LUND UNIVERSITY
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The Impact of Foreign Trade on the Development of Germany's Energy Intensity during the Industrialization Phase

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Abstract: The development of Germany's energy intensity of the 19th and 20th century shows a clear inverted U-shaped trend, which supports the hypothesis of the *environmental Kuznets curve* (EKC) of energy intensity. In this article this development will be analyzed from a consumption perspective to investigate the impact of international trade on the upswing phase of Germany's EKC of energy intensity. It is assumed that Germany's foreign trade played a vital role for its industrial energy consumption and that trade reinforced the rising trend of the energy intensity throughout the industrialization. The relative changes of the energy balance of trade indicate if foreign trade might have increased Germany's energy consumption between 1880 and 1913. The increase of this balance after 1898 supports the hypothesis that trade impacted the EKC of energy intensity and that the peak might have been reached at lower levels without the reinforcing effect of foreign trade. A deeper analysis of the industrial sub-sectors indicates that the net exports of energy intensive industries influenced Germany's rising energy intensity in the late 19th and early 20th century positively.

Key words: Environmental economics, economic growth, international trade, environmental Kuznets curve

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I. Introduction

Globalization is one of the most debated topics of our time. No matter if recent discussions focus on the pros or the cons that come along, it is undisputed that the effects of globalization shaped our economies greatly. We benefit from foreign trade on a daily basis when we consume fruits from Southern Europe, clothes from Asia or heat our houses with gas from Russia. The exchange of goods and services exceeded national borders a long time ago and kept increasing to a level that makes it hard to imagine a life without the benefits of international trade. Alike, international trade energy consumption has increased over time to record highs. We consume more energy than we have in any other historical period. Regardless of the economic structure we need energy inputs in form of fossil fuels or renewable energy carriers to drive agricultural machines, to generate electricity for industrial machinery or light up the offices we work in. However, we become more efficient in our energy use as we need less energy input per unit of GDP (energy intensity). According to the *environmental Kuznets curve* (EKC) hypothesis the energy intensity rises in the process of industrial development to a certain inversion point and decreases afterwards (Panayotou, 2003). This development implies that after a certain developmental stage the amount of energy decreases per unit of income produced. However, it has not to be confused with the absolute energy use in an economy, which has seen unprecedented growth despite the described gains in energy efficiency. The economic growth of the last 200 years has supported the rise in energy consumption although energy intensities were decreasing in the developed World[1], especially in the second half of the 20th century (Kander, Warde and Malanima, 2012).

While developed countries could decrease the energy intensity for example by shifting from energy intensive industrial economies to less energy intensive service economies, the developing countries[2] (DCs) still rely heavily on manufacturing industries and are in some cases believed to be in the upswing or peak phase of the EKC (Dinda, 2004; Kander et al., 2012). However, this view seems not to cover the whole story as international trade between

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[1] *"While there is no one, set definition of a developed economy it typically refers to a country with a relatively high level of economic growth and security. Some of the most common criteria for evaluating a country's degree of development are per capita income or gross domestic product (GDP), level of industrialization, general standard of living and the amount of widespread infrastructure. Increasingly other non-economic factors are included in evaluating an economy or country's degree of development, such as the Human Development Index (HDI) which reflects relative degrees of education, literacy and health."* (Investopedia, 2013 [Accessed 7th of May 2013])

[2] *"...a nonindustrialized poor country that is seeking to develop its resources by industrialization"* (the free dictionary, 2013 [Accessed 7th of May 2013])

the developed and the developing world flourished throughout the 20th century. Although developed countries do not produce as energy intensive as developing countries, the developed world consumes many goods produced in the developing world. According to Peters and Hertwich *"…all environmental impacts of production occur due to consumer purchase and approximately 70% of exports from DCs are to meet the needs of developed countries"* (Peters and Hertwich, 2006).

Therefore this study tries to analyze the impact of international trade on energy intensity, more particularly the development of Germany's energy consumption and intensity in the early industrialization phase.

Previous analyses that considered the consumption patterns of countries found out that the decreasing energy intensity of developed countries was in some cases supported by increasing imports of energy intensive goods (Peters and Hertwich, 2006). These findings support the hypothesis that developed countries could become more energy efficient because of international trade. Furthermore, these studies claim that reductions in energy intensity or environmental degradation do not exist on a global scale as energy intensive production is rather shifted to the developing world than actually decreased on a global scale.

This study will turn this hypothesis around and investigate the role of international trade during the upswing period of Germany's energy intensity. It will be attempted to investigate if the development of Germany's energy intensity in the early stages of industrialization was influenced by international trade. Is it possible that the steep rise in Germany's energy intensity between 1850 and the 1920's was caused or at least reinforced by the increasing exports of energy intensive goods to non industrialized countries and that the EKC of energy intensity (EKCE) does not follow the typical bell shape if energy consumption is considered? It will be tried to analyze energy consumption patterns of Germany and to find indicators for the impact of international trade on the upswing of the EKCE.

The energy balance of trade shows the direction of the impact of trade on the total energy intensity. If the ratio between net exported energy and total energy consumption grows over time it is supposed that international trade contributed increasingly to the energy consumption and intensity. A decrease would indicate the opposite effect (Kander and Lindmark, 2005). Thus the ratio per se is not the decisive factor in this matter, but the changes are. The aim of this study is to find indicators for a possible change in the energy balance of trade.

The fact that finished goods constituted the lion share of Germany's exports and that the imports were dominated by raw materials at that time, make Germany an excellent case study for the described analysis (Henning, 1996). Not only that Germany shows the cleares EKCE trend among the Western European countries, but the long history of international trade renders the hypothesis that Germany was a net exporter of energy (Kander et al., 2012). It is assumed that the energy balance of trade increased over time and that trade therefore influenced the rising EKCE positively during the upswing and peak phase.

1.1 Purpose, Motivation and Contribution

The author believes that our daily consumption choices influence the commodity supply in all fields of the economy significantly. After all the majority of businesses in the world follow the *share holder value approach* which follows the prime goal of profit maximization. Therefore profitable products will be sold and less profitable products will be withdrawn from the market. The simplified rationale is that *"sold is what sells"*. Hence, our consumption is crucial for the type of goods and services offered in the market. This impact might appear marginal on a personal level, for instances when it comes to grocery shopping, choice of car dealership or furniture stores. However, the effect gains significance on aggregated levels, and is not negligible on national levels. The following examples of multinational industries, which have to adjust their products to domestic consumption habits, illustrate the power of consumption. If a country avoids beef consumption on a national level, the whole food industry will react and supply substitution products that are in line with the consumption patterns. This can be observed in the case of the food industry in India, where even fast food giants like Mc Donald's, Subway and others offer substitution products for beef, because the majority of Indians does not eat beef due to cultural and religious heritage. The Indian consumption patterns impact the supply significantly as the industry adjusted to the demand (The Globe and Mail, 2013).

Therefore it appears only logical to analyze a country's consumption patterns rather than focus solely on production output to give proper recommendations for decision makers. By applying the described rationale on the field of energy economics one has to include the consumption of energy intensive products to give comprehensive recommendations for decision makers. The measures to reduce energy intensities and the associated detrimental effects for the environment have to consider production and consumption patterns to avoid single edged, incomprehensive policies. This means that foreign trade has to be included in order to measure energy intensity developments to cover the whole energy consumption.

Following this principle the energy consumption and energy intensity of Germany between the late 19th and early 20th century will be analyzed under consideration of international trade. Previous research has revealed that Germany shows a clear EKC trend for energy intensity in contrast to other countries (Kander et al, 2012), which makes it an excellent case to test the hypothesis. According to the authors knowledge the consumption based approach has not been applied to the upswing period of EKCs, especially not to the case of Germany's EKCE in the early industrialization phase.

An additional reason for this study is the growth of foreign trade throughout the described period. Although the volume of international trade had not the dimensions of current foreign trade, it has to be noted that international trade increased considerably at that time and that Germany in particular benefited from exports of manufactured goods (Henning, 1996). Manufactured goods were energy intensive which leads to the hypothesis that Germany actually consumed less energy as depicted in previous studies because parts of the energy intensive goods produced in Germany were consumed elsewhere.

This study will support the application of the consumption based approach and give new insights in the energy history of Germany. The aim is to investigate the relation between foreign trade and energy intensity during the upswing period of the EKCE of Germany. Furthermore it is supposed to encourage more in depth research on this topic not only for Germany but for other countries as well.

1.2 Outline

Before the impact of international trade on the EKCE of Germany can be examined and the hypothesis about an increasing energy balance of trade can be tested this study will provide a brief historical background about the early industrialization phase of Germany. In this section the theoretical framework of the *environmental Kuznets curve* hypothesis will be explained in more detail and the key concepts of previous studies will be defined. By that way the used terminology will be clarified and insights into relevant literature are given. Section three focuses on the methods and data applied. Beside the explanation of the conducted calculations and estimations this section will shed light on the inherent limitations of the applied method and the available data. The main analysis will be conducted in section four. The EKCE for Germany will be recreated and the energy consumption of the industrial sub-sectors will be calculated. Furthermore, the industrial energy intensity will be compared to the total energy intensity and the role of international trade will be examined. In this main part, the hypothesis of an increasing energy balance of trade will be tested, and the research questions will be answered. The final part of this study will discuss the results, in particular in relation to the shortcomings of the available data and will therefore encourage further research. In the end of part five the main results will be summarized to present a conclusion and complete the analysis.

II. Theoretical Background and Key Concepts

The 19th and early 20th century in Germany was characterized by vast changes in the economy and the society due to increasing industrializing processes. With the introduction of coal as a main energy carrier and new technological production processes the German economy experienced unprecedented growth, structural changes and increased productivity in almost all industrial sectors (Henning, 1996). Kander et al. (2012) state that the coal consumption of Germany rose constantly and that coal became the dominant energy carrier in the second half of the 19th century. While coal consumption constituted only 2.5% of the overall energy consumption in 1800, it increased its share to 27.6% in 1850 and up to 89.5% in 1913 (Kander et al., 2012). Thus coal displaced fuel wood as the main energy carrier during that period and one can classify Germany as a coal country. This development was positively influenced by the big coal resources in the Ruhr area, as coal was an abundant factor in Germany (Henning, 1996). The progressing industrialization influenced also the structure of the German economy. Due to the increasing employment of machinery the productivity could be increased in almost all sectors and greater parts of the population could be provided with substantial goods. Thus, the shift from an agrarian society to an industrialized economy was promoted. Hoffmann (1965) points out that the agricultural sector contributed almost 50% to the economic output till the mid 19th century followed by the industrial sector and services. By 1913 this structure has changed dramatically and the industrial sector accounts for almost 51% to the net domestic product, while the role of agriculture became smaller. The agricultural sector contributed only 23.4% by then, and would further diminish (Hoffmann, 1965). The German economy remained growing throughout that time. The net national product in current prices from 1913 increased from 10.53 billion marks in 1850 to 52.440 billion marks in 1913 and the number of employees tripled between 1800 and 1913 (Mitchell, 1998; Henning, 1996). This development is also reflected in the foreign trade of Germany, which increases according to estimations by Henning (1996). The researcher states that the volume of exports and imports rose from far less than 1 billion marks to over 10 billion in that period. The most drastic increase was seen between 1860 and 1870 from around 2 billion marks to roughly 5 billion. Although this development slowed down after the 1860's the export volume still rose by 27% between 1870 and 1880. Germany's exports were dominated by finished goods, followed by raw materials, mainly coal. The import structure was clearly dominated by raw materials, followed by intermediate goods after 1850 (Henning, 1996).

The described economic growth was accompanied by tremendous increases in energy consumption. Kander et al. (2012) points out that the energy consumption of Germany was raised from 365 Petajoules in 1800 to 635 Petajoules in 1850, and boosted even more to 6504 Petajoules in 1913. This development seems logic under the given circumstances of economic growth, employment of coal instead of firewood and the structural shift towards the more energy intensive industries throughout the 19th century. The growing energy consumption goes hand in hand with growing energy intensity, which depicts the ratio between energy units applied per unit of income. The energy intensity of Germany rose steeply from the mid 19th century till it peaked in the early 20th century and declined afterwards (Kander et al., 2012). This development of energy intensity resembles the shape of an inverted U-shape often referred to as *environmental Kuznets curve* (EKC).

2.1 The Environmental Kuznets Curve Hypothesis

The EKC depicts the relation between income per capita and environmental degradation. It is named after the economist Simon Kuznets who examined the relationship between income inequality and income per capita. According to Kuznets (1955) the inequality rises with economic growth in the beginning and the trend is reversed after a certain peak. This development is illustrated as an inverted U-shaped curve of income inequality; the so called Kuznets' curve (Kuznets, 1955).

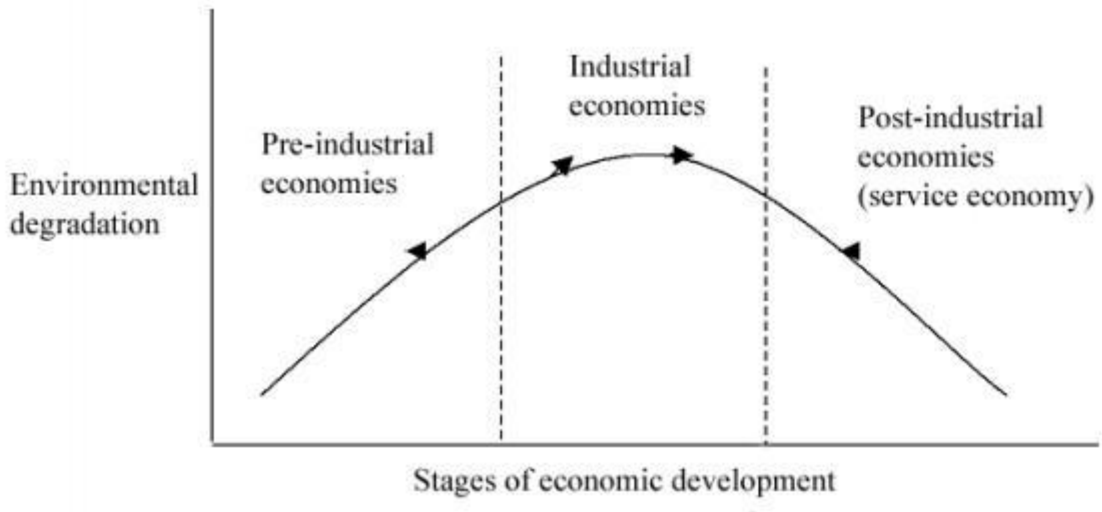
Following this trend, the EKC illustrates a similar relationship between environmental damages and income per capita. The advocates of the EKC hypothesis state that environmental degradation increases in the early phase of economic growth but levels off and declines with increasing income in modern economies. This implies that the development of the exhaustion of environmentally harmful substances follows and inverted U-shaped function of income per capita just like the original Kuznets curve (Stern, 2004).

The EKC hypothesis challenges the so called “neo-malthusian” school, and the work of its most prominent supporter Dennis Meadows (2009) who described scenarios of resource depletion and overwhelming quantities of waste by-products that accumulate rapidly because of the world wide acceleration of unsustainable economic growth. This development will cause fatal outcomes for large parts of the population if the political and economical agenda regarding economic growth does not change (Meadows, 2009). However, supporters of the EKC hypothesis contest these assumptions and state that the dismal scenarios of Meadows are based on static models which do not account for structural shifts and technology changes within an economy. Beckerman (1993) argues that high incomes generate demand for less material intensive goods and services as well as demand for environmental quality. This leads to political measures that preserve the environment. Hence, it can be inferred that environmental improvement could be reached with steady economic growth as the trend of an EKC depicts (Beckerman, 1993).

In contrast to the static models that suggest that economic growth must cease in order to reduce environmental degradation, the theoretical construct behind the EKC relies on a dynamic economic development. This includes structural change towards less material intensive and less energy intensive sectors, and supposes technological progress towards more efficient use of resources over time (Panayotou, 2003).

