examples are the equity initiative of the public promotional agency Austria Wirtschaftsservice, or the €1 billion broadband initiative (BMWFW, 2016). But due to restrictive EU fiscal rules and fear of ‘crowding out’ effects, there seems to be little scope left for significant and sufficient expansion in the short term.

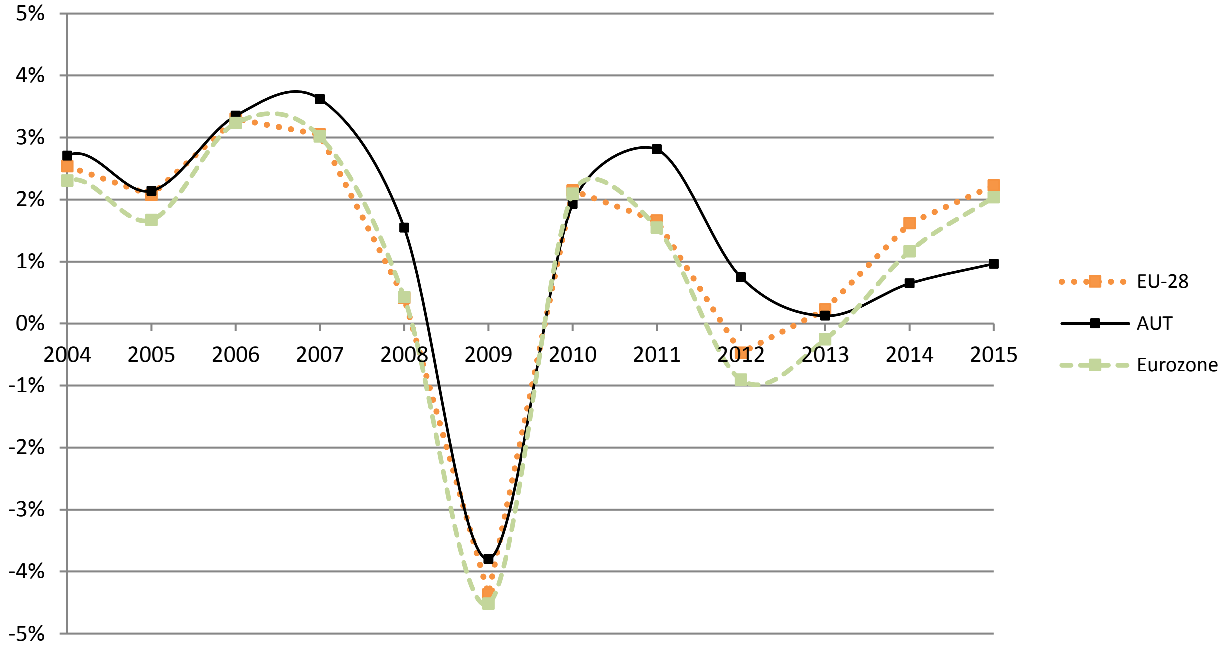

Figure 8: Reported economic growth rates per anno for Austria, EU-28 and the Eurozone (EUROSTAT, 2016c); own calculation and representation.

However, the ambitious temperature target of the recently ratified Paris Agreement necessitates a joint public and private course of action. Up until now there is little clarity on which economic opportunities, risks and uncertainties, as well as the needed support frameworks accompany sector specific effort sharing pathways. This is why the Austrian case study focuses, as previously mentioned, on two sectors with significant contribution to GHG emissions (cf. Figure 6-Figure 7) and to economic development. The iron and steel sector (Ö-NACE C24 - production and processing, and Ö-NACE C25 - manufacturing of metal products) accounted for 2.66% of gross value added to GDP in 2014, and the energy supply sector for 1.57% (Ö-NACE D35). Together this two focus sectors employed 5.35% of total employees in 2014 (Statistics Austria, 2016b,c).

This first insight hides to a certain degree the interdependencies of the Austrian economic sectors with the two focus sectors. Hence developments in the latter potentially contribute to the economic development in other domestic areas. For instance, developments in the energy supply sector affect the energy-intensive production of iron and steel, which will have impacts on a variety of domestic down-side applications (automotive industry, buildings, roads and railway, etc.), and their respective usage of primary and intermediate inputs as well as capital and labour inputs. According to the International Labour Organization (ILO, 1997, p. 30), *“in the long run people will make the difference between success and failure”* in the twenty-first century iron and steel industry. This emphasises the significance of education and training and necessitates integration in the quantitative model of the Austrian Case Study.

1.2.4 Societal priorities perspective on climate change

Demographic change in Austria followed similar routes of other industrialised countries exhibiting slow population growth (from slightly above 7 million inhabitants in 1960 to 8.5 inhabitants in 2015) and ongoing societal ageing (Figure 9). 12 out of 100 people were older than 64 years in 1960, compared to 18 in 2016. As the middle-aged group (representing 15 to 64-year-old people) almost sustained its share of about two thirds, this development is at the expense of the youngest age group – 20 out of 100 people in 1960 were below 15 years, compared to 14 out of 100 in 2015 (EUROSTAT, 2016a). Also within this middle-aged group, EUROSTAT (2016a) data reveal a slightly left skewed distribution. Hence, also in this group a small but non-negligible ageing development took place.

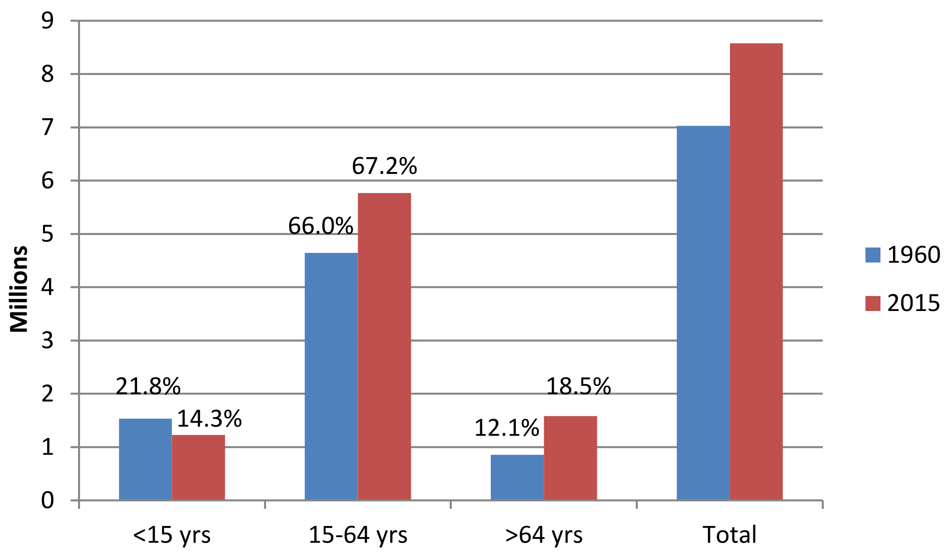

Figure 9: Austrian population by age group for 1960 and 2015.

