(Much) More for Less

- How sustainable is Swedish economic growth?

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Abstract: This working paper studies how environmentally harmful emissions and the use of natural resources in Sweden have changed over time. The results are cautiously encouraging: Overall, we get more out of less. Since 1990, Sweden's population has increased by more than 1.6 million and the economy has almost doubled. At the same time, carbon dioxide emissions have decreased by 27 percent between 1990 and 2018. GDP per carbon dioxide unit thus decreased by 60 percent during the period. In many areas, it is possible to see examples of absolute disconnection between emissions and economic growth, which can mean, for example, that when the economy grows 1 percent, emissions go down 0.5 percent. In other areas, it is possible to see economic growth that is greater than the additional resource utilization, that is, relative disconnection. An example of relative decoupling could be that if car driving in Sweden increases by 1 percent, emissions only increase by 0.2 percent. Sweden's environmental goals are not yet achieved and there is much that needs to be done - but these results are in many ways promising.

Key words: Sustainability, Environment, technological change, More for less.

JEL classification: K23, L11, Q2, P18.

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1. Introduction

> *Think about the world. War, violence, natural disaster, man-made disasters, corruption. Things are bad, and it feels like they are getting worse, right?*
>
> Hans Rosling – Factfulness (2018. p.13)

That our perception of the world usually matches reality poorly was something the now deceased professor Hans Rosling emphasised (Rosling et al., 2018). In a survey by Rosling, concerning the respondent’s perception of the state of the world, respondents performed worse results on multiple-choice questions than monkeys picking bananas marked with a), b) or c). In areas such as child mortality, literacy, violence and war, development is significantly better than people think (Pinker, 2012).

What about the environment? Sustainability issues have increased in importance over several decades. In the media, an impression is often conveyed that the environment only gets worse and we often see headlines instilling a sense of hopelessness. Is this picture correct, or is Rosling's reasoning about man's inability to see the progress around us equally applicable to the environmental?

The purpose of this paper is not to trivialize the seriousness of environmental issues. The ambition is rather to make an empirical survey of how environmentally harmful emissions and the use of natural resources in Sweden have changed over time. The results are encouraging to the extent that we can say that we generally get more wealth from less natural resources.

The inspiration comes from the book *More for less* by MIT researcher Andrew McAfee which was released in 2019 and the essay "The Return of Nature: How Technology Liberates the Environment" by Jesse Ausubel (2015), which showed that the US economy is being dematerialized. Dematerialization means fewer natural resources used for the same consumption. Dematerialization is an improvement as there is a debate about over-utilization of natural resources and an unsustainable population growth (see e.g. Weber and Sciubba, 2019). Given that McAfee's book is being released in Swedish, there is an interest in applying McAfee´s approach to the Swedish economy to see if we also get more out but using less.

Jesse Ausubel (2015) likewise showed evidence for environmental improvements, especially in reforestation, decreased impact from agriculture and various metals. Out of a list of 100 commodities, 36 have peaked in absolute size and another 53 have peaked relative to GDP (Ausubel, 2015). Dematerialisation is an improvement as there is a debate about unsustainable population growth and over-utilization of natural resources to the point of depletion (see e.g. Weber and Sciubba, 2019).

Our report begins with a brief literature review on growth theory and sustainability. Here some of the mechanisms that could lead to sustainable growth are explained. In the subsequent chapters we go through trends in several areas. Chapters 6 and 7 summarize and discuss the results and gives a brief conclusion and summary.

While the economy and the population have increased over the period studied, overall, we are generally obtaining more wealth from fewer resources and environmental impact in Sweden. In many cases, however, we have not been able too determine whether Swedish consumption is instead causing more emissions in other parts of the world. We welcome future research investigating this matter in greater detail.

2. Theoretical background - Economic growth and sustainability

Overuse of natural resources and unsustainable population development is not a new topic. Biologist Paul Ehrlich published in 1968 the bestselling book *The Population Bomb*, where he argues that population growth is problematic and must decrease. *The Population Bomb* led, among other things, to a concern that mankind consumed all natural resources on earth. In 1980, economist Julian Simon and Ehrlich made a very symbolic bet. Ehrlich predicted that the prices of five selected metals would rise sharply over the decade as humanity would face greater and greater scarcity of resources. Simon tipped the opposite and won. All prices fell in real numbers.

Ehrlich was and is not alone in being skeptical of how the environment and climate are affected by human economic activity. Today, many are engaged in environmental issues and point out that we pollute, chop, and generally destroy the planet, depleting its natural resources and extinct species (which is a major problem).

2.1 Externalities and environmental degradation

There is a considerable literature in economics that helps us understand why damage to the environment come about. The research is broadly concerned with various forms of externalities. Environmental degradation occurs as a by-product of economic growth. A firm can be efficient when manufacturing and selling goods to consumers on a market. If the production plant, however, releases toxic waste into nearby waters because of its production a third party can be affected. The presence of a third party means that neither the market price nor the production cost fully reflect the resources used. In such a situation, it becomes rational for a company to produce more and not take into consideration harm on the environment. Growth is generated, but in this case, it happens at the expense of the environment.

This logic can be applied to society on a more general level. Consumers buy goods, but the costs of consumption are never fully reflected in the price. Packaging needs to be handled afterwards and the transport of various raw materials and end products leads to emissions. The consequence becomes that people do not consider their environmental [impact] - toxins accumulate, greenhouse gas emissions increases, and more resources are used.

The linkage between negative externalities and environmental policy developments is to this day a relevant research field (Butler & Macey, 1996; Parry et al., 2007; Itaya et al., 2008; etc.). Consumers buy goods, but the costs of consumption are never fully reflected in the price. Packaging needs to be handled afterwards and the transport of various raw materials and end products lead to emissions. Consequently, as people do not consider their environmental impact, toxins accumulate, greenhouse gas emissions increase and more resources are consumed.

2.2 Is sustainable growth possible?

If the reasoning above is carried to its logical extreme, the conclusion is that economic growth and sustainable development are incompatible with each other. At the same time, there are studies indicating that this would be an oversimplification. Stanford researcher Morris Abramowitz showed in 1956 that only 15 percent of growth in the US economy in 1870–1950 could be attributed to increased usage of resources. The remaining 85 percent of GDP growth, that is, the overwhelming majority, came from something else in the form of innovation and rationalization.

Abramowitz´s and others' results show that economic growth can be achieved by using more resources, but that growth can also be accomplished by using resources more efficiently. As a science, economics has at times struggled to integrate these effects into formal equations. Technological development was often regarded as exogenous, that is, it was not incorporated into the mathematical models of reality.