The theoretical framework of the EKC is built upon the long-term observations of economic development. Panayotou (2003) points out that both the quantity and the intensity of environmental degradation were rather limited to the impacts of subsistence economic activities of the relatively low developed pre-industrial economies. With the take off of the industrialization more intensified resource extraction began and both resource depletion and waste generation accelerated in the industrial economies. At higher levels of development, structural change towards the information-based industries and towards services occurred which resulted in leveling off and declining environmental degradation of the service oriented, post-industrial economies (see graph 1). The decline of environmental degradation is not only caused by structural shifts towards service economies, but also influenced by technical changes towards more efficient technologies and improved production methods (Panayotou, 2003). Moreover this development is reinforced by the income elasticity of environmental quality demand. Dinda (2004) points out that the demand for better environmental conditions rises with rising income and that *"...the willingness to pay for a clean environment rises by a greater proportion than income"* (Dinda, 2004). Thus societies with high incomes have more possibilities to preserve the environment than low income societies and they tend to do so (Dinda, 2004).

The environmental Kuznets curve: a development-environment relationship



Graph 1: Graph taken from Panayotou (2003). Source: Panayotou, T. (2003). Economic growth and the environment. *Economic survey of Europe*, 45

2.2 Previous Research[3]

In the early 1990's the concept of the EKC became prominent through three independent studies of Grossman and Krueger (1991) on the environmental impacts of the NAFTA, of Shafik and Bandyopadhyay (1992) on the relation between economic growth and environmental quality and of Panayotou (1993) on empirical tests and policy analysis of environmental degradation. The hypothesis that environmental quality can be improved or maintained through economic growth was already presented in the World Commission on Environment and Development (1987) in the study *Our Common Future* (Stern, 2004). Researchers have analyzed the development of various environmental indicators to show the expansion of environmental degradation caused by economic growth. All three studies gave

[3] Parts of this section were used in the final paper for EKHM 40 Research Design (Research Proposals EKHM 40) – Sven Hagen

special interest in examining threshold values or turning points of the EKCs of different environmental indicators. Grossman and Krueger (1991) calculated EKCs for SO2, dark matter and suspended particles in their early work. Although the scholars find the typical inverted U-shape curve for all three pollutants, they also found a slight subsequent rise at income levels over 10.000$ (Grossman and Krueger, 1991). However, Panayotou (2003) rather observes a pure EKC for those pollutants. He criticizes that the subsequent rise of the EKC of Grossman and Krueger (1991) is due to a limited number of observations in the high income segment and that the use of the cubic equation might be responsible for the refreshed increase of the EKCs (Panayotou, 2003).

Later Grossmann and Krueger (1995) focused on the relationship between income per capita and urban air pollution, the state of the oxygen regime in river basins, fecal contamination of river basins, and contamination of river basins by heavy metals. The researchers state that "*…economic growth brings an initial phase of deterioration followed by a subsequent phase of improvement"* (Grossmann and Krueger, 1995), which corroborates the EKC hypothesis for those indicators.

Shafik and Bandyopadhyay (1992) estimated EKCs for 10 different environmental quality indicators like lack of clean water and sanitation, deforestation, municipal waste, sulphur oxides and carbon emissions. Their analysis of environmental degradation shows mixed results. While air pollutants seem to confirm the EKC hypothesis, water pollution and municipal waste show deviating development patterns with growing income. Deforestation appears to be independent of income levels. Yet, Panayotou on the other hand found that deforestation confirms the EKC hypothesis in his later work (Panayotou, 2003).

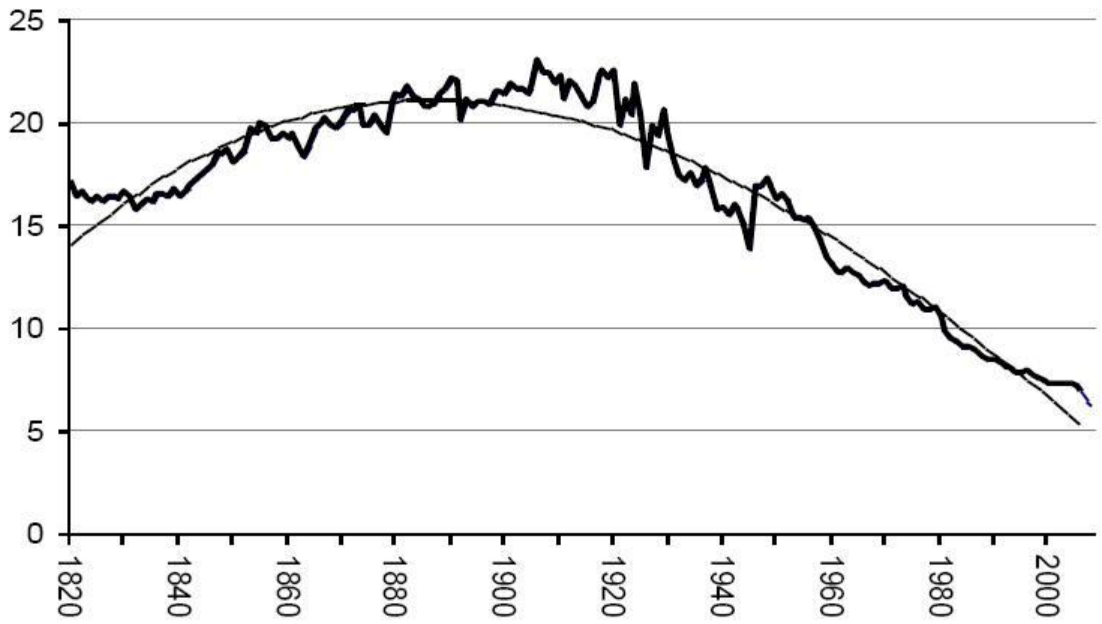
During the advent of the EKC studies in the 1990s many micro analyses have been conducted in order to investigate the development of certain environmental measures in relation to the income level. Panayotou (2003) provides a summary of those studies and advocates the existence of the EKC for indicators such as CO2 and SO2 (see appendix 1; table 1 and 2). The enthusiasts of the EKC, such as Beckerman (1992) see sufficient empirical proof of the EKC hypothesis and argue that the improvement of environmental quality is reached best through economic growth. According to Beckerman "*…the surest way to improve your environment is to become rich."*(Beckerman, 1992). The optimistic picture drawn by advocates of the EKC strengthens the belief, that societies can "outgrow" their environmental problems by accelerating their economic growth.

This opinion is not shared among the environmental economists and has been debated extensively. Stern (2004) argues that there is only little evidence for a common EKC development among different countries. Stern (2004) criticizes both the theoretical base and the statistical analysis of previous studies and argues that the empirical bases for the calculated EKCs are not robust.

Although Stern (2004) expresses his skepticism about the theoretical and empirical research that has been conducted, he states that there may be an inverted U-shaped relation between urban ambient concentrations of pollutants, like fine dust, and income (Stern, 2004).

While the early studies of the EKC concentrated on micro evidence for environmental degradation, like exhaustion of airborne pollutants or toxic waste production, and focused on rather short term periods of 10 to 20 years, more recent studies of Kander et al. (2012) put the focus on a macro level instead. Kander et al. (2012) used energy as a proxy for environmental degradation, due to its association to pollution and waste production. Although some energy carriers are more harmful to the environment than others and countries rely on different energy mixes, the development of the energy to GDP ratios (energy intensity) follows the trend of the EKC for some countries. Kander et al. (2012) state, that one can speak of an *Environmental Kuznets Curve for Energy* (EKCE) in some cases. The critical research revised the EKC and examined the long-term development of energy intensities in Western Europe (see graph 2).

The Environmental Kuznets Curve for Energy for Western Europe 1820 to 2005



Graph 2: Energy/ GDP (Energy Intensity), mega joule per constant international 1990 dollar, in Western Europe 1820-2005. Source: Kander et al. (2012)

The graph above shows the development of the energy intensity of Western Europe at an aggregated level. The depicted development shows that the energy consumed to produce one unit of GDP grew throughout the 19th century and started to decline after a peak in the early 20th century. The theoretical explanations for the EKC trend apply for the EKCE in a similar manner. The energy consumption of the Western Europe rose in the 19th century, due to the replacement of organic energy carriers with more powerful fossil energy carriers. Smil (1994) points out that the transition from pre-industrial to industrial economies was a period of unprecedented energy consumption due to the extraction and usage of more powerful energy carriers, particularly coal.

According to Anderson (1993) the coal consumption of Britain rose from 6 million tons in 1800 to 60 million in 1850, and to 300 million tons by 1914. In Germany the coal consumption between 1860 and 1914 increased 20 fold from 12 to 280 million tons (Anderson, 1993).

The increasing employment of coal triggered the industrialization and led not only to a boost in energy consumption but also to the emergence of new technologies, global markets, mass production and an abundance of goods (Smil, 1994). Thus, the energy intensity grew in the early stages of industrialization because the growth of energy consumption exceeded the growth of GDP. According to Kander et al. (2012) the underlying idea of the EKCE is that early industrializing countries use relatively inefficient technologies in the beginning which become more efficient after a phase of maturation. This argumentation goes hand in hand with Panayotou's theoretical framework of the EKC, which includes technology maturation and structural change towards service economies as the most important reasons for the decline of EKCs (Panayotou, 2003).

However, the investigations of Kander et al. (2012) have shown that the long-term development of energy intensity of Western Europe follows this trend at an aggregated level but not necessarily at domestic levels. Critical research has shown that the energy intensities of countries like Sweden, Spain or the Netherlands do not follow the EKCE pattern but rather showed a remaining downwards trend. Kander's analysis of the domestic economies of Western Europe has shown that the aggregated EKCE was strongly coined by the development of the energy intensities of Britain and Germany. The two big economies influenced the aggregated development so much, that a distorted picture of the European development was created, although, the EKC hypothesis and the typical inverted U-shaped curve of the EKCE hold for the "coal countries", Britain and Germany (Kander et al., 2012).

Even though previous research has shown that the energy intensity of Germany and Britain follows the inverted U-shaped curve, some researchers contest the EKC hypothesis and point out that the applied models are sometimes flawed and not comprehensive enough.

Stern (2004) argues that there is a new research challenge to expand the EKC literature and include the effects of trade on energy and emissions into the measurements. He argues that new decomposition models, panel data and time-series statistics are needed to examine the effects of globalization and foreign trade on the environment (Stern, 2004)

2.3 The Role of International Trade[4]

The so far introduced discussion about the trajectories of environmental degradation and energy intensities was led from a production perspective and failed to mention the role of consumption patterns, respectively international trade.

Modern studies emphasize the impact of globalization and foreign trade on the environment and argue that the energy consumed in a country should be put into the spot light as trade

[4] Parts of this section were used in the final paper for EKHM 40 Research Design (Research Proposals EKHM 40) – Sven Hagen

increasingly exceeds national borders (Peters and Hertwich, 2006). This idea gained momentum throughout the late 20th century as not only the developed countries but also a large number of developing countries experienced a soaring growth in world trade and the commodity and service flows between countries increased, especially in the second half of the century (Krugman et al., 1995).

The interest in energy and pollution embodied in trade also arises from the increasing awareness of detrimental effects of CO_2 emissions on the environment. Consequently, the question of who is actually responsible for carbon dioxide emissions, the exporting or the importing countries receives more attention (Munksgaard et al. 2009).

Researchers like Kander et al. (2012), Peters and Hertwich (2006) point out, that studies on the energy consumption issue are not to allocate moral responsibilities for emission to nations but to a) analyze how and if the structure of trade impacts production structures and b) to find new strategies for reducing the emissions of global pollutants (Kander et al.,2012; Peters and Hertwich, 2006).

Suri and Chapman (1998) state, that some studies have incorporated the impact of international trade on the EKC, however the impact of the actual movement of goods, which embody energy and therefore to some extent pollution, has not been given a lot of attention in the early 1990's.

Due to the growing trade between countries the concept of *energy embodied goods* became more prominent to examine the energy consumption of a country. The aim here is to extent the traditional measurements of energy input by including the net exported energy in the analysis. The net exported energy comprises the energy embodied in the exported goods minus the energy embodied in imported goods. By including the amount of energy embodied in traded goods it is possible to analyze the development of EKCs from a consumption rather than from a production perspective and give accurate information about the disposition of energy or pollutants.

The focus on consumption enables to check if the overall emission reductions during the downward phase of an EKC have been caused by so called *pollution leakages*. This means that emission reductions of one country are reinforced or even caused by a shift of energy and pollution intensive production to developing countries through international trade (Faehn, 2009). Moreover, Peters and Hertwich (2006) argue that global climate change policies are more effective if they focus on the consumption side of pollution as opposed to the production side. The researchers point out that the consumption accounting principle does not punish countries for pollution and energy intensive exports which gives greater flexibility for reducing emissions (Peters and Hertwich, 2006).

Suri and Chapman (1998) examined the EKC hypothesis in regard to commercial energy consumption and attempted to quantify the effect of international trade on the EKC using pooled cross-country and time series data. The researchers compared their model to previously applied econometric models and extended it by the trade variable. They found significantly higher turning points of the EKC when trade is considered. Suri and Chapman (1998) state that most exports from industrializing countries are consumed in the industrialized world and reason that imports have reinforced the downturns of EKCEs and EKCs of developed countries (Suri and Chapman, 1998).

Hence, Suri and Chapman support the hypothesis that reductions of environmental degradation along EKCs are due to pollution leakages and that there is a shift of energy and pollution intensive production from developed to developing countries rather than a general decoupling of environmental degradation and income per capita.

These results contradict findings of earlier studies of Grossmann and Krueger (1995) who concluded that openness is rather beneficial for the environment (Grossmann and Krueger, 1995).

The possible shifts of energy and pollution intensive production to developing countries were analyzed by Taylor and Copeland (2004) in respect to the impact of pollution regulation policies. The hypothesis that a reduction in trade barriers will lead to a shift of pollution-intensive industries to countries with weak environmental regulations is labeled *pollution haven hypothesis*. The researchers found no support for this hypothesis, but found a marginal effect that weak environmental regulations do influence the choice of production locations. They named this marginal factor the *pollution haven effect* (Taylor and Copeland, 2004).

Researchers like Peters and Hertwich (2006) also support the changing focus of pollution generation from production to consumption and advocate the existence of pollution leakages. In their case study of pollution embodied in traded goods in Norway in 2000, the researchers perform a multi-regional input-output analysis to analyze how much CO2 was embodied in Norway's net exports. The CO2 embodied in the net exports is obtained by firstly, investigating all the related CO2 emissions that occurred throughout the whole production chain for all exported and all imported goods, and secondly, by subtracting the CO2 embodied in the imports from the CO_2 embodied in the exports. In order to limit the data requirements the researchers assume uni-directional trade to estimate the CO_2 emissions embodied in the traded goods. To grant more accuracy the scholars account for regional technological differences by applying an error quota for the vague assumption that imports are produced with the technology of the importing country. Their findings show that CO_2 emissions embodied in imports to Norway accounted for 67% of Norway's domestic CO_2 emissions in 2000. Additionally, they found that the carbon leakage from *non-Annex I countries*[5] was up to 30% (Peters and Hertwich, 2006).

However, Kander et al. (2012) criticize the chosen approach by Peters and Hertwich (2006) and argue that a pure multiregional input-output analysis blames the low pollutant country for all the emissions done in the high pollutant country during the production of the goods which will be imported in the low pollutant country. In addition, this approach gives the low pollutant country no credit for the foregone emissions resulting from its exports of "cleaner" products to the rest of the world. It is argued that the foregone emissions should be accounted for as well (Kander et al., 2012).

On the contrary to the study of Peters and Hertwich (2006), Faehn and Bruvoll (2009) included the foregone emissions in their study and augment the multiregional input-output analysis to calculate pollution leakages for Norway in the period between 1980 and 2000. The researchers calculate the Net leakage by subtracting the export related leakages from the import related leakages. The import related leakages are defined as the direct effects on the emissions in the country of origin, given the specific emission coefficients of that country. The export related emissions, on the other hand are obtained by calculating the avoided emissions abroad from the domestic production of traded goods. It is supposed that the exported goods would have been produced in the importing country if not imported. In the case of Norway the avoided emissions abroad are usually higher than the emissions actually taking place in the domestic production process, due to relatively clean production and the application of advanced technology. The researchers find no support of increasing pollution leakages in Norway. The empirical study shows that the decoupling of environmental

[5] *"The group of countries included in Annex I (as amended in 1998) to the UNFCCC, including all the OECD countries and economies in transition. Under Articles 4.2(a) and 4.2(b) of the Convention, Annex I countries committed themselves specifically to the aim of returning individually or jointly to their 1990 levels of greenhouse gas emissions by the year 2000. By default, the other countries are referred to as Non-Annex I countries"* (Annex 1 Glossary, 2013) Source: http://www.ipcc.ch/pdf/glossary/ar4-wg3.pdf, accessed 12 of April 2012

degradation and income in previous decades came along with decreasing emission leakages, at least in the case of Norway from 1980 to 2000 (Faehn and Bruvoll, 2009).