Source: EUROSTAT (2016a).

This ageing trend poses distinct health issues resulting from climate warming. There is significant evidence from heat wave impact studies like D'Ippoliti et al. (2010, p. 8) which suggest that *"prevention programs should specifically target the elderly, women and those suffering from chronic respiratory disorders"*. The *Austrian Strategy for Adaptation to Climate Change* report (BMLFUW, 2013, p. 46) extends and summarises this list of vulnerable population groups:

- The poor and those at risk of poverty.
- Chronically ill people, people in poor health condition (especially during heat waves or outbreaks of vector-borne diseases).
- Children.
- The elderly.
- People living in areas at risk of natural hazards.

- People living in areas increasingly subject to heat waves.
- People who are occupationally exposed to extreme weather conditions.
- People whose income may be at least temporarily threatened by the effects of climate change.

Recall the previous section where it was argued that education and training is a key area for economic development (not only in the iron and steel sector). In this regard, EUROSTAT (2016d) data on the development of the Austrian working age population (15-64 years) differentiated by educational attainment reveals the following. About 13% of the working age population had less than primary, primary and lower secondary education (levels 0-2) in 2015 (EU-28 17.8%). Upper secondary and post-secondary non-tertiary education (levels 3-4) are attributable to about 54% of the Austrian, compared to 48.5% to the EU-28 working age population. Tertiary education (levels 5-8) in Austria is similar to EU-28 levels with a share of about one third.

The share of people attaining tertiary education increased in recent time, accompanying other macroscopic developments like general rising productivity requirements or digitisation of production and services. Moreover, the productivity challenge raises distributional questions. Currently, the average household net-adjusted disposable income per capita in Austria is 9% above OECD average. By contrast the top 20% income group in Austria earned about four times as much as the bottom 20% income group (OECD, 2016a). However, since Austria joined the European Union income inequality remained almost constant (GINI coefficient 0.27 in 1995 and 2015 according to EUROSTAT, 2016b).

Recent trends also point to the fact that the ratio of total population to the total working age population is widening. This development has resulted in an increasing inter-generational controversy between these two groups because pressure on public retirement remunerations has accumulated. Considering that only about 75% of the working age population participate in the labour market (OECD, 2016b), and noticing high post-crisis unemployment rates (5.7% in 2015 (international definition) according to Statistics Austria, 2016d), an intra-generational conflict area has to be taken into account. With regards to these issues, the future course of political debate remains vague.

1.2.5 Politics of energy development priorities

The IEA 2014 Review (IEA, 2014) states that there is a need for Austria to formulate an evidence-based position on how to reach climate mitigation targets that are in line with the EU 2030 Energy and Climate Package rebalancing the objectives of “competitiveness” with “sustainability” and “security of supply”.

A first attempt has been made by the Austrian Energy Strategy in 2010, that integrated security of supply, energy efficiency and renewable energy sources as the three pillars of Austrian energy policy. The Austrian Energy Policy aims to promote economic growth, environmental protection and security of energy supply in a balanced manner. Therefore, dependence of energy imports has to be reduced by increasing supply especially by bioenergy. Austria still sticks to its anti-nuclear policy.

While the energy supply sector, as well as the steel and iron sector, are regulated by the ETS, energy demanding sectors like the buildings and transport sector are regulated mainly by the provinces. Therefore, the Climate Change Act launched in 2011 focuses on collaboration between provincial and the national level (see section 1.3.3 for more details on government institutions). However, a burden sharing agreement for the provinces is still missing, leading to a stagnation of emission reduction efforts in Austria.

Furthermore, close cross-ministry coordination is seen as crucial for developing an effective climate policy in Austria (IEA, 2014).

1.2.6 Conflicts and synergies of priorities

Asking stakeholders about the current state of transition towards reaching the 2-degree target revealed many conflicts and obstacles. In Austria the federalism and differing interests between the provinces and the capital are perceived as further obstacles to a concise climate and energy strategy. Exploring risks and uncertainties, as well as learning about sector specific obstacles and how they could be overcome, will be a main target for the Austrian stakeholder process.

1.3 The Human Innovation System Narrative

1.3.1 Overview of the development of the case study focus

The focus sectors of the Austrian Case study are the iron and steel sector. As all sectoral energy efficiency and energy reduction measures have impacts on the overall energy supply the energy supply sector is the second focus sector in our case study.

Steel is an alloy with an iron (Fe) content of more than 95%$_m$ (mass-percentage). Besides iron (Fe) the most essential alloy element is carbon (C). If the carbon content is below 2.06%$_m$ (Figure 10) the product is considered to be steel and the carbon is presented as iron carbide (Fe_3C). If the carbon content is above this threshold, the product is called cast iron. In this case part of the carbon is present in the form of graphite. Depending on the desired specific properties of the final product, additional elements such as chromium, nickel, molybdenum, vanadium, silicon, manganese, titanium and many others are added. Besides these elements that can improve the properties of steel in some way, there are also a few elements which have adverse effects on a wide range of different characteristics of steel and are therefore in general undesired. Among others, hydrogen, oxygen and nitrogen belong to this group as they reduce the ductility of steel.