The critics of this approach often argued that a model of reality becomes unrealistic if the most important factors are not built into it. In the last few decades, this approach has had an increasing impact. Already in 1957, Nobel Laureate Robert Solow came up with similar results as Abramowitz. The Nobel Prize in 2018 was awarded to Paul Romer, mainly for his work on developing endogenous growth theory, i.e. models and theories that consider to a greater extent that economic development is about innovation and changes in human capital.

2.3 Factors that lead to sustainable growth

There are several different factors promoting sustainable growth. For starters, companies in a competitive market have an incentive to be frugal with their resources as this leads to lower costs. As a result, they are motivated to adopt new technologies and organize their operations so that fewer natural resources are used. The Swedish company Bona was the first in the world to launch water-based floor paints, which led to lower costs as they no longer needed to use toxic, carcinogenic chemicals. The introduction of 3D Printers and 3D scanners in the hearing aid industry has resulted in less transport of physical products and the manufacturing process has become significantly cleaner (Sandström, 2016).

In other words, companies often have incentives to devote themselves to technological development and rationalizations, which means that they use less resources. According to economist William Baumol, most firms have no choice. Competition in an open market means that if some firms make rationalizations and cut costs, it becomes necessary for other firms in the industry to also do this. To the extent that they do not have the incentive to do so, laws and regulations need to be changed to make it rational for economic actors to use resources carefully. There are several measures that can be used to do so.

The environmental impact of economic and social activities is in many ways affected by the level and direction of technological development, and climate policy tools can both limit and contribute to technological progress. We need not only to stimulate the introduction of new technologies through research and development, but also [that] which can give us new technological breakthroughs.

Technological change is almost uniformly regarded as a necessary, but not sufficient condition for a transition to a more sustainable energy system (Reichardt and Rogge, 2014). As the global climate issue transcends national boundaries, global solutions are required to reduce greenhouse gas emissions.

Technology can affect emission levels and change the amount of goods that can be created with the same amount of emissions. Thus, improved technology can either allow us to emit less than before without reducing our current level of consumption, or an improvement in the same way may allow us to consume more with unchanged levels of greenhouse gas emissions (Del Río, 2004).

Environmental taxes and environmental legislation can be used to reduce the demand for what is harmful to the environment or to remove the demand altogether. In general, it can be said that laws and regulations need to be designed so that it is profitable and rational to take the environment into consideration. The Swedish economist Erik Dahmén wrote an article already in 1968 entitled *Put a price on the environment*, arguing that over-use of the environment would decrease if price mechanisms are introduced.

2.4 Sustainable or unsustainable growth - an empirical question

The aforementioned McAfee concluded that the United States uses a smaller amount of natural resources to generate more wealth, per unit of prosperity, but also in absolute terms in some cases. These results seem difficult to digest for some.

It seems that as we get richer, we use resources more efficiently, use less energy, cause less pollution, and clean up past pollution. For example, forests do not become smaller in Europe but rather they grow and protect more species (World Economic Forum, 2019). McAfee shows compelling data and many examples, but many are still skeptical that things get better: unfortunately, good news is not news because we all love a good horror story.

Ausubel (2015) researched resource use, agriculture, and evidence for resulting reforestation in the US and found that there were large increases in agricultural output occurring side-by-side with decreasing total acreage used. Similar trends are noted for woodlands and logging, where forests have been increasing in area since 1990. Meanwhile, logging produces more output from a smaller area, leading to an area of 3,1 million hectares (more than three times the size of Yellowstone park) being freed up between 1976-2001. (Ausubel, 2015)

Krausman et al. (2018) investigated global material extraction between 1900-2015 and concluded that over the period as a whole resource use had increased by a factor of 12. Material use had grown with population, albeit slower than GDP since the 70's and 80's, with an increase in the 21st century. Resource use accelerated post-2002 however, with a 53 percent increase between 2002-2015. Steinberger et al. (2010) looked at domestic material consumption for the year 2000 in 175 countries, finding it to be somewhat correlated with both income levels and population. Of the studied resources in domestic material consumption, fossil fuels and mineral ores were found to be more correlated to income, while biomass and construction materials were more strongly correlated with population.

Material efficiency is a central aspect of creating dematerialization and sustainable growth. It has not only an important role in decreasing extraction of raw materials, but also in reducing the carbon footprint by saving energy from heavily energy-intensive industries (Schandl et al., 2015). However, depending on which measurement is used for material efficiency, results can vary. Zhang et al. (2018) concluded that while developed countries have been able to combine further economic growth with falling domestic material consumption, no such evidence of decoupling for consumption-based material footprint have been found.

In the research field of sustainable growth, Schandl et al. (2015) found that decarbonization and dematerialization do not necessarily imply less economic growth. Schandl et al. (2015) concluded that with strong and appropriate environmental policies, reducing global carbon emissions and increasing resource efficiency is not only possible, but could be achieved with little or no impact on economic growth.

Based on the studied literature, there seems to be a clear trend towards increased global resource use. However, both Ausubel (2015) and McAfee (2019) noted large changes in the US when looking at areas such as agriculture, emissions, and use of natural resources. Whether the development in the US is part of a larger trend amongst developed countries toward a greener economy or just an isolated blip is, however, not certain.

Questions about whether economic growth is sustainable or not are often riddled with ideological tensions. However, as we have seen above, there are theoretical arguments that go both ways. The theory of negative externalities suggests that environmental degradation will be rational under some circumstances, while the new growth theory, the existence of technology development, environmental legislation, a functioning price mechanism and the creation of property rights in the environmental area would imply that economic growth can be achieved by using less resources. However, these theories are nothing more than just theories. Ultimately, they must be tested against reality to see if they are correct or not. In the next section, we present descriptive statistics on how developments have taken place in several different areas.

3. Empirical observations and Results

This section presents data on environmental developments in Sweden, mainly from 1990's and onwards. The primary areas studied are carbon dioxide emissions, usage of natural resources (including consumption of oil, fuel, and water), resource productivity, miscellaneous air pollution and land & forestry.

3.1 Carbon dioxide

Human economic activity, which has been heavily dependent on fossil fuels for the past century, increases the atmospheric concentration of carbon dioxide and drives global warming. Although carbon dioxide (CO_2) is a normal component in the atmosphere, and has made life on earth possible, there is no doubt that the increased concentrations can change our climate in hazardous ways (e.g. changing weather patterns with increased variability and extreme features, rising sea levels and drought (see, for example, Dietz and Maddison, 2009; Suganthi and Samuel, 2012).