Seppälä et al. (2001) use a different approach to test EKC hypothesis in regard of international trade. Instead of measuring the energy or pollution embodied in traded goods, they analyze the general development of direct material flows (DMF). The rationale behind material flow accounting is that economic growth unavoidably leads to environmental degradation because of intensified material use of natural resources. This point of views is contrasted by the afore mentioned argument that economic growth is needed to increase wealth to enable societies to afford better environmental quality (Seppälä et al., 2001).

The researchers examine the DMF development between 1975 and 1994 for the cases of Germany, Japan, the Netherlands and Finland. They include in their DMF analysis ores, minerals, limestone, peat, stone material, wood, fossil fuels, cultivated resources produced in agriculture, market gardening, forest by-products and fisheries output. In order to measure the DMF trend they apply a cubic polynomial model, which is a basic statistical form of an EKC model. This model allows the determination of the number of turning points of DMFs as a function of GDP and is therefore sufficient to analyze if the DMFs of the investigated countries turn at a certain level of GDP and if they show the typical inverted U-shaped curve. For investigating the relationship between DMF per capita and GDP per capita Seppälä et al. (2001) used a stepwise regression analyzes and estimated time series models by corrective auto regression procedures.

The results of the empirical study do not support the EKC hypothesis for DMFs in any of the investigated countries. The DMF curve for Germany for instance shows rather a U type shape than an inverted U-shape, which suggests that the DMF first decreased with rising GDP and increased later on with further rising GDP. However, the researchers point out limitations of their time series data and suggest that a longer time series analysis could have shown the inverted U-curve for DMFs. Therefore, Seppälä et al. (2001) state that based on their analysis it is difficult to deny the EKC hypothesis entirely (Seppälä et al., 2001).

Yet, another approach to shed light on the role of international trade in relation to environmental degradation was chosen by Kander and Lindmark (2005) in their long-term case study on the Swedish economy. In contrast to previous studies Kander and Lindmark

(2005) address the question of long-term directions in the balances of trade with respect to energy intensities and CO_2 emissions (Kander and Lindmark, 2005).

In order to examine the impact of international trade on energy intensity the researchers compared the ratios between the net exported energy (NEE) and total industrial energy intensity (IEI) in the benchmark years 1970, 1987 and 2000. According to Kander and Lindmark (2005) one can infer the influence of foreign trade on national energy intensity (NEI) as the IEC is part of the NEI. Though, the researchers point out that the important variable for the assessment of the impact of international trade on changes in the energy intensity (or consumption) of a country is not the energy balance per se, but rather changes in the balance. The relative changes of the energy balance in trade can be investigated by analyzing the ratio of NEE to NEI. If this ratio increases during the observed period trade contributed to increasing energy consumption and perhaps increasing energy intensity. A decrease would have the opposite effect (Kander and Lindmark, 2005). The analysis of trade and energy intensity in Sweden has shown that trade can have an influence on the total energy intensity, however, it does not support the hypothesis that the downswing of EKCs is reinforced through the outsourcing of energy intensive production ("pollution heaven hypothesis"). Kander and Lindmark (2005) found out that the ratio of NEE and NEI increased between 1970 and 1987, but fell back to the levels of 1970 in 2000. Therefore international trade cannot be the decisive variable for the decline in Sweden's energy intensity. In fact, the rise of the ratio of NEE and IEC between 1970 and 1987 indicates that Sweden's foreign trade even raised the energy intensity, which counteracts the hypothesis of lower energy intensity due to increased trade (Kander and Lindmark, 2005).

In this section various empirical and econometrical approaches to investigate the role of international on energy intensities were presented with different findings and results. Although the methods applied were diverse, the introduced studies have a common constant; they focus on energy intensity or CO_2 emissions related to a countries' consumption patterns. This modern and nowadays widespread approach was applied to test the EKC-hypothesis, and to check if the downswings of EKCs were rendered or at least reinforced by international trade, with mixed results.

There is however, little research on the impact of foreign trade on the upswing period of EKCs. According to Kander et al. (2012), the EKC-hypothesis for energy intensity does not hold for various countries, though, it holds for Germany. In fact, Germany of all Western

European countries shows the clearest development of an EKC in terms of energy intensity (Kander et al., 2012).

Therefore this study will focus on the upswing period of Germany's EKC of energy intensity (EKCE) and investigate the impact of international trade on the EKCE during the industrialization phase.

In the following sections it will be analyzed if development of Germany's energy use during the industrialization was influenced by international trade, or not. Is it possible that the steep rise in Germany's energy intensity between 1850 and the 1920's was caused by the increasing export of energy intensive goods to non industrialized countries and that the EKCE does not follow the typical bell shape if energy consumption is considered? This study attempts to investigate this and tries to find indicators for the impact of international trade on the upswing of the EKCE of Germany.

As stated by Henning (1996) the foreign trade of Germany expanded significantly during the 19th century, in particular in the second half of the century. In this period Germany also experienced the boost of energy intensity (Kander et al., 2012). The fact that finished goods constituted the lion share of Germany's exports and that the imports were dominated by raw materials at that time, support the hypothesis of an increasing energy balance of trade. The following section will describe the data and methods used to investigate the possibly increasing energy balance of trade.

III. Applied Methods

In order to answer the raised questions and test the hypothesis of an increasing energy balance of trade during the upswing of the German EKCE, it will be attempted to investigate possible changes of this balance between 1880 and 1913.

In a first step the EKCE of Germany will be recreated, by the use of data about the total energy consumption provided by Kander et al. (2012) and time series data about the net national product (NNP) of Germany, obtained from Hoffmann (1965). The EKCE is essential to the subsequent analysis of the role of international trade and should therefore be displayed as a starting point of this study. Moreover, the recreation of the EKCE conduces to check if Germany really showed an inverted U-shaped curve for energy intensity and to determine the periods of upswing and peak phase. The EKCE will be obtained simply by dividing the figures of the total energy consumption and the NNP between 1850 and 1950.

The missing values of Hoffmann's time series of economic variables (NNP, industrial output and foreign trade) between 1913 and 1925, and 1938 and 1950 are generated through linear interpolation, to visualize the development of energy intensity between the benchmark years.

The ratio between net exported energy and industrial energy consumption is hypothetically increasing until the curve decreases again, thus the ratio of energy embodied in trade and total energy consumption is expected to increase too and indicate the reinforcing contribution of trade. To analyze this possible development the energy consumption of the different industrial branches has to be investigated first to generate the industrial energy intensity. The aggregated industrial energy consumption will then be divided by the sales values of the industrial sector to obtain the industrial energy intensity. By that way not only the development of the industrial energy intensity will be revealed, but the energy consumption of the sub-sectors can be analyzed individually. Furthermore the entire industrial energy consumption can be compared to the overall energy consumption to examine the contribution to the total energy consumption.

Through the generation of the industrial energy intensity the energy embodied in trade can be estimated by multiplying the industrial energy intensity with the net exports of the industry. The net exports of final goods will be used as a proxy for the net exports because it is stated that final goods constituted the major share of the exports at that time (Henning, 1996).

The hereby gained values of energy embodied in final goods will subsequently set into relation to the industrial energy input to reconstruct the energy balance of trade. This approach is similar to the methods used by Kander and Lindmark (2005) to investigate the role of international trade for Sweden's energy intensity throughout the second half of the 20th century.

In a final step the net exports of final goods will be analyzed specifically for certain sub-sectors to find further indicators of an increasing energy balance of trade during the upswing period of the EKCE.

3.1 The Consumption Based Approach

The energy consumption of the industrial sectors will be predicted by investigating the number of employed steam engines, their efficiency and horsepower (hp), and their working time. Kander et al. (2012) state that capital intensive production was equal to energy intensive production in Germany throughout the observed period. Therefore the applied hp is assumed to be a valid proxy for the investigation of the consumed energy of the industrial sub sectors.

In a first step it will be attempted to generate the energy figures of the sub-sectors of the German economy by calculating the energy output of the branches (EO_s). This will be done by multiplying the total applied horsepower of each industry (hp_s) with the estimated working time per year (h).

$$(1)\ EO_s = hp_s * h$$

The working time will be estimated in regard of the specifications of the statistical yearbook of the German empire 1882 (Kaiserliches Statistisches Amt, 1882). The statistical yearbook segregates the steam engines into four groups according to their working time. It is stated that the majority was employed for less than 18 hours a day and a small share was used for more than 18 hours a day. In regard of the yearly run time it is differentiated between machines that ran less than ¾ of the year and more than ¾. Due to inaccuracies in the statistics an average running time has to be applied to create the total hp applied per year. To avoid an overstatement of hp the time was estimated rather low with 12 hours a day for all the machines and 260 days per year. This actually implies that no machine ran for ¾ of the year. The estimation can however be justified a) by the minor part of the machines that ran more than ¾ of the year and b) by the understated downtime in the official statistics. There is no evidence of maintenance cost or outage time for steam engines. Furthermore, Kander et al. (2012) state that the machines of the 19^{th} and early 20^{th} century were prone to breakdowns and a lot of engineering skills were needed to maintain them. Therefore the working time per year will be assessed with 3120 hours per year consisting of 260 days and 12 hours per day.

Hoffmann (1965) estimated the hp of the sub sectors for the years 1875, 1895, 1907, 1925 and 1933, and provides the figures for this analysis.

To shorten down the biggest time gap between the benchmark years 1875 and 1895 the applied hp are calculated for the year 1879 as the data about employed steam engines are available for this year. Furthermore, the manual calculation of the hp for 1879 expands the data set particularly during the upswing period. The generation of the hp data of 1879 longs for a more detailed data analysis and deeper disaggregation. The approach for the hp estimations of 1879 is explained in detail in the appendix (see appendix B).

The energy consumption of the sub sectors (EC_s) can now be investigated under consideration of the level of efficiency (e) of the steam engines. The studies of Smil (1994) and Anderson (1993) shed light on the development of the thermal efficiency of the steam engines throughout the 19th and 20th century. The thermal efficiency describes the factor by which the energy input exceeds the energy output of an engine. The steam engines of the early 19th century had thermal efficiencies of around 5%, which means that the energy input exceeded the energy output by a factor of 20. However, due to the technical progress the thermal efficiency could be raised up to 20% by the end of the 19th century (Anderson, 1993). For that reason different thermal efficiencies will be applied to calculate the energy input of the steam engines. For the years from 1875 to 1895 the thermal efficiency of 17% will be applied while 20% appear more accurate for the years 1907 and 1925, and 23% in the later period. Although the triple expansion engine of 1906 could already reach efficiencies of 23%, this study supposes that mainly less efficient engines were applied even after the introduction of the triple-expansion engine, as it takes some time until a market maturation of new technologies is reached (Anderson, 1993). With these assumptions a possible overstatement of the energy consumption and thus the industrial energy intensity will be avoided.

$$(2)\ EC_s = EO_s * e$$

The energy input of the sub-sectors will then be added up to the total industrial energy consumption (EC) for the benchmark years 1875, 1879, 1907, 1925 and 1933. To display the development in this study the data will be interpolated linear between the benchmarks.

$$(3)\ EC = \sum EC_s$$

The energy intensity of the entire industry (EI) can now be generated by dividing the total energy input of the industry by the sales value of the industrial production (P).

$$(4)\ \mathrm{EI} = \frac{\sum \mathrm{ECs}}{\mathrm{P}}$$

The hereby gained information about the industrial energy intensity and the energy consumption in the sub-sectors will be used to generate the energy embodied in traded final goods (EET) after the net exports of final goods (NEG) are calculated. Hoffmann (1965) provides the time series for those values in current prices between 1880 and 1913.

$$(5)\ \mathrm{NEG} = \mathrm{Exports} - \mathrm{Imports}$$

$$(6)\ \mathrm{EET} = \mathrm{EI} * \mathrm{NEG}$$

To shed light on the impact of international trade on the development of the EKCE, the EET can be used to create the energy balance of trade (EbT) in a final step. For this purpose the ratio between energy embodied in traded final goods and the industrial energy consumption will be created.

$$(7)\ \mathrm{EbT} = \mathrm{EET} / \mathrm{EC}$$

The examination of the EbT will show if the expected increase in this balance occurred throughout the upswing period of the EKCE or not.

In the last part of the analysis the development of net exports of final goods will be investigated on a disaggregated level for the sub-sectors. Thereby it can be revealed if particular energy intensive goods were traded to a higher degree than others and if Germany was rather the importing or exporting entity of energy intensive goods.

For that reason the net exports of finished goods will be investigated for certain industrial branches. The statistical yearbooks of the Germany Empire give disaggregated information about the trade of certain sub-sectors (Kaiserliches Statistisches Amt, 1888-1904).

By examining the historical trade statistics the development of the commodity trade can be analyzed and put into relation to the sub-sector's energy consumption.

To follow the described method a data pool has to be compiled, including on the one hand modern sources like Kander et al. (2012), and on the other hand historical statistics like the statistical yearbooks of the German Empire. The compilation of data is explained in the following section to give this study more transparency.

3.2 Data and Limitations

The NNP series, the aggregated sales values and the trade statistics of the industrial sector are provided in Hoffmann's (1965) comprehensive work about the growth of the German economy since the 19th century (*"Das Wachstum der Deutschen Wirtschaft seit Mitte des 19. Jahrhundert"*). The researcher summarized and reprocessed the historical statistics of the German Empire *("Statistisches Jahrbuch des Deutschen Reiches")* and created various time series by combining data of the statistical yearbooks (Kaiserliches Statistisches Amt, 1880-1930). Hoffmann (1965) created an index of the estimated production of different industries and weighted the individual sectors according to their production values in the benchmark year 1913. He calculated the industrial output by adding the earned income and the capital income in 1913. The earned income is obtained from the statistical yearbooks of the German Empire. To estimate the capital income various studies were used because the statistics about the capital stocks are not structured properly in the statistical yearbooks (Hoffmann, 1965). The estimated NNP values in current prices of the benchmark year 1913 are extrapolated with the support of the individual production indices for the period from 1850 to 1959 (Hoffmann, 1965).

The NNP comprises the value of all goods and services produced by residents or residential entities in Germany, reduced by the depreciation of tangible assets (Investopedia, 2013).

Though, it is unusual to use the NNP instead of the GDP to generate the energy intensity, it is the most common economic output measure found in the literature, which reaches back to the period of interest. Researchers like Hoffmann (1965), Burhop and Wolff (2005) and Mitchell (1998) present NNP series for Germany rather than GDP series. Moreover, the NNP appears to be a valid measure as the development throughout the period of interest nearly does not differ from the net domestic product due to the limited mobility at that time. According to Burhop and Wolff (2005) the difference is less than 1%.

Hoffmann's (1965) economic time series are incomplete and exhibit gaps for the period from 1913 to 1925, and 1938 to 1950. Through linear interpolation the gaps of the economic NNP series and the trade statistic of final goods will be closed in order to visualize the trends of the EKCE, the net energy embodied in trade and the energy intensity. Because of the inaccuracies of interpolated values the main analysis of the energy balance of trade will be restricted to the actual values up to 1913. The interpolated values of the gaps will be used to depict long-term trends and are not taken as solid values for the main analysis. The available data until 1913 cover the most relevant times for the upswing period and contribute therefore sufficiently to this study.

A clear limitation of Hoffmann's (1965) data sets is the aggregation in his work. The production values in prices are not available on a sub-sector level. The researcher presents estimated index numbers for sub-sectors like the metal or chemical industry but no price values, neither constant nor current. Production values are only presented through the described estimation based on weighted indices for the whole industrial sector. The same applies for the trade statistics which are not disaggregated to a sub-sector level. Therefore the energy intensity and energy embodied in trade will only be calculated for the whole industry. The shortcomings of this aggregated analysis are discussed in more detail in the discussion section of this study.