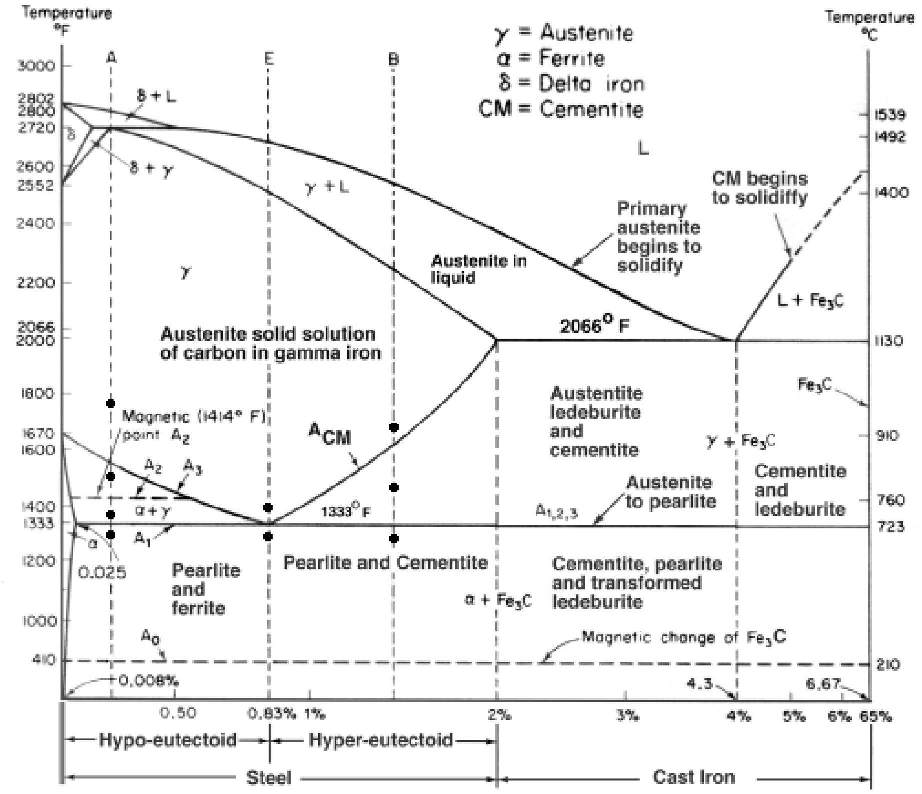

Figure 10. The iron-iron carbide phase diagram.

Source: Pollack (1988).

The production process is considered as a primary route if the iron used for steel is extracted from iron ore. The iron itself is usually found in the form of magnetite (Fe_3O4), hematite (Fe_2O_3) or siderite ($FeCO_3$). In order to get a generally useful metal, the iron needs to be reduced (removal of oxygen) and carbon needs to be added. A simple and most commonly approach to do this is by using a very pure and carbon rich coal (coke) to which oxygen has a higher affinity than to iron. The reduction of iron ore is usually done in a blast furnace and comprises the step, in which carbon is introduced to the system for the first time (except for siderite iron ore) and from which subsequently carbon dioxide emission arise from.

In order to reduce the CO_2 emissions stemming from the production of steel, alternative processes have been developed over decades, using energy carriers with lower carbon content such as natural gas (COREX process) or hydrogen and carbon monoxide. For economic, as well as technological reasons, these processes are not as widely applied as the basic blast furnace process.

The product of this first step of the primary route is called pig iron (MPI) if the process operates above the melting point (blast furnace process). If the iron ore is reduced directly at temperatures below the melting point of iron, the product is called sponge iron (hot briquetted iron (HBI) or direct reduced iron (DRI)). Pig iron and sponge iron are an intermediate product towards steel. Besides unwanted impurities, the carbon content of pig iron coming from blast furnaces is too high and needs to be reduced in subsequent steps.

In a second step — the steel cooking — the pig and sponge iron is purified from unwanted elements and components, the carbon content is reduced and alloy components are added. To keep the temperature below certain levels, this primary route requires some share of recycled (secondary route) steel (about 20%).

The worldwide commonly used routes at an industrial level are the basic oxygen furnace (BOF), also known as the Linz-Donawitz process, developed by the Austrian iron and steel industry and applied at an industrial level for the first time in the 1950s. A second important process to transform pig or sponge iron into steel is the electric arc furnace (EAF). The direct carbon emissions from this process stem from the reduction of iron ore in the previous step and the resulting high carbon content of the pig iron. Indirect emissions (can) occur from the energy consumption (production of electricity and/or pure oxygen).

In contrast to the primary route, which produces native steel from iron ore, secondary routes use recycled steel scrap. In this route steel scrap is melted and steel is cooked using an electric arc furnace (Wyns and Axelson, 2016).

The European and international steel industry is currently struggling to cope with low steel prices due to overcapacities. Future deep reductions in GHG emissions will yet not be easy and are not feasible with efficiency improvements along the traditional BF-BOF route (Wyns & Axelson, 2016).

In the EU-27 29% of steel is produced by the EAF route and the rest with traditional routes, however in Austria it is only 9.3% (worldsteel, 2009). This relates directly to historical development and subsequently applied BOF route in Austria. In Austria, currently there are three sites for EAF route (Mürzzuschlag, Kapfenberg) and 2 major sites for integrated (traditional) routes (Linz and Donawitz). Most Austrian companies work within the steel refining sector and produce high tech products. The biggest company is Voestalpine AG with annual revenues of 11 billion of euros (rank 9 worldwide) and about 50,000 global employees in 2015. A switch from the traditional blast furnace process towards a direct reduced iron production could significantly reduce the associated emissions. This is especially true if electricity from renewable energy carriers is used to produce hydrogen as the reduction agent. This implies that electricity generation from renewables has to be increased substantially if the current steel output in Austria is maintained, which raises the question of domestic renewable energy potential.

1.3.2 TIS life cycle value chain: a cradle to grave analysis

The value chain of steel production is given in a simplified version in Figure 11. The life cycle begins with the extraction and preparation of the raw material. This comprises of iron ore mining and the cokemaking process (concentrating the carbon from coal). Other raw materials that can be used are natural gas or oil with its corresponding life cycle of processing. For all processes, energy is needed for transport, machinery or heat production. Coke, gas, oil or hydrogen are needed for reducing the iron ore in a blast furnace (BF) where ore is smelted to remove the oxygen from the iron oxides that form iron ore or via direct reduction (DRI) where iron is reduced in solid state. Depending on the ironmaking process, iron is further converted to steel either in a basic oxygen furnace (BOF) or an electric arc furnace (EAF) using pig-iron and scrap. An alternative secondary route involves using scarp only to be reused and converted into steel in an electric arc furnace.

Differing routes involve different energy use. For instance, producing 1 tonne of steel by the blast furnace route demands 16.5 GJ of energy while the EAF route only requires 4.3 GJ/t (Worrell et al., 2008). Crude steel is then cast or manufactured in sheets or bars etc. for further processing by forging, extrusion or forming. Steel components are used for manufacturing, construction and engineering for a variety of different products, e.g. for buildings, rails, the automotive industries.