The average temperature of our planet in 2017 was 1.1°C degrees higher than in 1880 (World Meteorological Organization, 2018). To achieve the goal, that the rise in temperature should not exceed 2°C, the atmospheric CO_2 equivalent concentration should not reach above 480-530 ppm at the end of this century (IPCC, 2014a, b). In May 2018, the atmospheric CO_2 concentration was 410 ppm, the highest in 800,000 years (Scripps Institution of Oceanography, 2018). Recently published research also indicates that these earlier estimates of what may be assumed to be a "safe" level may be revised downwards (Steffen et al. 2018).

The lower Paris target of 1.5°C is ambitious, and models indicate that it is already too late for the goal to be achieved (Rogelj et al., 2013). Others believe that ambitious climate measures are still possible (see, for example, Millar et al., 2017). However, the measures announced so far in connection with the Paris Agreement are not estimated to be sufficient to keep the CO_2 equivalent gases concentration below ~ 500 ppm (Rogelj et al., 2016).

Table 1 Possible routes to limit heating to 1.5 or 2 degrees. Source: UK Committee on Climate Change, 2016.

Table 1 Possible pathways do limit warming to 1,5 or 2 degrees. Source: UK Committee on Climate Change, 2016.

Level of Ambition	**Decades with zero global emissions net**	
	Only Carbone dioxide	All greenhouse gases
1,5-degree heat increase	2040	2060–2080
Below 2 degrees heat increase	2050–2070	2080–2090
Note: The time scale is based on cost-optimal path choices in an integrated global climate model. All roadways assume that measures at a global level are limited until 2020 and that carbon dioxide emissions will be net negative by 2100. "Below 2 degrees" refers to a 66% chance of achieving that goal. The "1.5-degree path" assumes a 50% chance of returning to a path where warming reach 1.5 degrees. There are no scenarios for us to receive a lower heating than 1.5 degrees.		

How has the situation changed in Sweden over the past decades?

3.1.1 GDP and carbon dioxide

From 1990 to 2018, total carbon dioxide emissions (excluding land use, forestry, and foreign transport have decreased from 71 185 million tons to 51 779 million tons. Emissions have decreased by 27 percent between 1990 and 2018. Emission reductions have mostly taken place between 2003 and 2014 and is partly explained by measures implemented (for example, transition to renewable energy and energy efficiency) and to some extent less growth within industrial sectors. At the same time, GDP has increased by about 90 percent. In Sweden, more GDP per consumed carbon dioxide is achieved, both in absolute and relative terms.

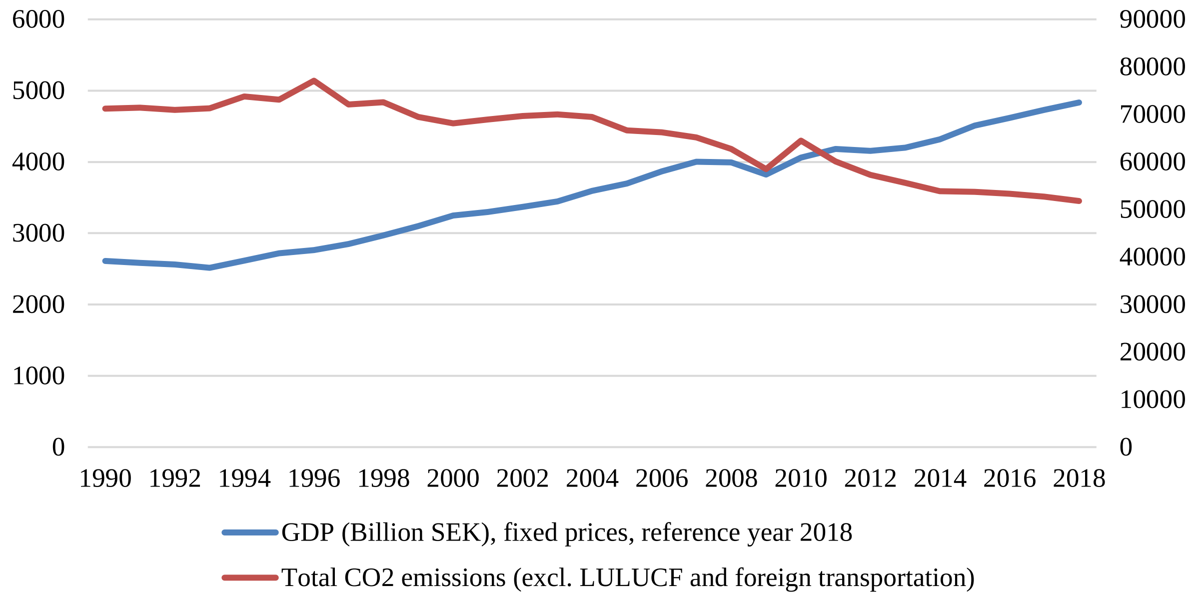


Figure 1 GDP on the left axis, carbon dioxide emissions the right axis. Source: Swedish Environmental Protection Agency and OECD.

The reduction in carbon dioxide is noticeable, but there is a problem. Sweden's goal is for greenhouse gas emissions to reach net zero by 2045. To achieve this goal, the reduction rate between 2015 and 2045 needs to reach an average of 5-8 percent per year over time.

Converted to an index starting in 1990, the amount of carbon dioxide used per GDP units has decreased by almost 60 percent. Data from the World Bank shows that a similar development globally where the decline is significant but not close to Sweden's. In the world, the intensity has gone from 0.73 kilograms of carbon dioxide emissions per $ PPP of GDP in 1990 to 0.33 in 2014, which is the last year we found data for (World Bank, 2019).