The examined period of this study does not comprehend the whole upswing phase of the EKCE, which began already around the 1850. To analyze the period before 1870 the data requirements exceed the scope of this study because many statistics of individual Kingdoms, like Bavaria, Thuringia or Prussia would have to be consolidated. Uniform statistics for Germany are only available after the foundation of the German Empire in 1871. Furthermore the generation of the net exports of final goods, specifically for the industrial sub-sectors are taken directly from the statistical yearbooks of the German Empire of 1888, 1895 and 1904 (Kaiserliches Statistisches Amt, 1888, 1895, 1904). However, the statistics after 1904 disaggregate the trade values not by industry branches but by commodity groups which makes an investigation of sub-sector trade after 1904 too comprehensive for this study. The accessible data of sub-sector trade will therefore only cover the period between 1880 and 1903.

To obtain the energy consumption of the industrial branches and subsequently the energy intensity and embodied energy the applied horsepower (hp) in the most important industries will be generated from Hoffmann's (1965) data set and partially from the statistical yearbook of the Germany Empire (Kaiserliches Statistisches Amt, 1882). The dimension of the previous data research and the issues regarding the data generation from the statistical yearbooks and are explained in more detail in the appendix (see appendix C).

For the calculations of the EKCE, Kander et al. (2012) provides a long term time series of the German total energy consumption. The researchers generated these statistics from previous research on the topic of Malanima, Kander, Warde, Henriques and used existing statistics from the International Energy Agency (IEA) about energy balances of OECD countries (Kander et al., 2012).

The collected data about the energy consumption, the hp use in the industry, the production values and the trade statistics are applied in the following section to find out if Germany's energy balance of trade increased, and if the hypothesis of the reinforcing impact of international trade on Germany's energy intensity can be proved right.

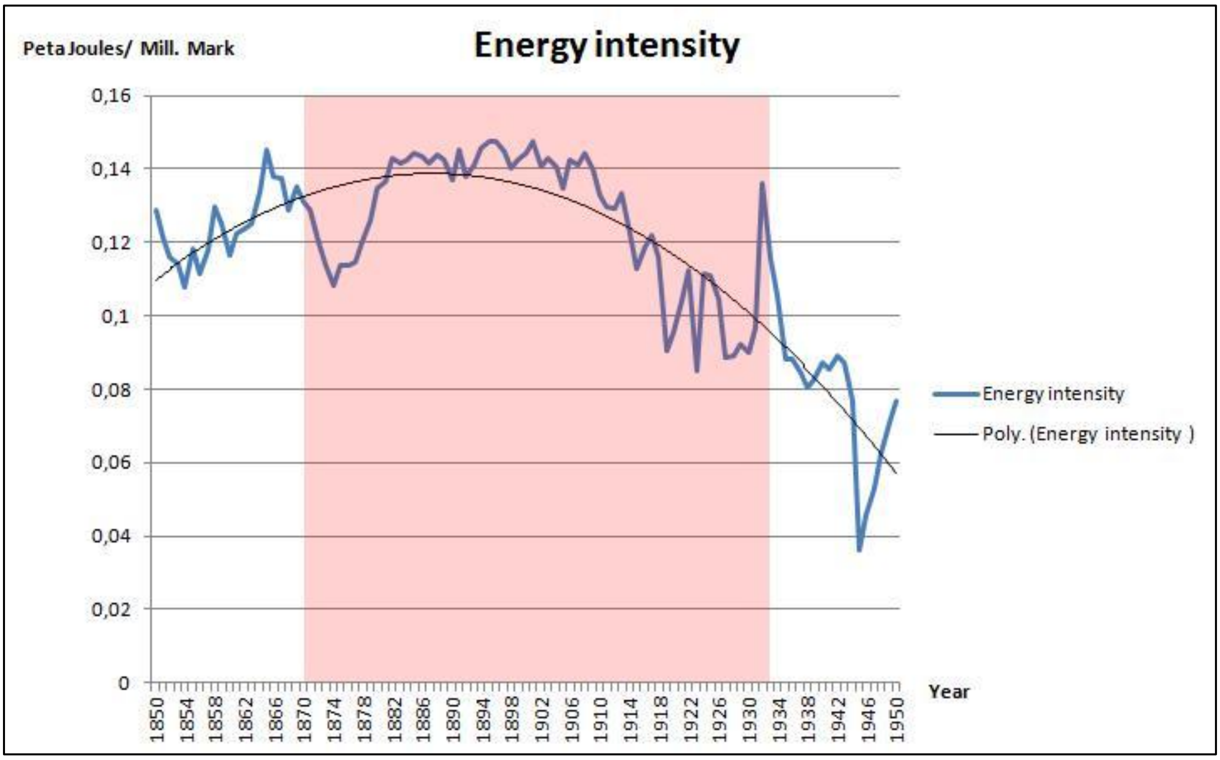
IV. Energy Throughout the Industrialization

Before the relation between industrial energy input and energy embodied in traded goods will be examined, this section will demonstrate that the energy intensity of Germany actually follows the EKC trend during the observed period. For this purpose the EKCE for Germany will be constructed for the Period 1850 to 1950 to show the long-term development and cover the whole upswing phase. The subsequent analysis of the energy consumption and energy intensity will not cover the entire upswing period, but consider the period between 1875 and 1933 due to the described issues in the data generation. Afterwards the energy balance of trade will be recreated and the net exports of certain industrial sub-sectors will be analyzed in more detail.

4.1 Germany's EKCE

It has already been pointed out that not all Western European countries show a clear EKC trend for the long-term energy intensity. To demonstrate that the EKCE exists in the case of Germany and that the period of interest constitutes the upswing and peak of the curve, the EKCE will be calculated by using the data of Hoffmann (1965) and Kander et al. (2012). The figures about NNP in current prices and constant prices from Hoffmann (1965) are incomplete and do not contain data for the years 1914 to 1924 and 1939 and 1949. The missing numbers are reconstructed through linear interpolation between the known values of the years 1913, 1925, 1938 and 1950. By dividing the values of energy consumption with the NNP values the energy intensity trend is obtained (see graph 3).

The development of the German energy intensity from 1850 to 1950

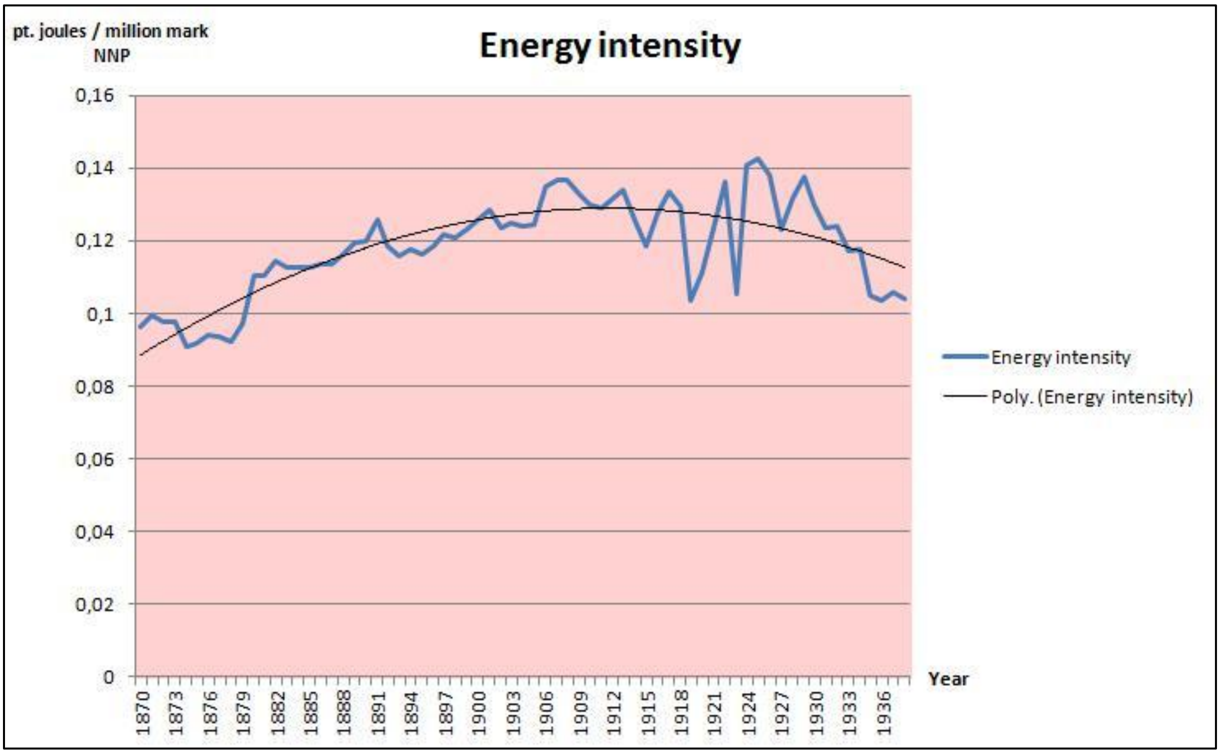


Graph 3: Ratio of energy input per unit of NNP in current prices. The energy intensity is depicted in peta joules per million mark of NNP. The red area will be analyzed in more detail. Source: own calculations.

The energy intensity of Germany between 1850 and 1950 follows the typical inverted U-shaped curve in the polynomial trend line, as graph 3 depicts clearly. The graph illustrates the upswing of the EKCE in the second half of the 19th century with the peak in 1896. Instead of a clear peak the graph shows rather a peak phase of energy intensities above 0.14 peta joules per mill. Mark NNP, between 1891 and 1908. Afterwards the curve shows a downward slope. The sharp rise in 1932 can be explained by the repercussions of the Worldwide Economic crisis in the late 1920's, which reduced the production and income of Germany dramatically in 1931 and 1932 (Aubin and Zorn, 1976). The spike in 1932 is therefore due to the more dramatic reduction in NNP than in energy consumption.

It has to be noted that the peak phase of the EKCE is shifted towards the early 20th century, which seems to contest the statements of Kander et al. (2012). The researchers point out that the peak of Germany's EKCE was reached around 1915 and not as early as graph 3 suggests. This shift is due to the employment of NNP figures in current prices. If the NNP figures in constant prices of 1913 are used for the calculation the peak appears around the early 1920's as described before (see graph 4).

The development of the German energy intensity from 1870 to 1940 in constant prices 1913



Graph 4: Ratio of energy input per unit of NNP in 1913 prices. The energy intensity is depicted in peta joules per million mark of NNP. Source: own calculations.

The analysis of the energy intensity has shown that the increases of energy consumption were more drastic than the increases in NNP in the late 19th and early 20th century. Although graph 3 and 4 show differences in the peak phase of the curves they both prove the existence of the EKCE in Germany. Moreover the graphs show that regardless of NNP figures in constant or current prices, the period between 1875 and 1939 (highlighted in red) contains the upswing and peak phase of the curve and both cases. Hence, the chosen periods for the analysis of energy consumption and the energy embodied in trade are ideal to examine the impact of international trade on the upswing of the EKCE. As this study deals mainly with economic indicators in current prices the upswing and peak phase can be determined between 1850 and 1908.

The following section will examine the development of the energy consumption in more detail to investigate the role of industrial energy consumption and the differences in industrial sub-sectors. Building on the results the role of international trade can be examined afterwards.

4.2 The Industrial Energy Consumption

Germany benefited greatly from its resource abundance of coal which supported the growth of many industries, in particular the highly energy intensive branches. Schön (1990) separates between light and energy intensive industries in the case of the Swedish industry. According to the researcher, mining, paper and pulp, chemical, metal, crude and manufactured minerals constitute energy intensive industries. Textile, Leather, Metal manufacturing, food, wood, graphic and construction are light energy industries (Schön, 1990). The separation between heavy and light industries supports a more specific analysis of the impact of energy consumption on trade, because heavy industries produce products that contain more embodied energy than light industries. Hence the energy embodied in trade of the heavy sub-sectors influences the EKCE development more significantly than the trade of the light industries. For the purpose of segregation between heavy and light industries in the case of Germany the industrial energy consumption needs to be analyzed first.

A crucial starting point to generate the energy figures of Germany are the hp records of the industrial sub-sectors (see table 1), which were partly taken from Hoffmann (1965) and partly generated through own calculations (see appendix B).

It has to be noted that the level of aggregation for the estimated hp of 1879 differs from the other benchmark years. In the display of the statistical yearbook of the German empire (*"Statistisches Jahrbuch des Deutschen Reiches 1882*") the pulp and paper industry was grouped together with the tanning and leather industry. Furthermore, there is no information about the number of steam engines or hp in the gas-, water- and electricity industry in 1879. Therefore the table shows blank sections for the pulp and paper industry and the gas-, water- and electricity industry in 1879. Another issue of aggregation is the sector clothing and leather which is listed in Hoffmann's (1965) work. This minor sector is aggregated into the textile industry in this study. Hence the textile industry contains also hp which originally belongs to the leather industry. However, as mostly the total numbers are of concern the aggregation of some leather producers into the textile industry plays no significant role in this section.

Horsepower distribution into industrial sub-sectors

Performance in 1000 hp							
Industrial sub-sectors	1875	1879	1895	1907	1925	1933	1939
Mining	228	368,66	545	1355	3940	4896	6710
Crude and manufactured minerals	37	44,28	197	506	941	1265	1820
Metal	199	54,38	489	1017	3451	3724	4124
Metal production	64	35,88	240	706	2907	3241	5498
Chemical Industry	21	28,48	102	248	1044	1702	3560
Textiles	176	193,21	535	926	1436	1707	2311
Tanning and Leather	4	47,25	21	58	156	192	232
Wood product	33	50,61	204	440	1046	1366	1879
Pulp and Paper	54		199	405	832	1102	1366
Graphical products	3	6,65	18	36	161	234	265
Food	112	213,87	693	1090	1747	2662	3396
Gas-, Water- u., Electricity	9		61	1051	496	1001	2050
Construction	7	2,35	46	160	473	768	1416
Total	947	1045,63	3350	7998	18630	23860	34627

Table 1: Distribution of hp between the industrial sub-sectors and totals. The hp figures for the years except 1879 are taken from Hoffmann (1965). The hp of 1879 for the sub-sectors are based on own calculations.

Because of the different aggregation in the used sources and the estimations of hp in regard to employed steam engines, the figures for some sub-sectors may differ in 1879 in comparison to other benchmark years, for instance in metal and metal production industry. However, the total amount of hp employed in 1879 appears to be accurate to an acceptable degree. The data limitation, and the differences between 1879 and the other benchmark years are explained in detail in the appendix (see appendix C).

A first analysis of the hp development shows a clear trend of rapidly increasing use of mechanical power. While the growth of hp seems moderate between 1875 and 1879, it more than triples till the year 1895, and keeps rising throughout the later years. Especially the growth from 7.998.000 hp to 18.630.000 hp between 1907 and 1925 is remarkable as the absolute growth is the highest throughout the whole period. The development of the industrial hp corresponds with the upswing phase of the German energy intensity (see graph 3 and 4).

Another observation is the concentration of hp in the mining, metal, food and textiles industry and the steep increase of hp in the chemical industry after 1907. According to Aubin and Zorn (1976) are the mining and metal industry particularly energy intensive due to intensive use of steam engines and very energy demanding smelting processes. In comparison to those industries is the wood or leather industry, despite increasing hp rather low in energy intensity (Schön, 1990; Aubin and Zorn, 1976).

The industrial energy input (see table 2) mirrors the trend of the employed horsepower. The calculated energy figures show a constant increase over the whole period, with the sharpest increase between 1879 and 1925 from 50.85 peta joules to 770.05 peta joules per year.