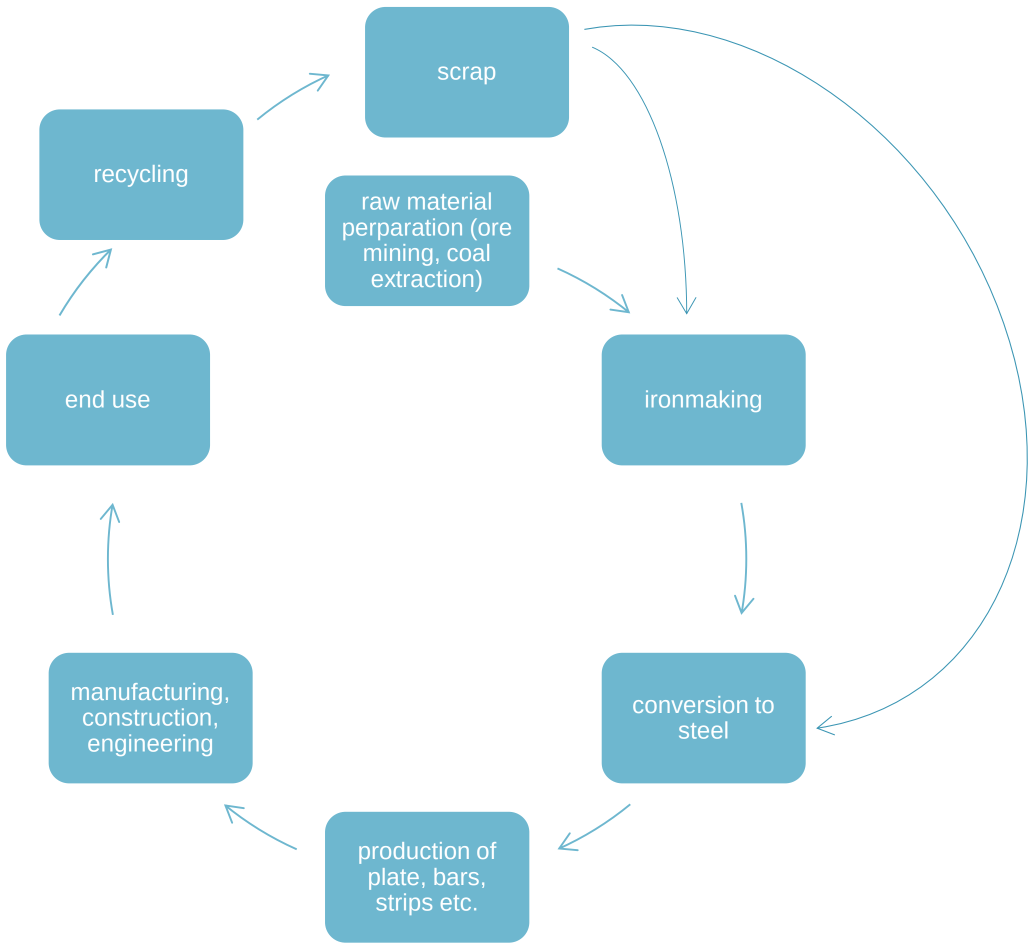

Figure 11: Life cycle value chain for the steel production

1.3.3 Enabling environment: policy mixes in the socio-economic system

Important enabling or limiting environments are created by present policies and policy mixes. They target different stakeholders and may incentivise their behaviour. Relevant Austrian policy instruments mainly result from the transposition of EU directives. Table 1 lists important EU and national policies and policy instruments that are relevant for the Austrian energy and steel sectors. The table is structured alongside EU environmental priorities. Most major EU environmental directives are relevant for the two chosen sectors. Some of them stimulate the expansion of renewables, other inhibit these, such as nature conservation directives. Limitations to the expansion of renewables in Austria will impact the low carbon transitions in other sectors, such as steel, that may need much more electricity.

Table 1: EU Environmental priorities and corresponding EU and national policies in the Austrian Steel and Iron as well as the Energy Sector

EU environmental priorities	Austrian National Policies	EU Directive Reference
1. "Preventing climate change"	P1: Austrian Energy Strategy and Climate Protection Law 2011 P2: Green Electricity Act (2002/2011) to foster renewable electricity generation P3: Co-generation law (2008), to promote the usage of waste heat for public district heating networks P4: Biofuel enactment (2009) P5: Petroleum tax	- Renewable Energy Directive 2009/28/EC (RED) - Energy Union Package COM(2014) 80 final - Clean Vehicles Directive 2009/33/EC (CVD) - EU Emissions Trading System
2. "Maintain and restore biodiversity"	P6: Nature conservation acts by provinces	- Birds Directive (Directive 2009/147/EC) - Habitat Directive (Council Directive 92/43/EEC) -Water framework Directive
3. "Substantially reduce natural resource use"	P1: Austrian Energy Strategy and Climate Protection Law 2011 P2: Green Electricity Act (2002/2011) to foster renewable electricity generation	- Energy Taxation Directive (ETD) - Landfill Waste Directive
4. "Make the EU a healthy place to live"	P7: Enactment of limits and treatment of pollutants for steel and iron industry (2016)	- Air Quality Directive

For Austria, a Climate Strategy exists with only indicative reduction targets (BMLFUW, 2002, 2007). The main aim of the Climate Strategy is the coordination of climate strategies across sectors and across provinces, but there has been no success so far.

After unsuccessful years (Austria achieved the Kyoto-target only with credit purchases from abroad) the Climate Strategy was presented to the Austrian Parliament and a Climate Change Act was passed in 2011. This concentrates on energy and emission reduction for the Non-ETS sectors (e.g. buildings, transport, etc.) (BGBl I 106/2011). As issues within the non-ETS sectors are regulated mainly by the provinces, the Climate Change Act focuses on collaboration between provincial and the national level (see section 1.3.3 for more details on government institutions). However, a burden sharing agreement for the provinces is still missing leading to a stagnation of emission reduction efforts.

Other highly relevant legislation is the Eco-Energy Law (BGBl I 2011/75) which aims at increasing the share of renewables (PV, wind, small water power plants), the Cogeneration Law (BGBl I 2008/111) that regulates the funding of cogeneration for public district heating and a law that prohibits Carbon Capture and Storage (CCS) and the use of nuclear energy.

Table 2: Austrian policy instruments that directly or indirectly impact the Steel and Iron and the Energy Sector

Policy themes	Austrian National Policy Instruments			
Energy **Climate** **Agriculture**	Austrian Energy Strategy and Climate Protection Law 2011	Green Electricity Act (2002/2011) to foster renewable electricity generation	Co-generation law (2008), to promote the usage of waste heat for public district heating networks	Biofuel enactment (2009), petroleum tax
Air	Enactment of limits and treatment of pollutants for steel and iron industry (2016)			
Waste/ resource use	Waste Management Act (2002/2011)			
Water	National Water Act (2003)	River basin Management Act (2010)		
Biodiversity	Nature conservation acts by provinces			

1.3.4 Enabling environment: government institutions

The major institutions relevant for the energy and industry sector in Austria are given in Figure 12. Austria is a parliamentary representative democracy comprising nine federal states. The Austrian parliament the Nationalrat is responsible for the formation of legislation and thus relevant for laws related to the energy and industry sector. Austria is a federal state and federalism plays an important role for decisions on energy issues. Many issues like nature conservation, spatial planning or transport are regulated on a provincial level. The distribution of nationally collected taxes and charges between the national and provincial level as well as on a municipality level, has to be negotiated. This leads to contracts between the national levels and levels below determining the duties and the budget for a period of time. Many provinces have regional climate strategies or energy strategies which are not coordinated on a national level and, although ratified by regional parliaments, contains only indicative targets.