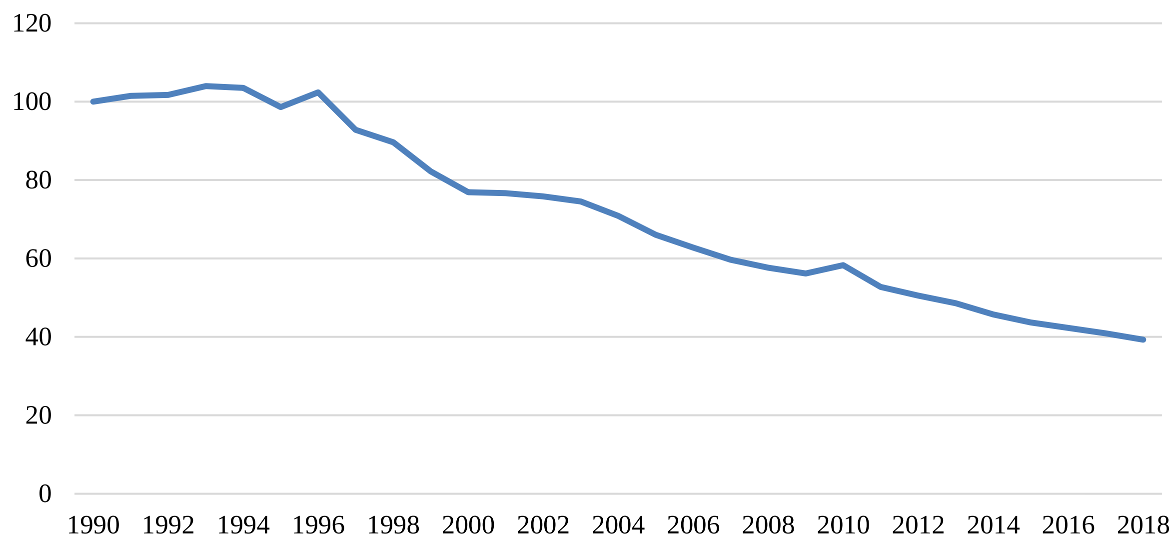


Figure 2 Index of carbon dioxide use per GDP unit in Sweden. Source: Swedish Environmental Protection Agency and OECD.

3.1.2 Carbon dioxide from transport and industry

Emissions from domestic transportations (Railways, Mopeds and motorcycles, Military transport, Buses, Aviation, Shipping, Light trucks, Heavy trucks, and Cars) account for a significant portion of Sweden's emissions, about 32 percent. Emissions in 2018 in this sector decreased 19 percent compared to 1990. Compared with 2017, emissions were two percent lower in 2018.

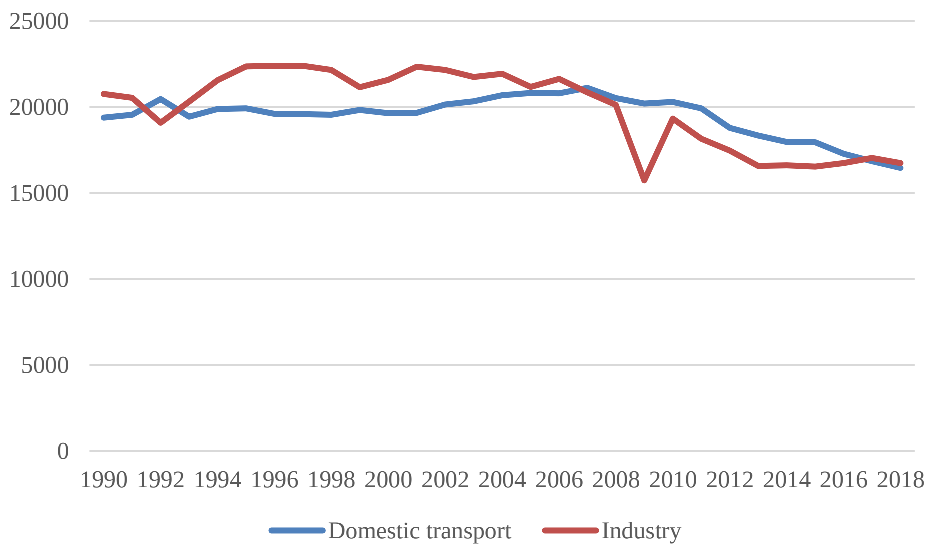


Figure 3 Carbon dioxide from industry and transportation. Source: Swedish Environmental Protection Agency

In addition to transportation and industry, several other sectors have reduced their emissions. The graph below shows the total emissions for waste, work machines, electricity, and district heating as well as agriculture. In all categories, we have seen a reduction in emissions.

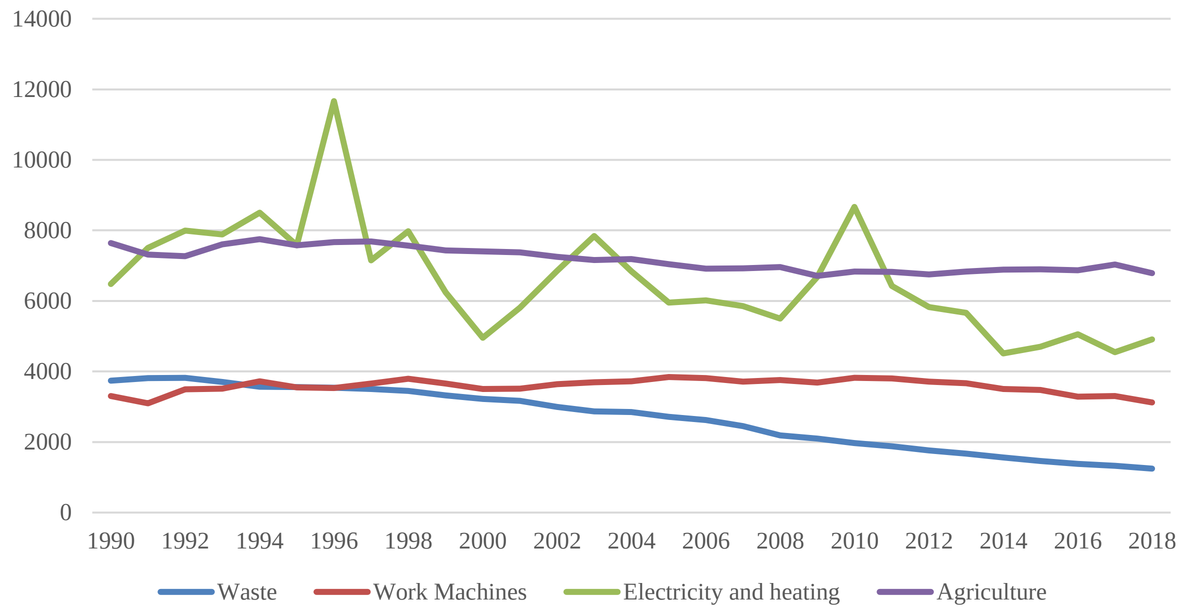


Figure 4 Carbon dioxide other sectors. Source: Swedish Environmental Protection Agency

The main factor behind this trend is the total traffic usage (i.e. how much transport that takes place), the fuel types used and the energy efficiency of the vehicles. The increase in biofuels and more energy-efficient vehicles has reduced emissions. However, as the total amount of traffic has increased the reduction is still lower than it could have been. Emissions in 2018 amounted to just under 17 million tons of carbon dioxide equivalent.