The energy input of the industrial sub-sector in peta joules

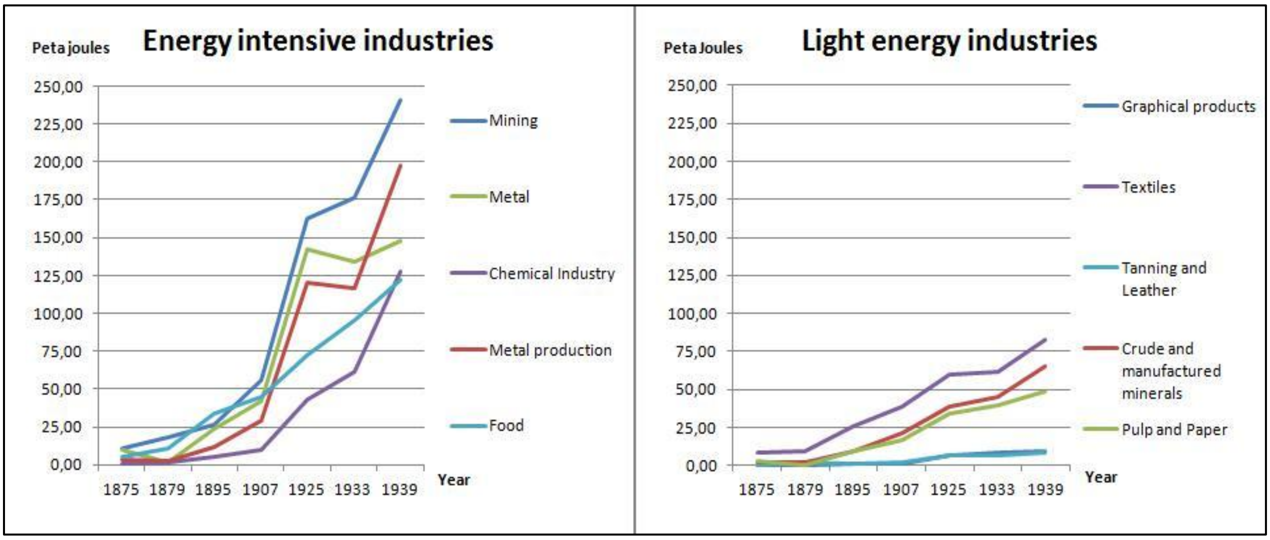
Energy input in pt joules (EO in peta joules*thermal efficiency)							
	Efficiency:						
	17%	17%	17%	20%	20%	23%	23%
Industrial sub-sectors	**1875**	**1879**	**1895**	**1907**	**1925**	**1933**	**1939**
Mining	11,09	17,93	26,50	56,01	162,86	175,97	241,17
Crude and manufactured minerals	1,80	2,15	9,58	20,91	38,90	45,47	65,42
Metal	9,68	1,74	23,78	42,04	142,64	133,85	148,23
Metal production	3,11	2,64	11,67	29,18	120,16	116,49	197,61
Chemical Industry	1,02	1,38	4,96	10,25	43,15	61,17	127,95
Textiles	8,56	9,40	26,02	38,28	59,36	61,35	83,06
Tanning and Leather	0,19	2,30	1,02	2,40	6,45	6,90	8,34
Wood product	1,60	2,46	9,92	18,19	43,24	49,10	67,54
Pulp and Paper	2,63	0,00	9,68	16,74	34,39	39,61	49,10
Graphical products	0,15	0,32	0,88	1,49	6,65	8,41	9,52
Food	5,45	10,40	33,70	45,05	72,21	95,68	122,06
Gas-, Water- u., Electricity	0,44	0,00	2,97	43,44	20,50	35,98	73,68
Construction	0,34	0,11	2,24	6,61	19,55	27,60	50,89
Total	**46,05**	**50,85**	**162,90**	**330,59**	**770,05**	**857,59**	**1244,58**

Table 2: Energy input in peta joules in regard of changing thermal efficiencies for the benchmark years 1875, 1879, 1895, 1907, 1925, 1933 and 1939. Source: Own calculations.

Table 2 shows that the energy consumption of the mining, metal, metal production, pulp and paper and chemical industries increased the most throughout the upswing and peak phase of the EKCE.

The energy input of the chemical industry follows the described development by Aubin and Zorn (1976) and surpasses the textile industry in terms of energy input by the end of the period. Following the example of Schön’s (1990) separation of heavy and light industries, the development of the energy input of the sub-sectors can be used to separate the German industries in the same manner (see graph 5).

Comparison of energy inputs between heavy and light industries



Graph 5: Comparison of energy input development between energy intensive and light energy industries from 1875 to 1939. Source: Own calculations

Graph 5 shows the separation of heavy and light industries for the case of Germany. The industries were separated according to their level of energy consumption in respect of their employment of steam engines. The sub-sectors that exceeded the input level of 100 peta joules are labeled heavy industries and the remaining branches were grouped into the light energy industries. This segregation differs from Schön's groups of the Swedish sub-sectors due to the application of hp as a proxy for energy consumption. While the food industry and the metal production belong to the energy intensive industries in the case of Germany, the pulp and paper and crude and manufactured minerals industry are grouped into the light industries.

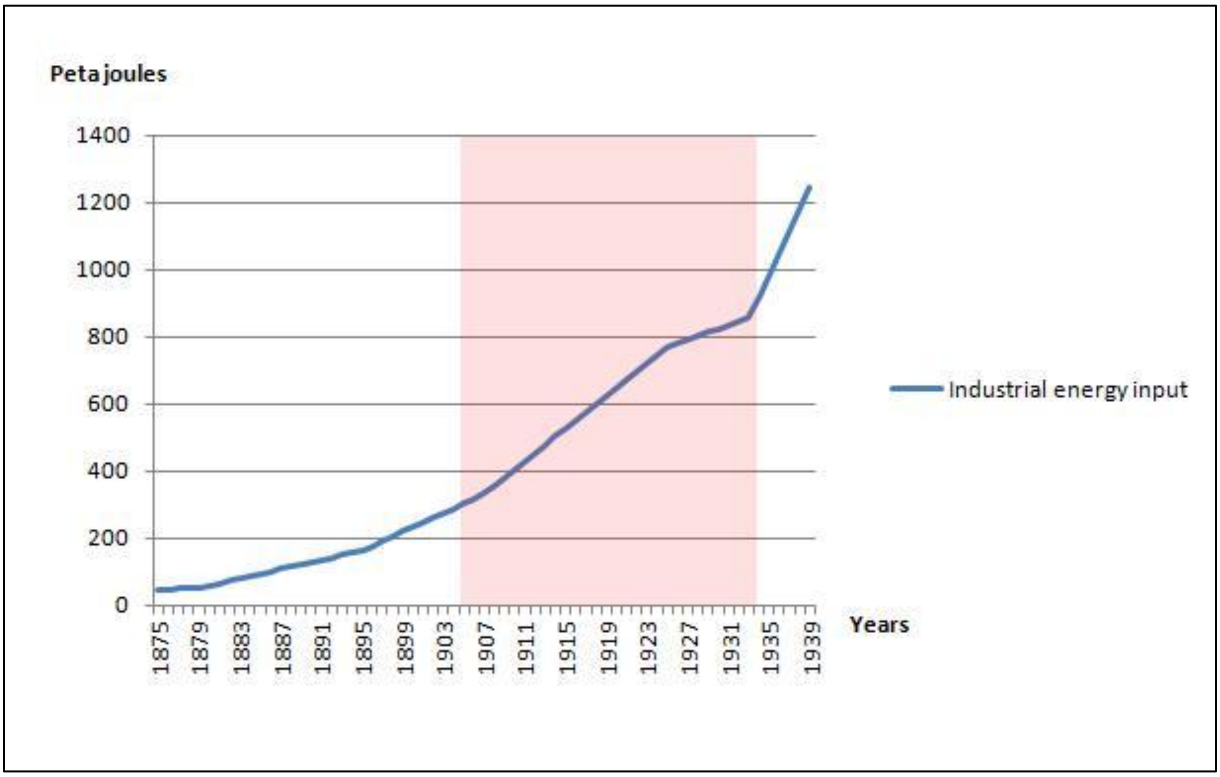
Industries like paper and pulp, and crude and manufactured minerals were dependent on heat power for the production which explains why Schön considers those industries energy intensive and this study does not.

The comparison of energy consumption in the heavy and the light industrial sectors reveals that the heavy industries not only consumed more energy in total, but that the energy inputs also increased steeper in the observed period. Graph 5 illustrates that the mining, metal and metal production industry rose the sharpest between 1907 and 1925, and passed the mark of 125 peta joules throughout the observed period. Although the light industries increased their energy consumption, their energy inputs accelerated slower than the heavy industries (see

Graph 5). The overall increasing trend is reflected in both heavy and light industries; however the heavy industries increased more rapidly throughout the observed period.

The energy consumption figures of the industry can be used on an aggregate level to show the development of the total industrial energy input (see graph 6).

Total industrial energy input



Graph 6: Industrial energy input in peta joules. Source: Own calculations.

Graph 6 summarizes the development of the aggregated industrial energy input of all sub-sectors. After the previous analyzes of energy consumption of sub-sectors the rising trend of the industrial energy input, as shown in graph 6, is not surprising. However, through the previous investigation of energy consumption on an disaggregated level it can be inferred that the heavy industries (mining, metal, metal production, food and chemical) contributed not only greatly to the increase in industrial energy input, but are also the drivers of the acceleration of industrial energy input between the early 20th century and the beginning 1930's as highlighted in the red area of graph 6.

In order to make the impacts of the industrialization on energy consumption visible, the ratio between industrial energy consumption and overall energy consumption can be created for the benchmark years (see table 3).

Comparison of industrial and total energy consumption

Ratio industrial energy consumption/ total energy consumption							
energy consumption in pt joules	**1875**	**1879**	**1895**	**1907**	**1925**	**1933**	**1939**
Total energy consumption	1621	1731	3209	5459	6498	5286	7203
Industrial energy consumption	46,05	50,85	162,90	330,59	770,05	857,59	1244,58
Ratio	**2,84%**	**2,94%**	**5,08%**	**6,06%**	**11,85%**	**16,22%**	**17,28%**

Table 3: Ratio of the industrial energy consumption and the total energy consumption. The total energy consumption figures are provided by Kander et al. (2012). The industrial energy consumption was generated through own calculations.

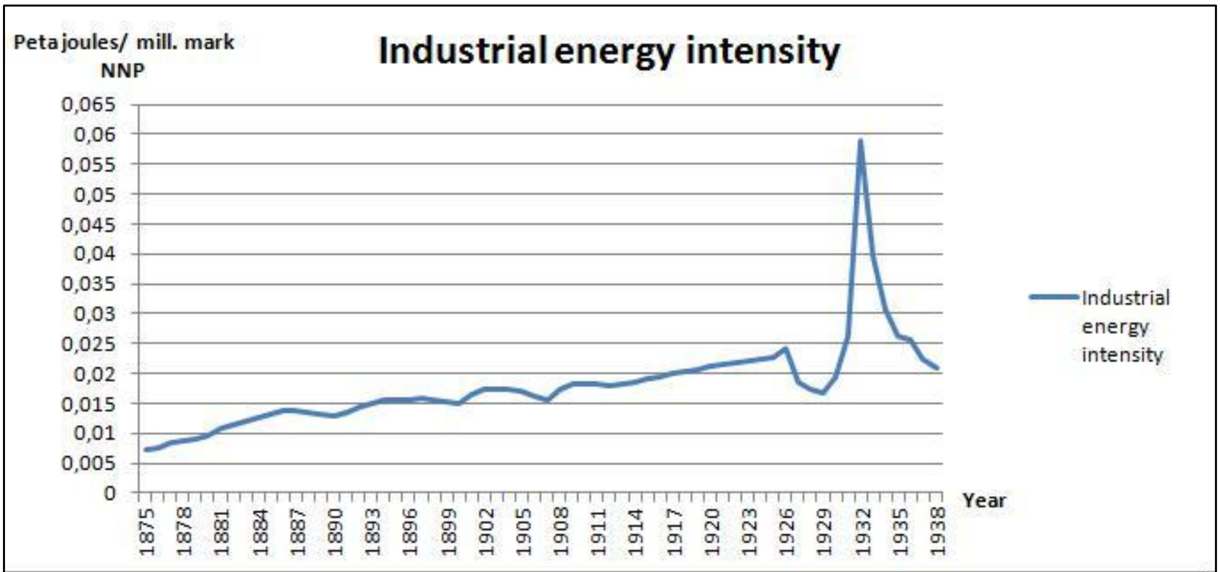
Table 3 shows that the industrial energy input continuously increased its share of total energy consumption. While in 1875 only 2.84% of the total energy was consumed in the industrial sector, it was 17.28% by 1939. Similar to the development of industrial energy consumption the share of industrial energy input increased the most between 1907 and 1933. The most drastic increase of 5.79 percent points between 1907 and 1925 mirrors the acceleration of energy inputs of the heavy industries (see graph 5).

This development shows on the one hand that the industrial sector grew in importance in terms of energy consumption, and on the other hand that the impact of the industrial energy consumption increased the most during the upswing and peak phase of the German EKCE (see graph 3 and 4).

For the further analysis of the possible influence of international trade on the upswing of the EKCE, the energy intensity of the industrial sector has to be calculated to estimate the energy embodied in traded goods.

The aggregated industrial energy intensity is generated by dividing the industrial energy consumption figures with production values of the aggregated industrial sector. Hoffmann (1965) provides the times series for the production values between 1880 and 1933 on an aggregated level in current prices, which does not allow a detailed examination of the sub-sector intensities in this section. The aggregated energy intensity of the industry is calculated for the benchmark years and interpolated in between to exemplify the development of the industrial energy intensity (see figure 1).

Industrial energy intensity graph and table for the benchmark years



	1875	1879	1895	1907	1925	1933
Industrial share of value added	6487	5732	10408	21081	33849	21682
industrial energy input	46,05	50,85	162,9	330,59	770,05	857,59
industrial energy intensity	0,0071	0,0089	0,0157	0,0157	0,0227	0,0396

Figure 1: Development of the industrial energy intensity in peta joules per mill. Mark NNP in current prices in the Graph. Production values of the industrial sector in mill. Mark, current prices and industrial energy input in peta joules for the benchmark years. Source: Hoffmann (1965) and own calculations.

Figure 1 shows the production values in current prices for the benchmark years except for 1939 as Hoffmann’s time series exhibits gaps from 1913 to 1925, and 1938 to 1950.

The illustrated development of the industrial energy intensity increases over the whole period. The moderate level of the intensity between 0,0071 and 0,0396 pt. joules/ mill. Mark can be explained by the use of the energy consumption proxy of hp. As discussed before, this proxy understates the energy consumption and therefore the energy intensity. However, the development of energy intensity is in the foreground in this study and can be examined regardless of the level of energy consumption or intensity.

The striking spike in 1932 in figure 1 reflects a sudden increase in industrial energy intensity due to the repercussions of the global economic crisis of the late 1920’s. This period constitutes a severe recession in Germany, which saw rapidly decreasing NNP and industrial production values (Hoffmann, 1965). Although the production slowed down faster than the energy consumption as suggested in the previous section (see graph 3), the peak in industrial energy intensity appears too extreme due to the applied method. This spike in the industrial energy intensity in 1932 is likely to be smaller if the working time of the steam engines is adjustable more flexible to exogenous shocks like the Great Depression. Hence the spike in figure 1 is a clear overestimation of the industrial energy intensity due to the applied method. This methodological issue will be discussed in more detail in the last part of this study. Though, it has to be noted that the erratic increase of the industrial energy intensity in 1932 will not be emphasized particularly in this study as it does not interfere with the upswing period of the EKCE.

The presented table in figure 1 shows that the production values of the aggregated industrial sector declined from 1875 to 1879 and increased rapidly between 1879 and 1925. Between 1925 and 1933 the production values decreased and fell almost back to the levels of 1907.

Despite the directional changes of the production values, the industrial energy intensity increased steadily with an exception between 1895 and 1907, were it remains steady at 0,0157 peta joules per mill. Mark NNP. This development illustrates that the energy inputs rose faster than the production values. The decline of the production values between 1925 and 1933 depicts the aftermath of the Great Depression (Henning, 1996), which could also explain the slower increase of the energy consumption after 1925 in comparison to years before.

Building up on the results of this section the following part of the study will attempt to find indicators for an increase in Germany's energy balance of trade to prove that foreign trade impacted the EKCE of Germany in the upswing phase. The calculated energy intensities and the energy consumption of the sub-sectors are crucial for the following analyzes.