The Government is the supreme administrative authority implementing relevant laws. In Austria unions and associations play a crucial role for cooperation and the coordination of interests of industries, employees etc. which is called the “social partnership”. Their targets are long term social and economic political goals that may or may not be in line with energy and climate targets. They work in close contact with political parties.

For the steel & iron and energy sectors in Austria the ETS of the European Union is highly relevant. Energy-Control Austria is a company responsible for the strengthening of competition and ensuring security of energy supply after the liberalisation of the markets for grid-bound energy.

Research in Austria is conducted in universities and semi-private research institutions. Projects on mitigation of climate change and innovation are promoted by the Climate and Energy Funds in Austria. ASMET is a think-tank for scientific, technical and business aspects of metallurgy and materials and corresponding routes.

Transition pathways for Austria that include an electrification of steel-making would mean a substantial increase in energy demand from renewables, thus raising the importance of civil organisations or NGOs like the society of Renewable Energy Austria, the Wind Association or Austria Solar, to just name some examples.

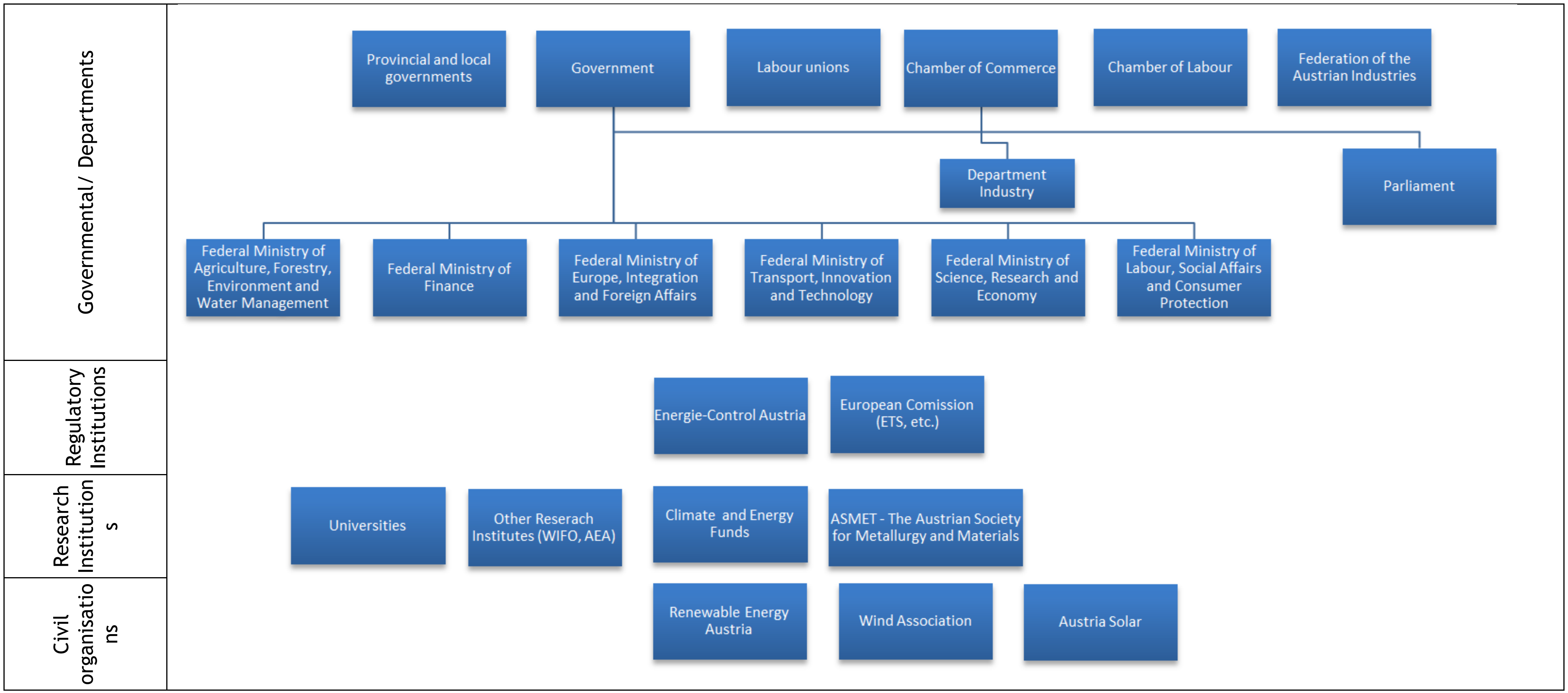

Figure 12: Major institutions in the energy and industry sector in Austria

1.4 The Innovation System

The system map for the Austrian Case Study is given in Figure 13 for the steel and iron sector. It is divided in 4 main boxes, i.e. the enabling environment (which can also be a limiting environment), the market chain, the policy options and the facilitating services and infrastructure. The market chain mainly represents the TIS life cycle value chain as it is given in section 1.3.2The rectangles represent several steps of the product chain, whereas important stakeholders are represented as ellipses. Stakeholders that play a crucial role are the steel producing companies, which are dependent on energy supply and on international markets as well as national and international policies. This influence is given by the arrow from the box 'enabling environment' entering into the box 'market chain'. Part of the enabling/limiting environment are several DGs of the European commission, as well as ministries and labour unions and chambers, the latter playing a crucial role in slowing down climate change efforts.

Important contextual factors influencing policies either, if they are promoted, in a positive way or, if they are absent, in a negative way, are institutional coordination, coherence of processes, transparency of policies as well as the international market framework. The future carbon price, and thus the steel price, is a highly significant influential factor for future decisions. Future decisions have to be made for different policy options. For the companies these could be via process innovation (e.g. electrification of steel), by product innovation (by improving the material properties of steel making it lighter or stronger) or by business model transition (e.g. leasing steel products instead of selling them would increase the usage of scrap). Cooperation between sectors and funding of research are seen as further facilitating transition within the steel and iron sector.