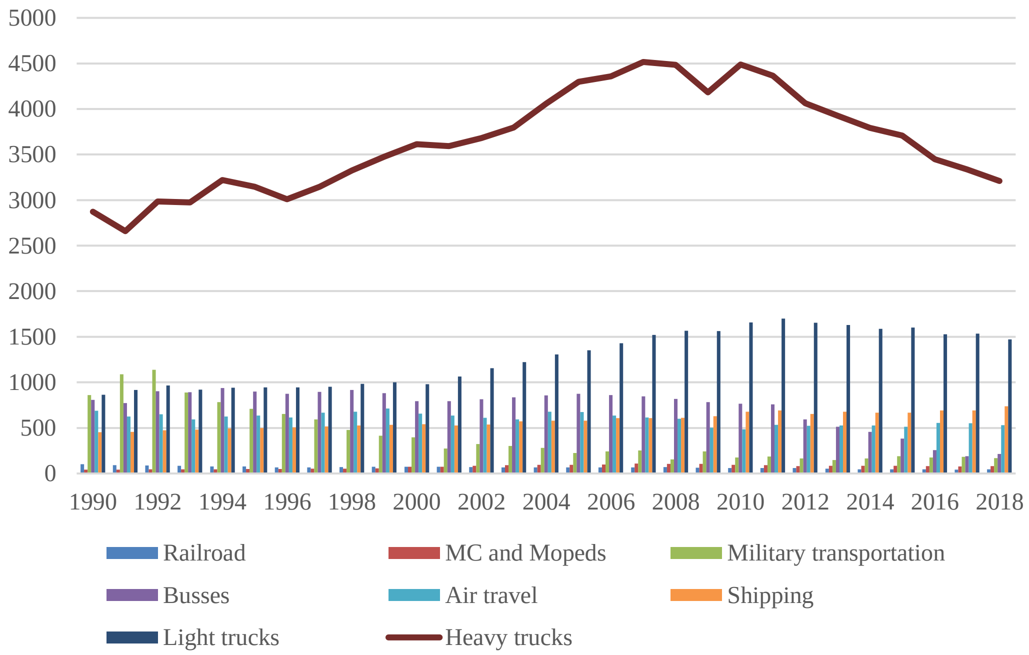


Figure 5 Domestic transport emissions. Source: Swedish Environmental Protection Agency.

Most emissions from the transport sector are related to road traffic. Emissions from passenger cars and heavy vehicles predominate. Emissions from passenger cars have decreased by 21 percent from 1990 to 2018. Compared to 2017, emissions from passenger cars decreased by two percent and amounted to 10 million tons in 2018.

With a population increase of 1.64 million inhabitants between 1990 and 2018 as well as a growing economy, personal transportation naturally increases in absolute terms. From the beginning of 1990 until 2007, car traffic increased, but thereafter it remained at a relatively steady level until 2013. Traffic has continued to increase since then. However, emissions have remained relatively constant as more and more biofuels are mixed into fuels. Energy efficiency (through a renewal of the vehicle fleet) helps to reduce fuel consumption and carbon dioxide emissions. The average fuel consumption of passenger cars registered in Sweden in 2018 was again higher than the previous year.

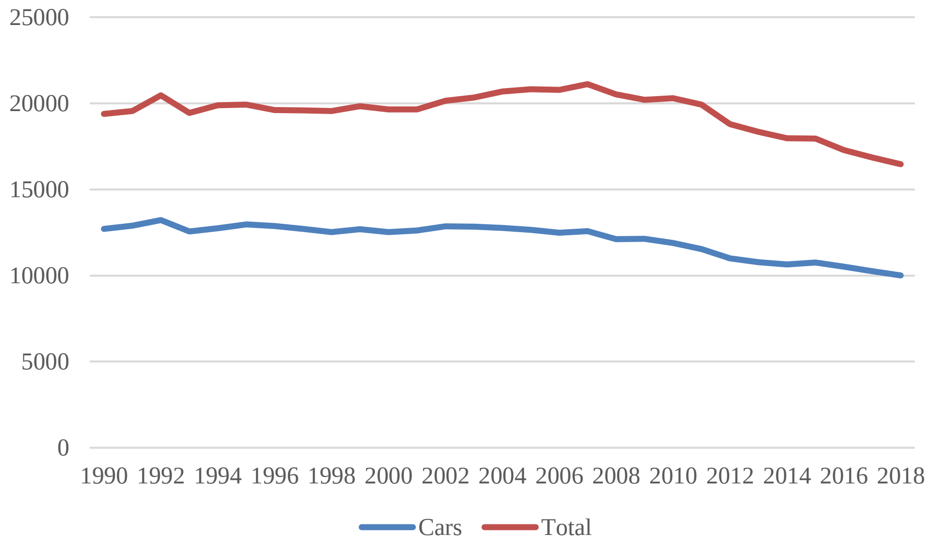


Figure 6 Domestic transport emissions: Cars and total. Source: Swedish Environmental Protection Agency.

3.1.3 Carbon Dioxide Flight

The total number of international flights has increased by 120 percent since 1990. By contrast, the number of domestic flights has remained almost steady since 1990. The climate impact of domestic flights has decreased and now accounts for only 7% of emissions (Kamb, Larsson and Åkerman, 2018). Total aviation related emissions have increased by 47% since 1990.

Emissions per person and travelled kilometer have decreased by an average of 1.9 per cent per year but are still high compared to cars or trains. In 2017, emissions (excluding high altitude effects) were 90 grams of carbon dioxide per person-km and including the high-altitude effect it amounted to 170 grams of CO_2 equivalents per kilometer travelled by each person. The overall impact of aviation is on par with that of passenger car traffic in Sweden.

The number of trips abroad has more than doubled since the beginning of the 1990s, from 0.47 trips per person per year to 1.1. The number of domestic journeys has decreased since the 1990s, averaging 0.47 journeys per person and year, in 2017 approximately 0.37 journeys per year and person.

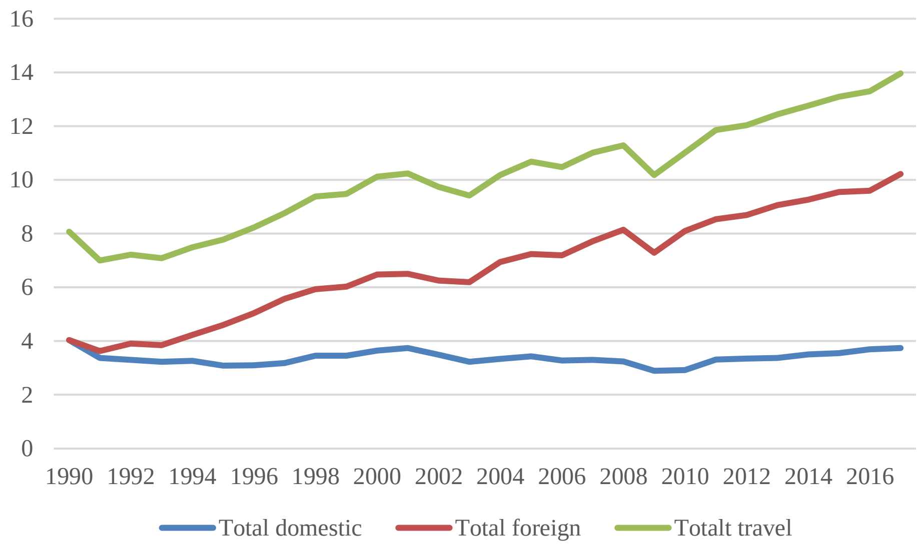


Figure 7 Air travel - number of trips (millions), based on the average number of trips per person multiplied by the population that year. Source: Swedish Environmental Protection Agency.