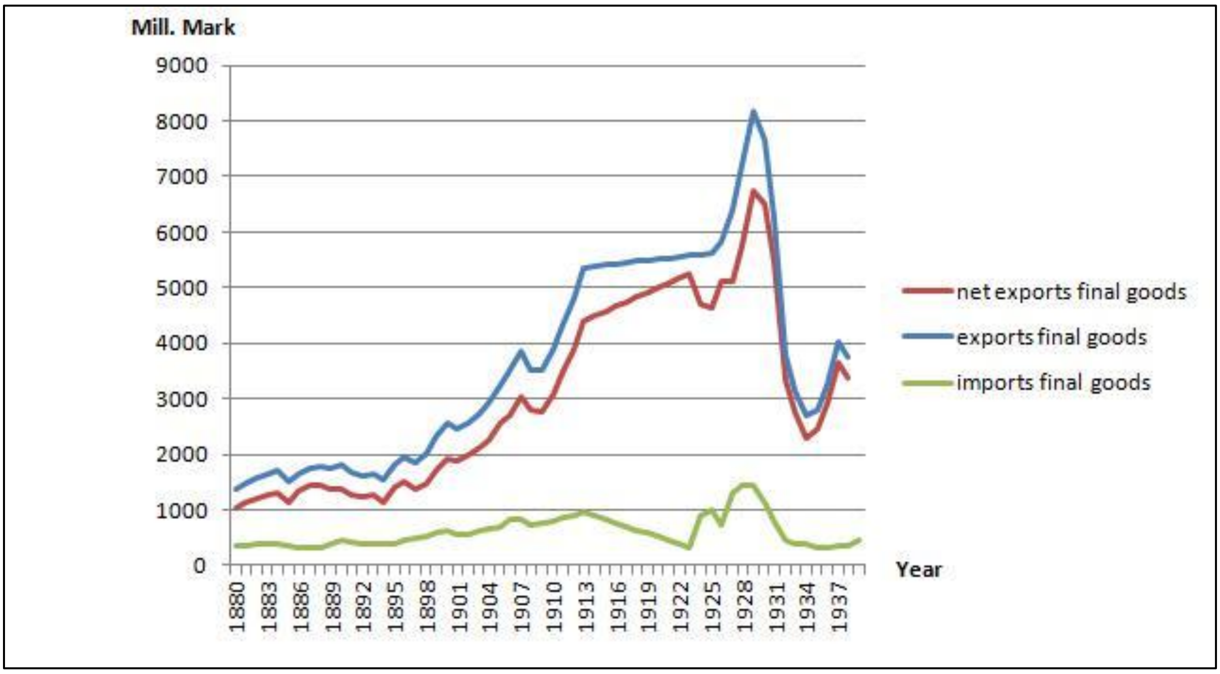
4.3 The Net Exported Energy

Henning (1996) points out that foreign trade grew rapidly in the second half of the 19th and early 20th century. Furthermore, the researcher states that final goods constituted the main part of Germany's exports (Henning, 1996). Therefore the energy balance of trade will be calculated in a first step for final goods because final goods are produced in the industrial sector and constituted the lion share of the exports (Rosenberg, 2007). The industrial energy consumption and intensity can be used to investigate the energy embodied in finished goods. Afterwards it will be attempted to investigate the role of heavy and light industries in relation to trade more detailed and find indicators for their contribution to the energy embodied in traded goods.

4.3.1 The Energy Balance of Trade

The energy embodied in traded goods can be calculated on an aggregated level for the whole industrial sector by multiplying the industrial energy intensity from the previous section with the net exports of finished goods. Hoffmann (1965) provides the trade statistics for exports and imports of final goods (see graph 7).

Net exports of final goods



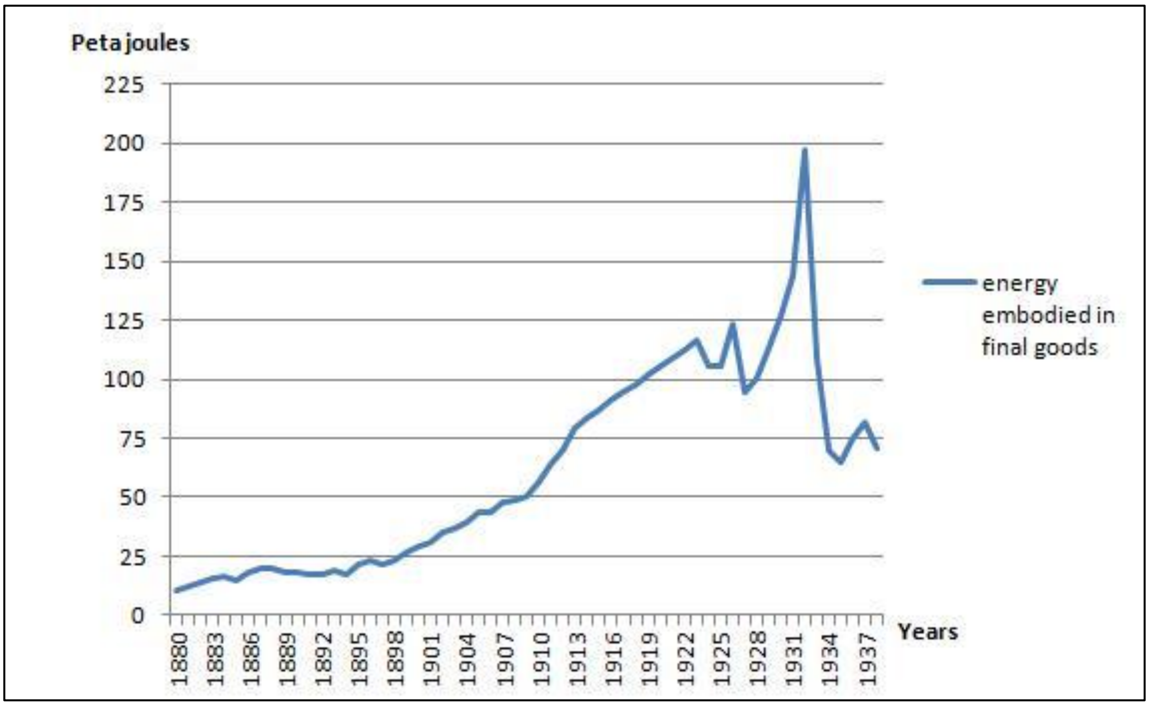
Graph 7: International trade of final goods in current prices in mill. Mark. Source: Hoffmann (1965)

Graph 7 illustrates the development of Germany's foreign trade in final goods. The graph shows a steep increase in net exports of finished goods between 1895 and 1929 and a decline afterwards. This development indicates the growing importance of international trade for Germany's economy throughout the upswing and peak phase of the EKCE. Moreover it shows the decrease at the beginning of the 1930's due to the Great Depression (Aubin and Zorn, 1976).

The graph shows clearly that Germany was a net exporter of final goods which proves the statements of Henning (1996) and is not surprising as the early industrialized countries shifted their production first to manufacturing and could produce final goods in higher quantities and cheaper prices before other trading partners.

In order to generate the energy embodied in trade, the data of net exported final goods are multiplied with the obtained industrial energy intensity from the previous section (see graph 8).

The energy embodied in final goods



Graph 8: Energy embodied in trade of final goods in peta joules. Source: Own calculations.

Graph 8 shows a constant increase in energy embodied in final goods and therefore in energy embodied in trade. While only in 10.13 peta joules of the industrial energy input were net exported and consumed in other countries in 1880, the energy embodied in net exported finished goods exceeded the level of 100 peta joules in 1919 and kept increasing. This development depicts a tenfold increase of net exported energy in final goods within less than 50 years. It has to be noted that graph 8 contains a similar error to the industrial energy intensity graph in figure 1. The spike in energy embodied in final goods between 1931 and 1933 is likely to be smaller due to the applied method. Although the net exports decrease significantly from 6502.6 mill. Mark in 1930 to 2754,3 mill. Mark in 1933, the energy embodied in final goods seems to increase due to the overestimation of the energy intensity throughout the crisis years. The spike of energy embodied in final goods in the early 1930’s reflects this error and shall not be considered in the following analysis.

The values of the energy embodied in final goods can be used to create the energy balance of trade for the period between 1880 and 1938 (see graph 9). The energy balance of trade gives valuable clues about the impact of international trade on the overall energy intensity. According to Kander and Lindmark (2005) the direction of the development of the energy balance of trade indicates if foreign trade supported a rising or decreasing energy intensity trend. The level of the balance is rather negligible (Kander and Lindmark, 2005).

The energy balance of trade of final goods 1880 - 1913

Graph 9: Energy balance of trade of final goods. Source: Own calculations.

Graph 9 shows the development of the ratio between industrial energy input (IEI) and energy embodied in trade (EET) between 1880 and 1913. The graph illustrates that the energy balance of trade of final goods follows a decreasing trend between 1880 and 1897 which indicates that trade of final goods did not contribute to the increasing energy intensity at that time. In this period the volume of international trade and therefore net exports and energy embodied in trade was rather small in comparison to the subsequent period from 1898 to 1913. This development could be explained by the considerably smaller amount of traded goods before 1898. The net exports of final goods increased most significantly after 1898 and so did the energy embodied in goods (see graph 7 and 8). Apparently the energy embodied in goods and the volume of foreign trade was too marginal to affect the energy intensity positively. The suggested hampering effect between 1880 and 1898 is therefore assumed to be smaller than the reinforcing effect suggested by the development after 1898.

Furthermore the graph illustrates that the direction of the energy balance of trade of final goods changes and increases between 1897 and 1913 which matches the late phase of the upswing period of the German EKCE. Thus international trade of final goods had a rather hampering effect on the increasing energy intensity of Germany between 1880 and 1897. However in the beginning phase of the most drastic increases of net exports and energy consumption between 1900 and 1913, the energy balance of trade of final goods also increased and reinforced therefore the upswing of the EKCE.

The available data do not allow a comprehensive analysis of the period after 1913. The time period is shortened because the interpolated values between 1913 and 1925 would show a flattening out which is not representative. The period after 1925 represents the downswing of the EKCE and is therefore not of concern in this study. Furthermore there are difficulties with the values of the late 1920's and early 1930's because they reflect a different development due to the exogenous shock of the Great Depression, which had great influence on the production output, foreign trade and therefore energy consumption (compare Graph 8 and figure 1). These difficulties are discussed in more detail in section 5.1 in this paper. The data issues for the period after 1913 are explained in the appendix (see appendix C).

It has to be noted that Graph 9 depicts the energy balance of trade in final goods, which excludes the net exports of coal as coal is a raw material and mining rather belongs to the primary sector (Rosenberg, 2007). Although the mining industry was a net exporter of energy embodied in goods it has to be excluded in energy balance. However the overall contribution of the mining industry to the net exports of the heavy industries is rather small and does not affect the energy balance significantly.

The analysis of the energy balance of final goods between 1880 and 1913 has revealed that trade, at the stage of finished goods, did not support the rise of the EKCE between 1880 and 1897 but rather hampered it, as indicated by the decreasing energy balance of trade. This development proves the hypothesis of the impact of international trade on the upswing period of the EKCE wrong for the early upswing phase. However, the analysis has also shown that trade became more significant for the upswing between 1897 and 1913 and contributed positively to the rising energy intensity. The increase of the energy balance of trade in late upswing period proves the hypothesis that international trade influenced the EKCE and reinforced its rise but only for the late upswing phase and not the entire upswing. However an analysis at such an aggregated level contains inaccuracies because differences in energy intensities between sub-sectors are not accounted for. If energy intensive industries, like the metal or chemical industry contributed greater to the net exports than light industries, it can be inferred that the energy balance of trade would increase more rapidly during the observed period because the energy embodied in goods would be higher.

For that reason it will be attempted to investigate the net exports of finished goods of heavy and light industry branches in the following section. The aim is to find evidence for a greater contribution of heavy industries to the energy embodied in trade and thus evidence for a more rapid increase of the energy balance of trade and an earlier increase than the one suggested in the previous analysis.

4.3.2 Trade Patterns of Heavy and Light Industries

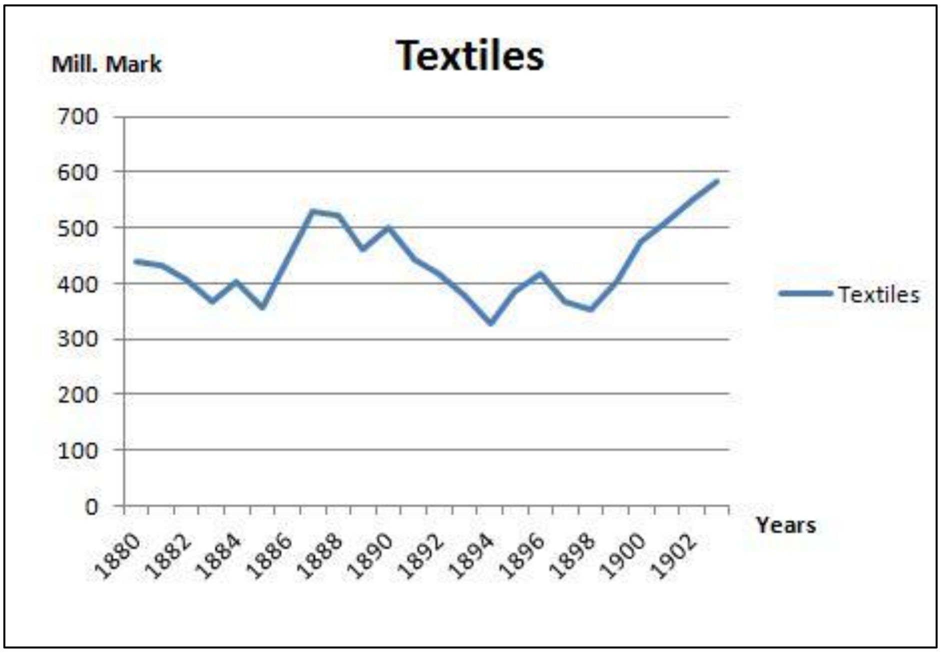
The previous analysis revealed the growing importance of international trade for the EKCE and suggests that Germany's foreign trade of final goods supported the upswing of the EKCE between 1897 and 1913 but not earlier. However, the analysis did not consider differences in energy intensities between heavy and light industry branches, which particularly influence the energy embodied in traded goods. Depending on which industry, heavy or light, had a greater share in net exports of final goods the energy embodied in trade could be greater or smaller as presented before. If the share of energy intensive net exports exceeds the net exports of light industries it can be inferred that the energy embodied in trade is actually greater than suggested in the section before. Thus the energy balance of trade would have shown a more rapid increase between 1897 and 1913 or a possible rise even before 1897. Therefore the net exports will be analyzed on a sub-sector level in the following.

The statistical yearbooks of the German empire 1888, 1895, 1904 present disaggregated trade statistics of some heavy and light industries. The statistics after 1904 follow a different disaggregation of foreign trade into specific commodities traded. The disaggregation after 1904 is more detailed; however, a possible aggregation of all traded commodities into the trade of industrial branches would exceed the scope of this study. Therefore will the following analysis focus on the data of the statistics from 1880, 1895 and 1904 which cover the net exports of heavy and light industries between 1880 and 1903. This 23 year period represents the mid and late period of the upswing phase of the EKCE and will provide valuable insight into the trading patterns of the industrial sub-sectors.

Through the merger of the statistics from 1880, 1895 and 1904 a time series of heavy and light net exports can be generated and the development and trade volume of the sub-sectors can be illustrated.[6]

The time series of net exports shows that the textile industry comprised the biggest share of net exports among the observed sub-sectors (see graph 10, 11 and 12).

Development of the net exports of the textile industry from 1880 to 1903



Graph 10: Development of the net exports of final goods of the textile industry in mill. Mark between 1880 and 1903. Source: Own calculations.