Table 3: System Map Matrix for the Austrian Steel and Iron Sector

GROUP [please insert the corresponding group of the concept underneath, in **Row 1**]	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	enabling/limiting environment	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Market Chain	Facilitating services and infrastructure	Facilitating services and infrastructure	Facilitating services and infrastructure	policy strategies	policy strategies	policy strategies
CONCEPT [please insert market map concepts in both **Row 2** & **Column B**]	**Federal Ministry of Science, Research and**	**Federal Ministry of Finance**	**Federal Ministry of Transport, Innovati**	**Federal Ministry of Agriculture, Forestry,**	**Labour unions, chambers of commerce and**	**DG Environment**	**DG Energy**	**International Market**	energy policies, trade policies, steel price	-institutional coordination -	raw material preparation (ore mining, coal	ironmaking	conversion to steel	production of plate, bars, strips etc	intermediate demand: manufacturing, constructi	final demand (end use)	recycling	scrap	energy supply	**voestalpine Stahl GmBH**	**other steel producing companies**	**energy sector (Verbund)**	**scrap traders**	**chemical industry**	cooperation between energy and steel sector	cooperation between steel and chemical industry	funding of research in new technology	process innovation	product innovation	business model transition
Federal Ministry of Science, Research and Economy									0																					
Federal Ministry of Finance									0																					
Federal Ministry of Transport, Innovation and Technology									0																					
Federal Ministry of Agriculture, Forestry, Environment and Water Management									0																					
Labour unions, chambers of commerce and labour									0																					
DG Environment									0																					
DG Energy									0																					
International Market									0																					
energy policies, trade policies, steel price															0	0												0	0	0
-institutional coordination -coherence of processes -transparency -international market framwork									3																					
raw material preparation (ore mining, coal extraction)												0																		
ironmaking													0																	
conversion to steel														0																
production of plate, bars, strips etc															0															
intermediate demand: manufacturing, construction, engineering (buildings, automobile, infrastructure)																0														
final demand (end use)																	0													
recycling																		0												
scrap												0																		
energy supply												0	0	0	0															
voestalpine Stahl GmBH												0							0											
other steel producing companies													0																	
energy sector (Verbund)												0							0	0										
scrap traders																	0	0												
chemical industry																				0										
cooperation between energy and steel sector																												0		
cooperation between steel and chemical industry																													0	
funding of research in new technology																												0	0	0
process innovation												0	0																	
product innovation														0	0															
business model transition																0	0	0												

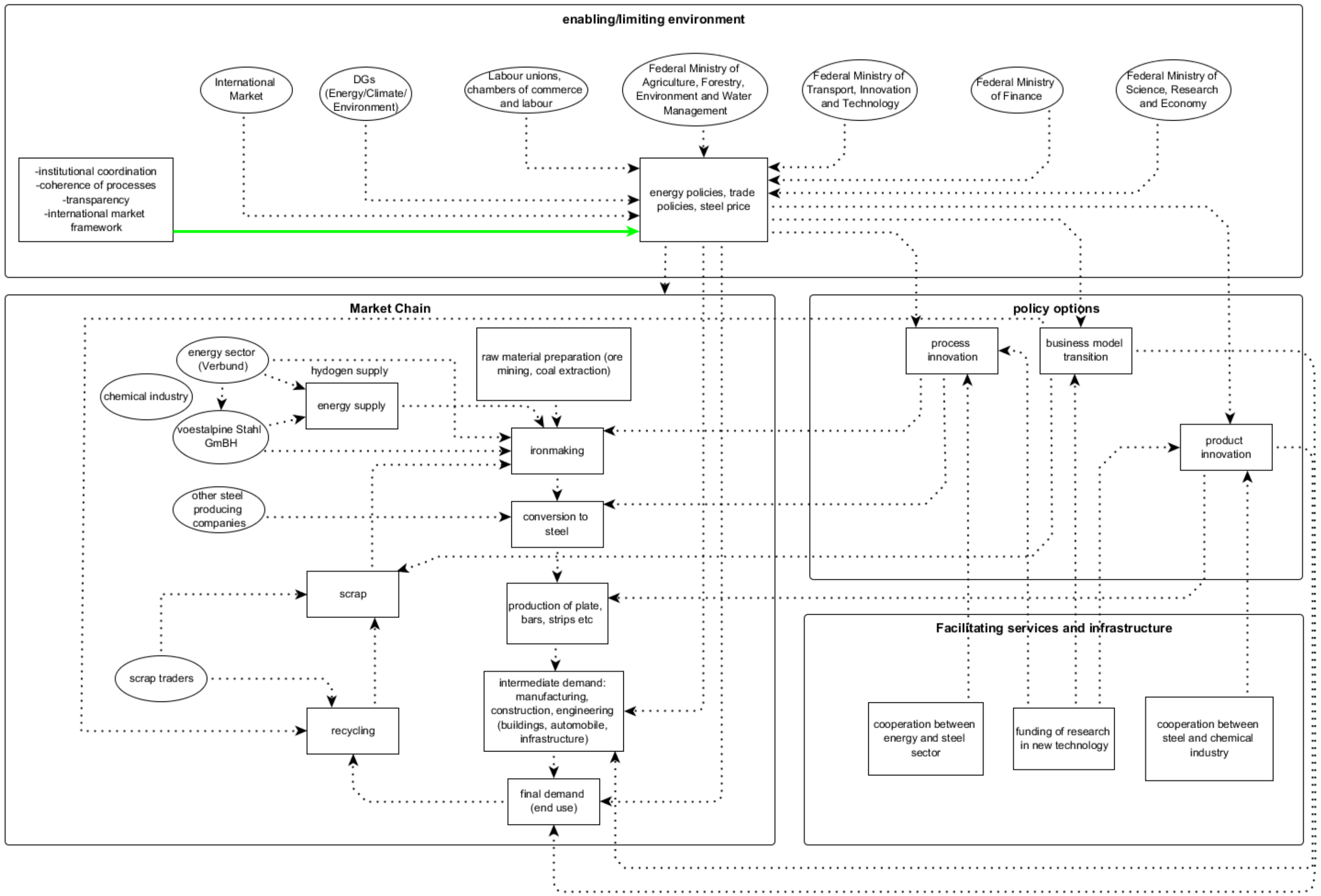

Figure 13: System Map for the Austrian Steel and Iron Sector

1.5 Stakeholder engagement

The Austrian stakeholder engagement process follows the logical order of the research questions asked, starting from the desired future (the vision) (RQ1) to possible transition pathways and their risks, uncertainties, costs and benefits (RQ2) to policy strategies for implementation and realization (RQ3) through to the needs of and consequences for policy makers (RQ4).