The Swedish Environmental Protection Agency estimates the total climate impact of the Swedish population's air travel in 2017 to be approximately 10 million tons of carbon dioxide equivalents (including the high-altitude effect). The increase in international flights since 1990 means that the climate impact has risen, from 7 million tons to 10 million tons.

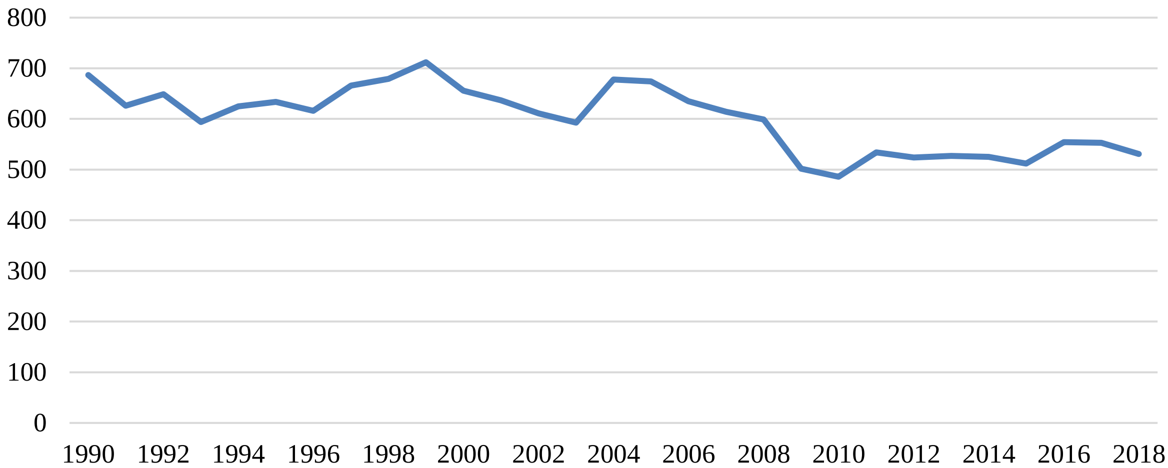


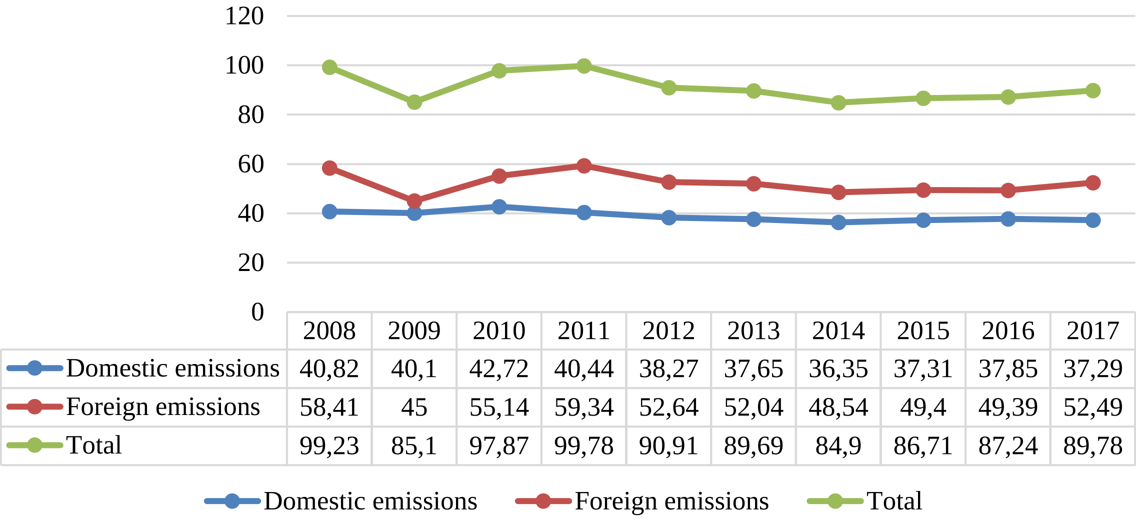
Figure 8 Domestic flight emissions, one thousand tons of carbon dioxide equivalent. Source: Swedish Environmental Protection Agency.

Emissions from domestic flights have gone from 687,000 tons of carbon dioxide equivalents in 1990 to 531 in 2018, a decline of about 13 percent. The declines have been greatest in connection with economic downturns. Although slightly fewer trips and technological development have played a role.

3.1.4 Carbon dioxide from imports

The climate-impacting emissions that result from Swedish imports make up a large proportion of Sweden's total consumption-based emissions. The size of the emissions caused by import, in addition to the absolute quantity of goods, depends on how emission-intense the goods or services are and how large the emission intensity is in the country where production takes place.

Imports consist of both end products (for example, clothing, shoes and electronics) as well as input goods (for example raw materials, components and energy) and services (for example transportation and banking), which are used to produce goods in Sweden. Geographically, over 80 percent of imports to Sweden from countries are concentrated to Europe.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Domestic emissions	40,82	40,1	42,72	40,44	38,27	37,65	36,35	37,31	37,85	37,29
Foreign emissions	58,41	45	55,14	59,34	52,64	52,04	48,54	49,4	49,39	52,49
Total	99,23	85,1	97,87	99,78	90,91	89,69	84,9	86,71	87,24	89,78

Figure 9 Consumption-based greenhouse gas emissions in Sweden and other countries. Source: Swedish Environmental Protection Agency.