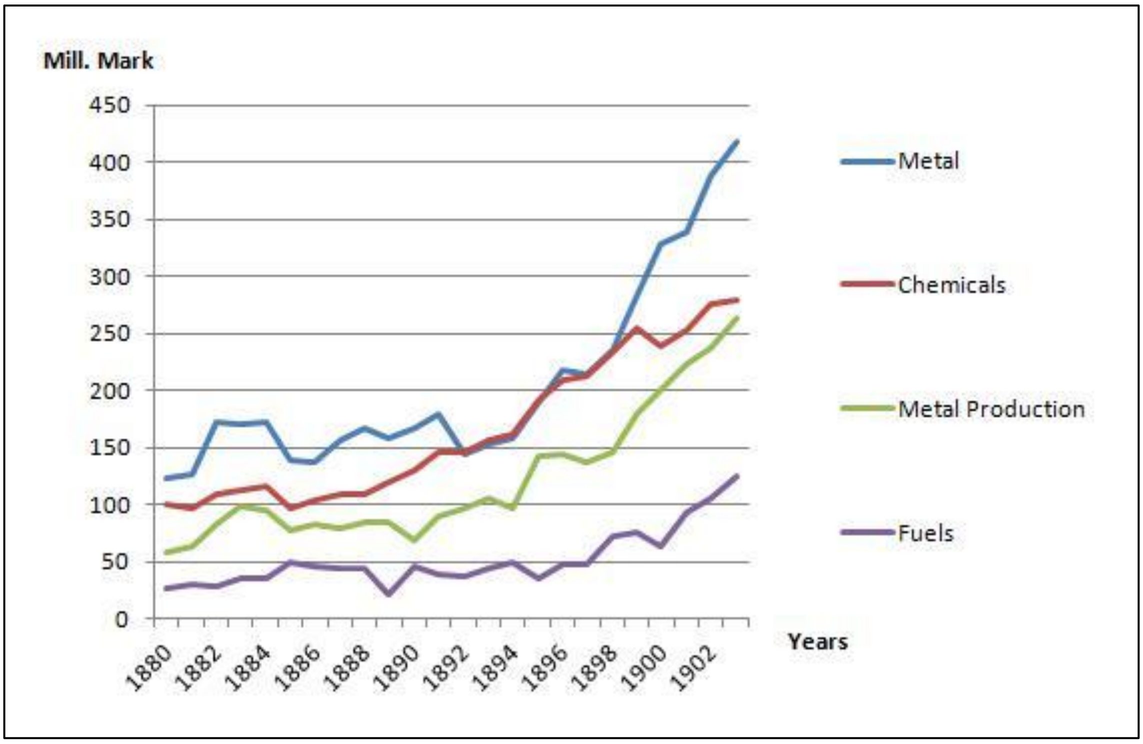
Graph 10 illustrates up- and downswing developments without a clear observable trend in the beginning. However, from 1894 onwards an increasing development till 1903 is visible.

[6] The statistical yearbook of the German Empire from 1888 differentiates between common commodity trade (*"allgemeiner Waarenverkehr"*) and special commodity trade (*"besonderer Waarenverkehr")*. For the years 1880 to 1887 only the common commodity trade was included in the calculations. Common commodity trade comprises the free movement of goods immediately or with consignment documents without outward or inward processing of goods. The statistical yearbook of 1895 differentiates between general trade of goods (*"Generalhandel"),* total proprietary trade ("*Gesamteigenhandel")* and special commodity trade (*"Spezialhandel"*). For the years 1888 to 1994 the special commodity trade was used in this study because it also comprises the free movement of goods immediately or with consignment documents without outward or inward processing of goods. The general trade of goods is only displayed in ton quantities and the total proprietary trade includes inward and outward processing of goods. In the statistical yearbook of the German Empire from 1904, even the special commodity trade includes the inward and outward processing goods from 1897 onwards. Therefore there is only a marginal difference between special commodity trade and total proprietary trade for the years from 1897 to 1903. In this study the total proprietary trade was used for the years 1895 to 1903. The slightly differing data sets of the statistical yearbooks from 1888, 1895 and 1904 are however used in all considered sub-sectors throughout the same period so that differences in the captured data apply to all sub-sectors and do not distort the overall trend.

The volume of net textile exports exceeds other sub-sectors significantly, reaching up to over 500 mill. Mark in net exports. This value is not reached by any other industry in the observed period, which seems to contrast the assumption that the heavy industries contributed greater to the net exports than the light sectors. However, the textile industry is a clear exception compared to the other light industries and is furthermore the most energy intensive industry among the light industries (see graph 5). Therefore the development of the other heavy and light industries has to be considered in more detail.

The development of the energy intensive sub-sectors is depicted in the following graph (see graph 11).

Development of net exports of heavy industries from 1880 to 1903

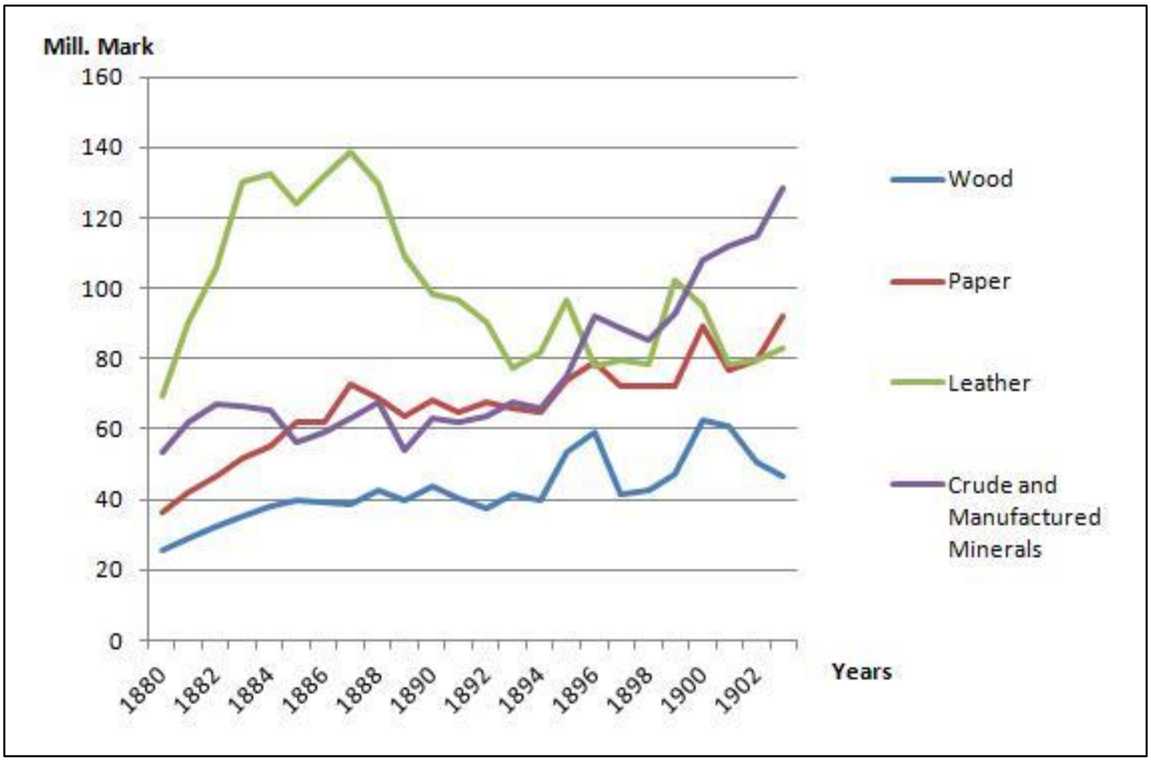


Graph 11: Development of the net exports of final goods of energy intensive industries in mill. Mark between 1880 and 1903. Source: Own calculations.

Graph 11 shows not only that the heavy industries metal, chemicals, metal production and mining were net exporters of final goods but also that all industries increased towards the end of the observed period steeply. The sharpest increase is exhibited in the metal industry, which starts rising in 1892 and remains steady till 1903. The net exports of the chemical industry rise more gradual than the metal and metal production exports and start increasing in 1885. The slowest increase is calculated for the fuels of all kinds, which are attributed to the mining industry sector as coal was the main energy carrier of that time (Henning, 1996).

The development of the light industries shows a rather gradual development throughout the observed period (see graph 12).

Development of net exports of heavy industries from 1880 to 1903

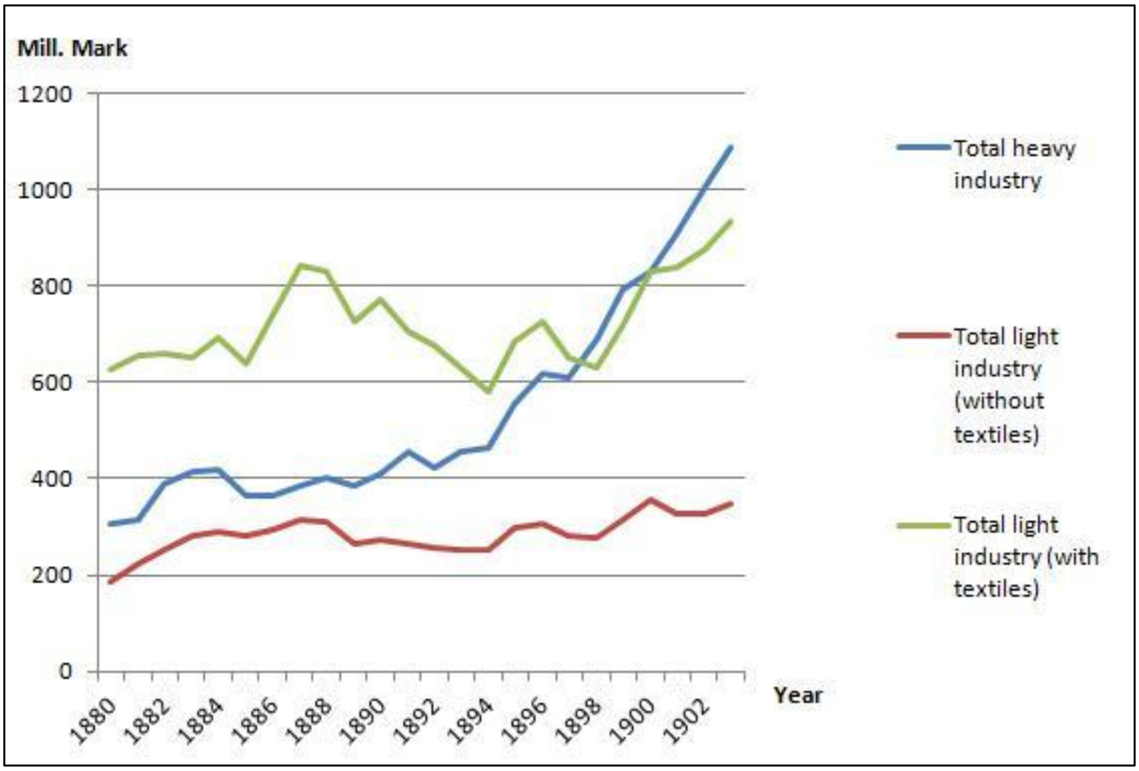


Graph 12: Development of the net exports of final goods of light industries in mill. Mark between 1880 and 1903. Source: Own calculations.

Graph 12 shows that although an increasing trend is identifiable for the wood, pulp and paper and particularly the industry of crude and manufactured minerals this development is not as clearly as in the case of the heavy industries. The pulp and paper industry shows an increase over the whole period but no significant take-off phase as seen in some of the energy intensive industries. The industry of crude and manufactured minerals on the other hand follows the increasing pattern of graph 11 and rises more sharply from 1885.

A comparison between the development of the aggregated net exports of heavy and light industries shows that the trade volumes of the heavy industries were, with the exception of the textile industry, notably higher than the trade volumes of the light industries (see Graph 13).

Comparison between the net exports of heavy and light industries



Graph 13: Comparison of the net exports in mill. Mark between heavy and light industries between 1880 and 1903. Source: Own calculation

Graph 13 illustrates the combined development of heavy and light industries between 1880 and 1903. The graph depicts that the net exports of the heavy industry exceed the light industry without textiles clearly over the whole period. Furthermore it shows the rapid increase of energy intensive net exports between the 1890's and 1903. If the textile industry is included the net exports of the heavy industry surpass the net exports of the light industry in 1898 and keep increasing more rapidly. The point of intersection in 1898 coincides with the increase in the energy balance of trade.

Although the format of the statistics does not allow a further analysis of the net exports after the year 1903, the examination of the net exports of final goods between 1880 and 1903 shows that the heavy industries comprised the major share of net exported final goods already in 1898. The sharp increase of the energy intensive net exports even before 1898 and the fact that the textile industry is more energy intensive than the other light industries supports the assumption that the energy balance of trade would show more drastic increases if the energy embodied in final goods would be calculated for the individual sub-sectors. Moreover the energy balance of trade is likely to show increases even earlier than stated in the section before as the heavy industries play a bigger role than the majority of the light industries in terms of net exports and increase already before 1898.

In order to determine the energy balance of trade and therefore the impacts of trade on the EKCE in more depth, further research has to be done on this topic.

V. Results and Reflections

The results of this study show that international trade of final goods contributed to the rising EKCE in the late upswing period between 1898 and 1913, which is indicated by an increasing energy balance of trade. A positive contribution of trade in the early upswing period could not be proved by the development of the energy balance of trade, rather the opposite was found. Although some of the presented evidence indicates that the energy balance of trade could have looked different if sub-sectors were analyzed individually. However, the used data and the applied method have to be reviewed critically before a final conclusion can be drawn.

5.1 Critical Discussion

The most striking limitations of this study can be located in the methodological approach and the applied data. The impact of trade on the energy inputs and intensity could only be analyzed on the aggregated stage of final goods.

Highly aggregated data contain the disadvantage that structural changes in the aggregates over time find no consideration. Specific changes of energy intensities in a sub-sector or changing quantities of traded commodities find no consideration. In the final part of the analysis it is tried to emphasize the varying importance of industries for the net exports, however an empirical analysis could not be conducted.

Additionally the available data did not permit an analysis of all energy inputs along the production chain in the style of an input-output analysis. As only final stage products are considered it has to be noted that the energy input throughout the whole production chain may vary from the one displayed in this analysis. Another important remark is that the study assumes that imports and exports are produced with the same energy effort, which implies that the production technology and the level of specialization is the same for all trading partners. It appears obvious that this is not the case and that imports might have been produced with more or less energy input than exports. To limit the data requirements to a manageable level this assumption had to be presupposed in this study. Further research could overcome these shortcomings by applying a comprehensive multi-regional input-output analysis which investigates on the one hand the energy inputs throughout the whole production chain and on the other hand accounts for regional differences in the energy consumption of production. By that way technological and developmental differences could be accounted for more accurately.

Another remark concerns the cross sectional character of this study which analyzes limited data points in time and does not give the deep insights of a comprehensive time series analysis. The in the data section stated restrictions did however not allow the creation of such a time series in this study. Although the examination of the data points gives valuable insights and generate clues about the impact of trade on the EKCE, further research has to be done to underpin those findings empirically.

A further shortcoming of the applied model is the inflexibility to adapt to exogenous influences on the economy and the energy consumption. Although, it is tried to award the method with flexibility by applying changes in thermal efficiency of the steam engines and regard technology changes, the application of an average working time of the machines leads to energy inputs that do not react to exogenous shocks in the economy. The spike in the energy intensity in the early 1930's (see figure 1) reveals this shortcoming as the working time is assumed to be 3120 hours a year even though it is known that the German production slowed down significantly at that time. This leads to an overstatement of the industrial energy intensity, thus the energy embodied in trade, thus the energy balance of trade. Though, it has to be noted that the period of main interest between 1880 and 1913 did not contain such a tremendous exogenous shock as the world economic crisis in the late 1920's. Therefore it is believed that a higher flexibility of the method would not have changed the results of this study significantly in the period between 1880 and 1913.

More influence on the presented results is however expected if the energy consumption would not have been estimated through the employment of the hp proxy. It is stated before that a considerable part of the energy consumption in the industry was used for energy intensive heating processes of furnaces. The applied proxy excludes therefore a considerable amount of industrial energy input, for example in the metal, chemical or pulp and paper industry. The figures of the energy embodied in trade are assumed to change if the heat energy would be regarded. However, the limited data accessibility of energy use for heating did not allow to include such data. Furthermore, it would rather reinforce the statement that international trade had an impact on the EKCE because the figures for energy embodied in trade would increase more rapidly, and so would the energy balance of trade. Some of the industries that are labeled light in this study would increase their energy consumption and become heavy industries, for example the pulp and paper industry which was dependent on heating processes (Schön. 1990). Moreover it is stated by Kander and Lindmark (2005) that the level of the energy balance of trade is not per se a good indicator of the influence of trade on energy intensity, but the relative changes are. Hence, the used proxy of horsepower per industry seems reasonable to indicate the energy consumption of industries and analyze the relative changes in the energy balance of trade.

5.2 Conclusion

In spite of the discussed data limitations and methodological issues the study could detect evidence for the existence of a reinforcing effect of international trade on the German EKCE between 1898 and 1913. The analysis of the foreign trade of final goods disclosed that trade became significant for the development of energy intensity already during the phase of the late industrialization due to the increasing globalization and the accompanied increase of commodity flows between countries.