In the first step guided interviews have been conducted to understand the background context and to reveal first ideas of barriers, risks and uncertainties. At the first stage seven generalists have been interviewed personally (5) or via skype (2). They were asked about the case study context i.e. the steel and iron as well as the energy industry, but also to explain their ideas of a desired future, possible transition pathways and corresponding risks and uncertainties thereof as well as of policy strategies for implementation. These results were entered into the planning of the first TRANSrisk stakeholder workshop for Austria which took place on November 4th in Vienna. 22 Stakeholders participated in the workshop and worked on the current state of Austria regarding climate targets (reaching the 2-degree target), examined desired futures and developed transition pathways to reach them. Risks and uncertainties along the transition pathways were revealed. To ensure the stakeholders' interest and commitment and to get insights into specific contextual factors 12 pre-workshop interviews had been conducted via telephone before the workshop. The list of stakeholders that have been involved in the process so far is given in Table 4.

Table 4: Stakeholder Engagement

Type of stakeholder		Position in the organisation* (keep this generic so it doesn't risk stakeholder anonymity)	Economic sector**	Type of engagement***	Month and year contacted
1.	**Generalist**	Professor	Science, Economist, Economic Research	Interview, Workshop participation, CS Advisor	April 2016/November 2016
2.	**Generalist**	Regional parliament	Politics	Interview, Workshop participation, CS Advisor	May 2016/November 2016
3.	**Generalist**	Ministry of Environment	Administration	Workshop participation,	May 2016/November 2016

4.	**Generalist**	Smart City Consulting	Science	Interview, CS Advisor	May 2016/November 2016
5.	**Generalist**	Environmental Agency	Economist, Science, Administration	Interview, CS Advisor	May 2016/November 2016
6.	**Generalist**	Federal Ministry of Finance	Economist, Administration	Interview, Workshop participation, CS Advisor	June 2016/November 2016
7.	**Generalist**	Professor	Polymeric Materials	Interview, Workshop participation, CS Advisor	June 2016/November 2016
8.	**Generalist**	Federal Chamber of Labour	Administration	Interview, Workshop participation, CS Advisor	June 2016/November 2016
9.	**Petrochemical Industry**	Strategy	Industry	Interview, Workshop participation	October 2016/November 2016
10.	**Solar Energy, Battery Systems company**	Solar Energy	Industry	Interview, Workshop participation	October 2016/November 2016
11.	**Architect**	Managing Director	Buildings, Energy	Interview, Workshop participation	October 2016/November 2016
12.	**Austrian Society of Metallurgy and Materials**	Member	Industry, Association	Interview, Workshop participation	October 2016/November 2016
13.	**Steel producing company**	Environmental Management	Industry	Interview, Workshop participation	October 2016/November 2016
14.	**Cement industry Association**	Member	Industry	Interview, Workshop participation	October 2016/November 2016
15.	**Power Supply Company**		Energy	Interview, Workshop participation	October 2016/November 2016
16.	**Power Supply Company**	Corporate Development and Innovation		Interview, Workshop participation	October 2016/November 2016

17. Association of companies supplying solar energy technologies	Consulting	Energy	Interview, Workshop participation	October 2016/November 2016
18. Power Supply Company	Risk Management	Energy	Interview, Workshop participation	October 2016/November 2016
19. Wind Energy Association	Member	Energy	Workshop participation	November 2016
20. Energy Consulting, European Energy Cooperation	Consulting	Energy	Interview, Workshop participation	October 2016/November 2016
21. Power Supply Company	Corporate development	Energy	Interview, Workshop participation	October 2016/November 2016
22. Austrian Parliament	Environmental Committee	Politics	Interview, Workshop participation	October 2016/November 2016
23. Federal Ministry of Science, Research and Economy	CSR	Politics, Administration	Interview, Workshop participation	October 2016/November 2016
24. Association "Building your own power plant"	Member	Industry	Workshop participation	November 2016
25. University of Klagenfurt	Social transformation	Science	Workshop participation	November 2016
26. Technical University	Energy scenarios	Science	Workshop participation	November 2016
27. Government	Environment, Water and Nature protection	Administration, Politics	Workshop participation	November 2016

* Government (national / subnational), research / consultancy, business, other (specify)
** Energy, Industry, transport, environment, agriculture / forest, financial / trader, other (specify)
*** Interview, focus group, workshop, survey etc.

References and interviews

Anderl, M., Bednar, W., Fischer, D., Gössl, M., Heller, C., Jobstmann, H., Ibesich, N., Köther, T., Kuschel, V., Lampert, C., Neubauer, C., Pazdernik, K., Perl, D., Poupa, S., Purzner, M., Riegler, E., Schenk, C., Schieder, W., Schneider, J., Seuss, K., Sporer, M., Schodl, B., Stoiber, H., Storch, A., Weiss, P., Wiesenberger, H., Winter, R., Zechmeister, A., Zethner, G., 2012. Klimaschutzbericht 2012 (REP-0391). Umweltbundesamt, Wien.

APCC, 2014. Österreichischer Sachstandbericht Klimawandel 2014 (AAR14). Austrian Panel on Climate Change (APCC). Verlag der Österreichischen Akademie der Wissenschaften, Wien.

BGBl, 2011. 106. Bundesgesetz zur Einhaltung von Höchstmengen von Treibhausgasemissionen und zur Erarbeitung von wirksamen Maßnahmen zum Klimaschutz (Klimaschutzgesetz – KSG).

BGBl, 2002. 149. Bundesgesetz: Oekostromgesetz sowie Änderung des Elektrizitätswirtschafts- und -organisationsgesetzes (ElWOG) und das Energieförderungsgesetzes 1979 (EnFG).

BGBl, 2008b. 111. Bundesgesetz, mit dem Bestimmungen auf dem Gebiet der Kraft-Wärme-Kopplung neu erlassen werden (KWK-Gesetz).

BMLFUW, 2002. Strategie Österreichs zur Erreichung des Kyoto-Ziels. Vorlage zur Annahme durch den Ministerrat am 18.06.2002. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

BMLFUW, 2007. Anpassung der Klimastrategie Österreichs zur Erreichung des Kyoto-Ziels 2008-2012. Vorlage zur Annahme im Ministerrat am 21. März 2007. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

BMWFW, 2016. Economic Report 2016. Federal Ministry of Science, Research and Economy. Available at: http://www.bmwfw.gv.at/Wirtschaftspolitik/Wirtschaftspolitik/Documents/Wirtschaftsbericht_2016_Englisch_WEBversion.ok%20HW9.pdf [21.10.2016]

BMLFUW, 2013. The Austrian Strategy for Adaptation to Climate Change. Federal Ministry of Agriculture, Forestry, Environment and Water Management. Available at: https://www.bmlfuw.gv.at/english/environment/AustrianAdaptation.html [18.10.2016]

Cuaresma, J.C. 2015. Income projections for climate change research: A framework based on human capital dynamics, *Global Environmental Change*. In press. Available at: http://dx.doi.org/10.1016/j.gloenvcha.2015.02.012