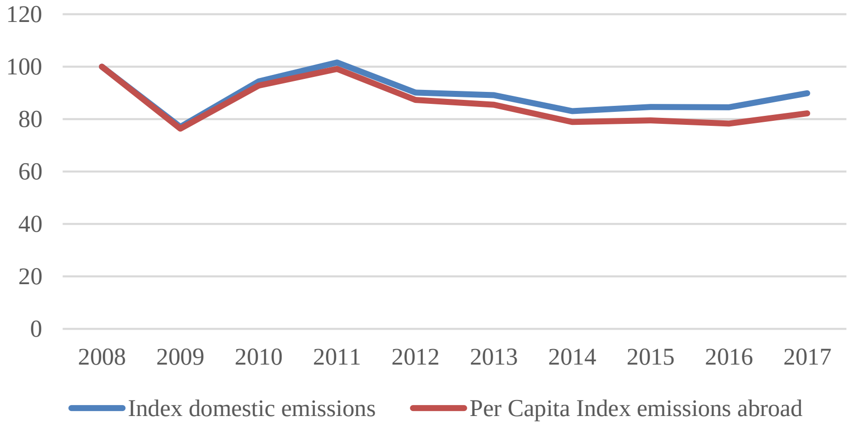


Figure 10 Index imported Co2 emissions. Source: Swedish Environmental Protection Agency.

3.2 Natural resources

Coca cola cans have an interesting history that illustrates in concrete terms the change in the use of natural resources. Coca cola recently started with long, narrow cans instead of the classic little short and chubby ones. Around the end of the 1950s, the weight of an aluminum can was around 85 grams. Today, an average can weighs 14–16 grams. So, we get 4–5 more cans on the same amount of aluminum (and in the case of aluminum a lot is recycled). The design brings down the amount of aluminum used. With less aluminum, they can probably cost less, both in transportation and in use of raw materials.

3.2.1 Fuel and oil usage

The energy efficiency of vehicles has improved greatly as older vehicles have been replaced with new, more fuel-efficient cars (Swedish Energy Agency, 2016). Imagine that someone has driven their Volvo for twenty years and is thinking of buying a new car. Twenty years is roughly the time difference between World War I and World War II. A huge technological development has happened during that period, especially in terms of fuel efficiency. Many large cars that are several decades old may consume one liter per 10 kilometers. Many of today's cars rather consume under half a liter. For example, if ten percent of the oldest / worst cars were replaced by new cars, this would mean significant reductions in emissions from the transport sector.

The total volume of oil products has declined since the 1970s. A driving factor is that the use of heating oil (E 2–6 and EO1) has been phased out.

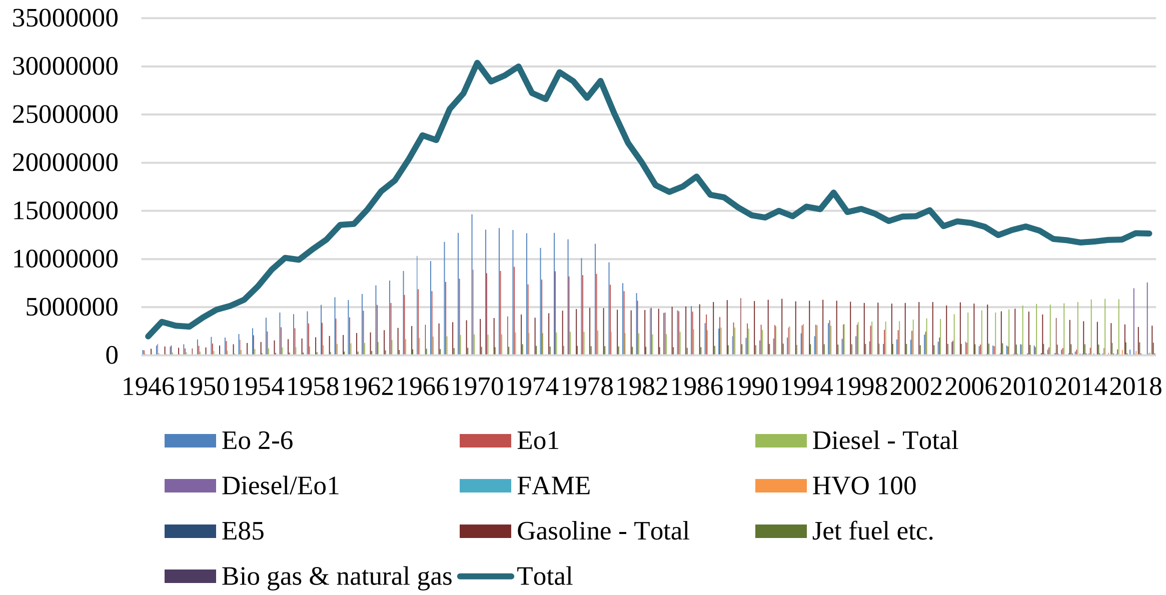


Figure 11 Delivered volume of oil products and renewable fuels. Source: Swedish Petroleum Institute

However, the total volume of fuel for vehicles has increased since the 1940s. This is natural as there were significantly fewer vehicles as well as people in the country at that time. In 1946, there were 138,489 registered passenger cars in Sweden and in 2019 there were 4,887,904 cars. Also note that the graph includes various forms of heating oil in the graph over the last two years resulted in a certain increase.

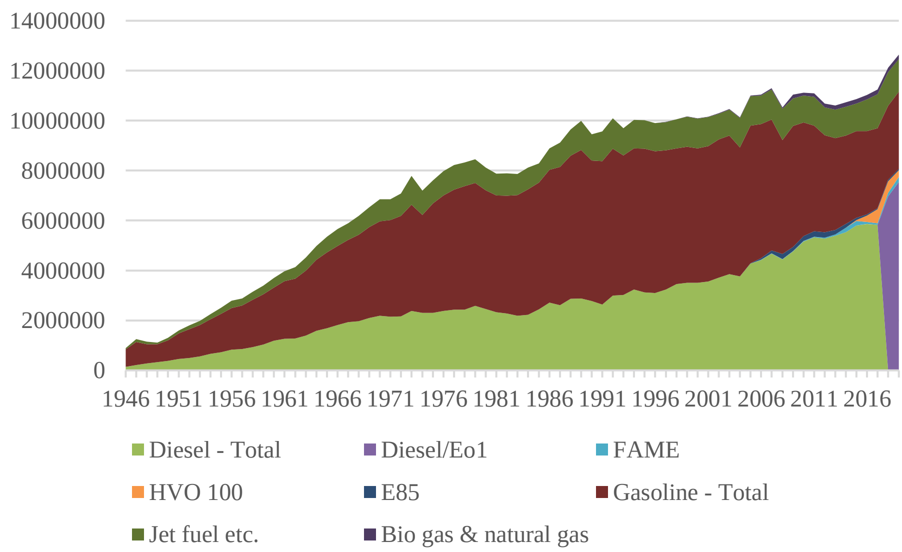


Figure 12 Delivered volume of oil products and renewable fuels for transports. Source: Swedish Petroleum Institute.

If instead we only study developments in the 1990s and exclude the years we cannot separate heating oil and diesel (2018-), we see an increase of 18 percent. However, the number of cars has increased by 34 per cent during the same period.