The assumption of an inverted U-shaped curve of Germany's EKCE could be strengthened by the application of NNP data in current prices and information about the overall energy intensity development. The use of Hoffmann's (1965) NNP in current prices as an economic indicator illustrated that the peak phase of the EKCE was earlier than stated by Kander et al. (2012), namely between 1891 and 1908. Therefore the analysis could determine the upswing period between 1850 and 1890 for further examination. The findings of the energy balance of trade revealed that trade cannot be held responsible for the entire upswing phase because the energy balance of trade showed a declining trend between 1880 and 1898. This development indicates that trade was too marginal to affect the energy intensity and suggests that trade had a rather hampering effect on energy intensity until 1898. For the peak phase between 1898 and 1908, the direction of the energy balance of trade changed however, and gives evidence that trade reinforced the rising energy intensity throughout this high phase. This development strengthens the assumption that international trade of finished goods increased the energy intensity between 1898 and 1908. Evidence for the presumption that the energy intensity of Germany would have peaked at lower levels without foreign trade could not be found empirically. However, the increase in energy embodied in goods and the rising energy balance of trade of final goods strengthen the hypothesis.

Moreover, the in depth analysis of the net exports of final goods of the sub-sectors show that the peak phase was initiated in 1898 which coincides with the interception point of heavy and light net exports. The development and the share of net exports of final goods suggests that the energy balance of trade would have increased more rapidly and most likely even before the initiation of the peak phase if the individual energy intensities of sub-sectors would have been considered. This statement is strengthened by the fact that the majority of net exports of finished goods belong to the group of the heavy industries even before 1898, if the textile industry is excluded. Aside from the textile industry the light industries show significant lower trade volumes in net exports of final goods than the heavy industries. Furthermore it has to be considered that the textile industry is the most energy intensive industry among the light once, which supports the argument that a more detailed analysis of the energy intensities and energy embodied in trade on a sub-sector level would facilitate an earlier and more rapid increase of the energy balance of trade.

Additionally to the presented evidence one has to bear in mind that the energy consumption in this study does not contain the energy used for heating and energy intensive smelting processes. As this energy consumption constitutes a considerable share of the energy consumption one can expect the energy embodied in trade to be even higher and so to be the energy intensity. Especially industries which were dependent on high temperatures for smelting or boiling processes, like the metal or the pulp and paper industry.

Summarizing the results of the study and the presented indicators it can be argued that the increasing development of Germany's energy intensity was most likely influenced by the ongoing rises in foreign trade especially between 1898 and 1908, and in the late phase of the upswing period between 1880 and 1898. Trade seem not to have reinforced the upswing of the EKCE before 1880 as the energy balance of trade decreased and the overall volume of international trade was small compared to the volumes after 1880. As the trade volumes were generally lower than during the second half of the 20th century one can argue that the EKCE of Germany existed even if the energy consumption is put into the foreground, but might have peaked at marginally lower levels without the reinforcement of international trade in the late upswing and peak phase from 1880 to 1908.

The statement that Germany was a net exporter of energy is true for final goods. However, the assumptions that the energy balance of trade increased over the whole upswing period is not valid, as the balance started to increase rather in the peak phase and possibly in the late upswing. Not throughout the entire period between 1850 and 1913. The energy balance of trade at an aggregated level revealed quite the opposite; a decrease of the balance between 1880 and 1898.

As a concluding remark it can be emphasized that although globalization only accelerated at the time of the industrialization, and economic transactions between countries did not have today's dimension, international trade mattered for the overall energy consumption.

In the case of Germany the consumption based approach has given valuable insights and evidence for the positive contribution of foreign trade on energy intensity development in the late upswing and peak phase of the EKCE. To analyze this development in more depth further research has to be undertaken. Hopefully this study can encourage more detailed studies on the topic and support the focus on the consumption side instead of the traditional emphasize on production.

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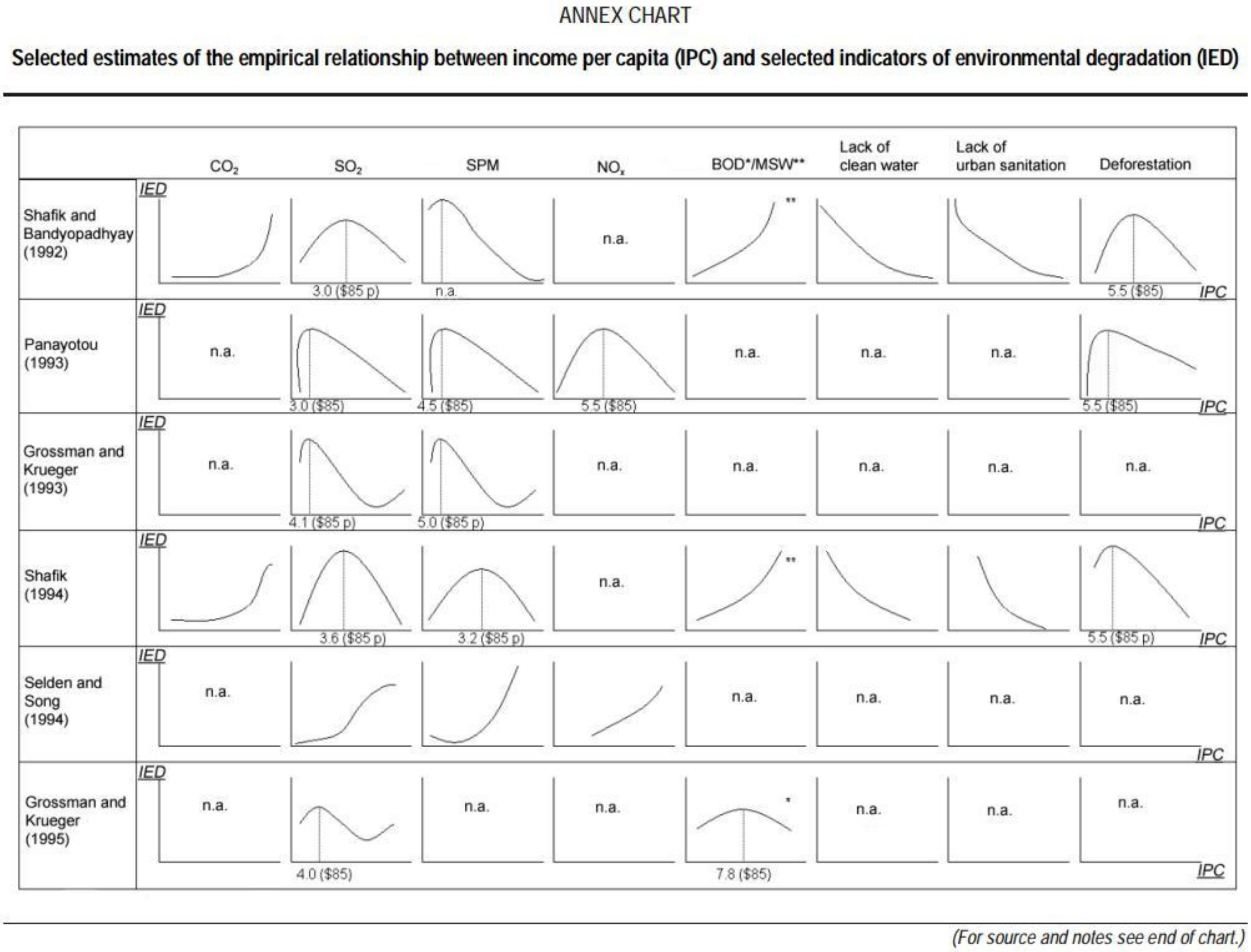
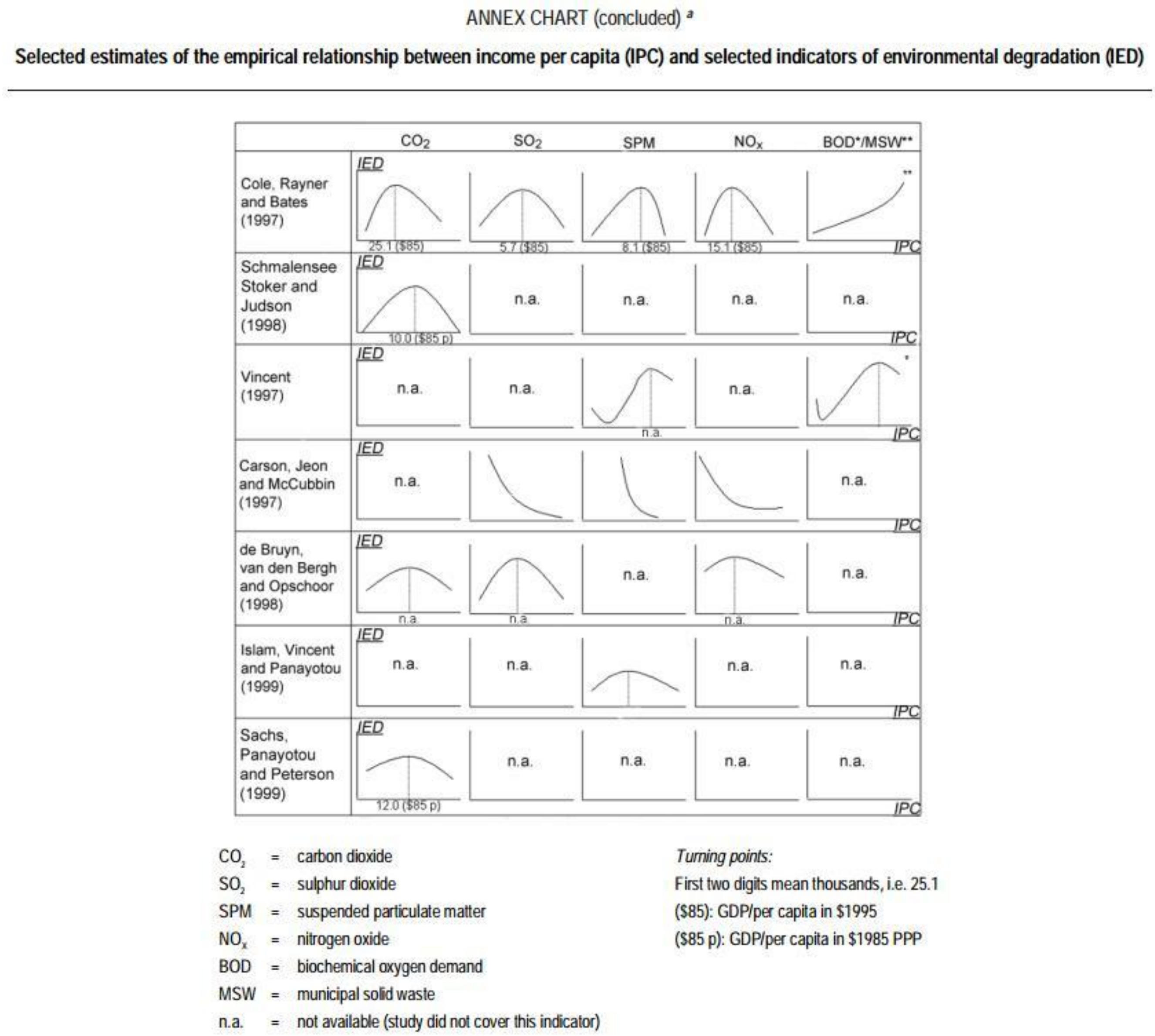
Appendix A



Summary of research results for several indicators of environmental degradation. Source: Panayotou (2003)



Summary of research results for several indicators of environmental degradation. Source: Panayotou (2003)

Appendix B

For the year 1879 own estimations of applied hp per sub sector are calculated due to a lack of available data. The horsepower for the year 1879 will be generated by using the number of steam engines employed in each sub-sector and multiplying them with an estimated average horsepower. The average hp has to be inferred from the rather vague information given in the statistical yearbook. The statistics of the German empire from 1882 provide a hp segregation into the following three groups; Machines below 20 hp, between 20 and 100 hp and above

100 hp (Kaiserliches Statistisches Amt, 1882). An accurate division is not given. Therefore, the horsepower is calculated by multiplying 6 hp, 45 hp and 100 hp with the number of engines in the corresponding group and adding them up to obtain the total hp of each branch.

The energy outputs for the years 1879 will then be investigated by multiplying the number of steam engines applied in each sub-sector (SE_s) with the corresponding horsepower (hp_s) and the working time per year (h) similar to step (1).

$$(1b)\ EO_s = SE_s * hp_s * h$$

Appendix C

The intensive work with the historical statistics of the German Empire (Kaiserliches Statistisches Amt, 1888 -1930) has revealed several, often unexpected shortcomings and therefore data limitations with significant impacts on this study.

The analysis of the upswing and peak phase of the EKCE between the 1850's and early 1920's could not be entirely examined in relation to the foreign trade of that time. The first uniform statistics for Germany are available after the foundation of the German Empire in 1871. Before that period the statistics are only compiled independently for certain regions of Germany like, Bavaria, Prussia, Silesia or Thuringia due to the heterogeneous governments of certain kingdoms. Those statistics are differing greatly in the statistical methods, data and coverage. An accurate compilation of those data would exceed the scope of this paper by far.

Furthermore, the statistical coverage and the display of the data between 1875 and 1930 of the statistical yearbook of the German Empire differ as well, however to a smaller extent. However, even though the accessible data of German Empire are quite comprehensive and uniform, the trade figures could not be aggregate for the period after 1903, because the following yearbooks disaggregate the trade not anymore by industry groups but report ample trade of commodity groups. Those commodity groups can be grouped and distributed to the respective industries; however this would have exceeded the scope of this thesis and is therefore recommended to be done in further research on this topic.

The generation of the hp statistics for the industrial sub-sectors posed another unexpected issue. The censuses of the steam engines are not conducted annually and therefore not reported on a regular base. Moreover, not the information of hp applied, or at least steam engines employed are decreasingly reported in the 20th century. The generation of hp applied, inferred from steam engines could therefore only be conducted for the years 1875 and 1879. As Hoffmann (1965) provides hp for the year 1875 and the later period, the reconstruction of hp of the sub-sectors is restricted to the year 1879.

The reported employment of steam engines of the census of 1879 appears however inaccurate in some cases. For instances the number of steam engines employed per industrial branch is reported in total and in a sub division that differentiates the three groups segregating according to hp (group 1: up to 20 hp; group 2: between 20 and 100hp; group 3: more than 100 hp). However the sum of the sub-groups does not add up to the reported total in some cases. Furthermore the information about the hp in the groups is vague due to the big ranges. Therefore an average of machines per sub-group had to be applied and multiplied with an average of hp for each sub-group. This approximation permitted the calculation of overall hp applied in the sub-sectors, lags however inaccuracies. Nevertheless, the total hp applied of the year 1879 appears to be in line with Hoffmann's (1965) estimations on an aggregated level. Due to the differences in sub-sector aggregation between the historical statistics of the German Empire and Hoffmann's data the sub-sectors do not match entirely (see table 1). The statistics don not list the hp used in the gas-, water- and electricity industry which is expected to play a minor role in this regard due to the time period and the little extent of electrification.

Further, the pulp and paper industry was segregated into the wood and the leather industry. Paper is reported as a part of the leather and tanning industry in 1879 and not yet independently displayed (Kaiserliches Statistisches Amt, 1882).

The attempt to generate the production values of all industrial branches had to be stopped after an in depth study of the historical statistics. The issue here is similar to the generation of the net exports for the period after 1904; the level of disaggregation is too high. The production values are reported in specific commodity groups traded and a total per industry is often not displayed. The manual aggregation of those production values of the sub-sectors is indeed possible but time consuming. The chemical industry is for example divided into over 30 commodities for the year 1913, 1925, 1926 and 1927 (Kaiserliches Statistisches Amt, 1930). Moreover the year 1913 is displayed twice, once the borders of the German empire before WW1 are regarded and once after WW1. The accumulation of all commodities of all sub-sectors for the whole period would have exceeded the given time frame of this thesis.

Therefore only the aggregated values of the industrial sales values provided by Hoffmann (1965) are used. For further research on this topic it is therefore recommended to generate the data from the original data of the statistical yearbooks, to analyze the industrial energy intensity and hence the role of energy embodied in trade on a more disaggregated level.

For further research on the upswing of Germany's EKCE not only the data requirements are high, but also the changing political, institutional and geographical conditions make an analysis time consuming and comprehensive. It is important that the described differences in the statistical format and the changing border and influenced areas of Germany vary significantly over time.