Dellink, R., Chateau, J., Lanzi, E. and Magné, B., 2015. Long-term economic growth projections in the Shared Socioeconomic Pathways, *Global Environmental Change*. In press. http://dx.doi.org/10.1016/j.gloenvcha.2015.06.004

D'Ippoliti, D., Michelozzi, P., Marino, C., de' Donato, F., Menne, B., Katsouyanni, K., Kirchmayer, U., Analitis, A., Medina-Ramón, M., Paldy, A., Atkinson, R., Kovats, S., Bisanti, L., Schneider, A., Lefranc, A., Iñiguez, C. and Perucci, C. A. (2010). The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environmental Health* (9)37. http://doi.org/10.1186/1476-069X-9-37

EEA, 2016. European Environment Agency. National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Available at: http://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-11 [21.09.2016]

European Commission, 2011. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS - A Roadmap for moving to a competitive low carbon economy in 2050 /* COM/2011/0112 final */. Brussels.

European Commission, 2016. Effort Sharing Decision. Available at: https://ec.europa.eu/clima/policies/effort/index_en.htm [08.11.2016]

European Council, 2014. European Council Conclusions November 2014, EUCO 169/14 CO EUR 13 CONCL 5. Brussels.

EUROSTAT, 2016a. Population on 1 January by broad age group and sex. [demo_pjanbroad]. Available at: http://ec.europa.eu/eurostat/data/database [28.09.2016]

EUROSTAT, 2016b. Gini coefficient of equivalised disposable income - EU-SILC survey. [ilc_di12]. http://ec.europa.eu/eurostat/data/database [28.09.2016]

EUROSTAT, 2016c. GDP and main components (output, expenditure and income). [nama_10_gdp]. Available at: http://ec.europa.eu/eurostat/data/database [28.09.2016]

EUROSTAT, 2016d. Employment by educational attainment level - annual data. [lfsi_educ_a]. Available at: http://ec.europa.eu/eurostat/data/database [28.09.2016]

Haas, R., R. Molitor, A. Ajanovic, T. Brezina, M. Hartner, P. Hirschler, G. Kalt, C. Kettner, L. Kranzl, N. Kreuzinger, T. Macoun, M. Paula, G. Resch, K. Steininger, A. Türk und S. Zech, 2014. Energie und Verkehr. In: Österreichischer Sachstandsbericht Klimawandel 2014 (AAR14). Austrian Panel on Climate Change (APCC). Wien: Verlag der Österreichischen Akademie der Wissenschaften, S. 857–932.

IEA, 2014. Energy Policies in IEA Countries – Austria 2014 Review. OECD/IEA, Paris.

IIASA, 2016. SSP Database (Shared Socioeconomic Pathways) - Version 1.1. Available at: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about [18.09.2016]

ILO, 1997. The Iron and Steel Workforce of the Twenty-first Century: Report for Discussion at the Tripartite Meeting on the Iron and Steel Workforce of the Twenty-first Century : what it Will be Like and how it Will Work. Geneva. International Labour Organisation. Sectoral Activities Programme. Available at: http://staging.ilo.org/public/libdoc/ilo/1997/97B09_184_engl.pdf [21.10.2016]

Mueller, A., Redl, Ch., Haas, R., Tuerk, A., Liebmann, L., Steininger K., Brezina, T., Mayerthaler, A. Schopf, J., Werner, A., Kreuzer, D., Steiner, A., Mollay, U. And Neugebauer, W. 2012. Energy Investment Strategies And Long Term Emission Reduction Needs - Strategien für Energie-Technologie-Investitionen und langfristige Anforderung zur Emissionsreduktion. Project report, Vienna.

Muñoz, P., Steininger, K.W., 2010: Austria's CO2 responsibility and the carbon content of its international trade. *Ecological Economics 69*, 2003–2019. doi: 10.1016/j.ecolecon.2010.05.017

OECD, 2016a. Quality of Life Index. Available at: http://www.oecd.org/ [28.09.2016]

OECD, 2016b. Labour force participation rate (indicator). Available at: https://data.oecd.org/emp/labour-force-participation-rate.htm doi: 10.1787/8a801325-en [27.10.2016]

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R. and van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic Change* (2014) 122: 387. doi:10.1007/s10584-013-0905-2

Pollack, H.W., 1988. Materials Science and Metallurgy. Prentice Hall International 4th edition. ISBN 0835942872.

Statistics Austria, 2016a. Gesamtenergiebilanz Österreich 1970 bis 2014. Available at: http://www.statistik.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/energie_und_umwelt/energie/energiebilanzen/index.html [21.09.2016]

Statistics Austria, 2016b. Bruttoinlandsprodukt nach Wirtschaftssektoren, laufende Preise. Available at: http://statistik.at/web_de/statistiken/wirtschaft/volkswirtschaftliche_gesamtrechnungen/bruttoinlandsprodukt_und_hauptaggregate/jahresdaten/019715.html [19.09.2016]

Statistics Austria, 2016c. Leistungs- und Strukturstatistik 2014 – Hauptergebnisse. Available at: https://www.statistik.at/web_de/statistiken/wirtschaft/produktion_und_bauwesen/leistungs_und_strukturdaten/index.html [19.09.2016]

Statistics Austria, 2016d. Arbeitslose (internationale und nationale Definition). Available at: http://www.statistik.at/web_de/statistiken/menschen_und_gesellschaft/arbeitsmarkt/arbeitslose_arbeitssuchende/index.html [27.10.2016]

Tovey, A. 2015. European steel industry 'must halve by 2030 in order to survive'. *The Telegraph* [online]. Available at: http://www.telegraph.co.uk/finance/newsbysector/industry/11997877/European-steel-industry-must-halve-by-2030-in-order-to-survive.html [15.06.2016]

World Steel Association. 2016. Steel Statistical Yearbooks 1978-2015. Available at: http://www.worldsteel.org/statistics/statistics-archive/yearbook-archive.html [21.09.2016]

Worrell E., Price L., Neelis M., Galitsky C., Nan Z. , 2008. World Best Practice Energy Intensity Values for Selecte Industrial Sectors. Ernest Orlando Lawrence Berkeley National Laboratory LBNL-62806 Rev. 2.

Wynes, T. Axelson, M. 2016. Decarbonising Energy Intensive Industries: The Final Frontier. Brussels: Institute for European Studies.

voestalpine, 2016. Kennzahlen im Ueberblick. Available at: http://www.voestalpine.com/group/static/sites/group/.downloads/de/publikationen-2015-16/2015-16-kennzahlen.pdf [26.10.2016]