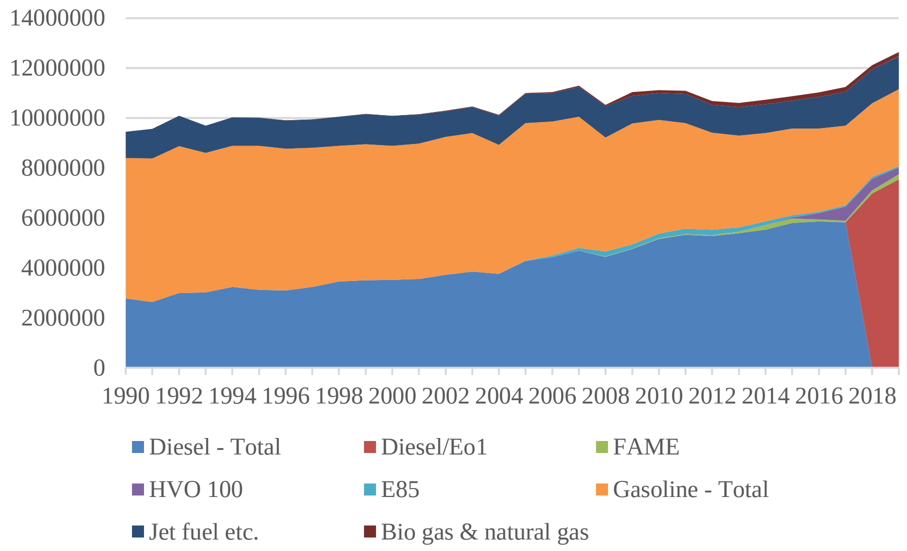


Figure 13 Delivered volume of oil products and renewable fuels for transport 1990-2017. Source: Swedish Petroleum Institute.

Indexed against population trends, fuel consumption has remained steady over the period, but for some years has been above the index value of 1990. In this case, we cannot say that fuel consumption has decreased overall or per capita. On the other hand, we do get more kilometers per liter of fuel.

The average of all new cars' fuel consumption has generally decreased over a longer period, but the average value increased between 2016 and 2017 for the first time since the 1990s. The increase was two percent. Fuel efficiency appears to have been counteracted to some extent by the fact that larger cars have become increasingly popular.

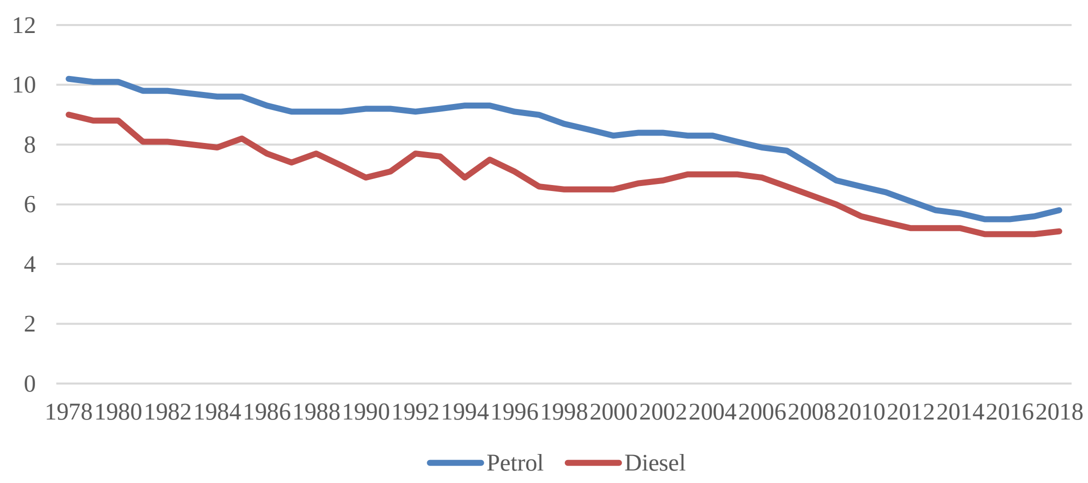


Figure 14 Fuel usage for petrol and diesel cars. Source: Swedish Environmental Protection Agency.

3.2.2 Water usage

A total of 2,431 million cubic meters of freshwater and 639 million cubic meters of seawater were used in Sweden during 2015. In Sweden, we consume on average 140 liters of water per person per day. Our drinking water comes from lakes, streams, and groundwater reservoirs. They fill up during winter and spring when the snow melts. Both groundwater and surface water taken care of properly provide adequate drinking water.

The total use of water has gone down in industrial parts of the economy as well as within agriculture, while production in these sectors has gone up. The sharpest decline is in agriculture, which saw a 24 percent reduction. Even in the industrial sector, the use of fresh water decreased by 14 percent (Statistics Sweden, 2017). Water use has gone down in absolute terms since the 1990s.

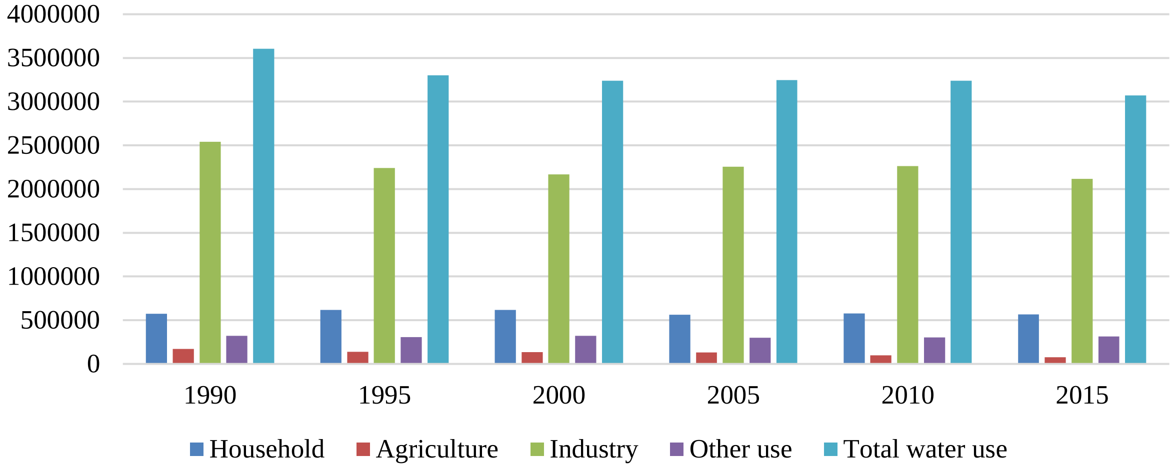
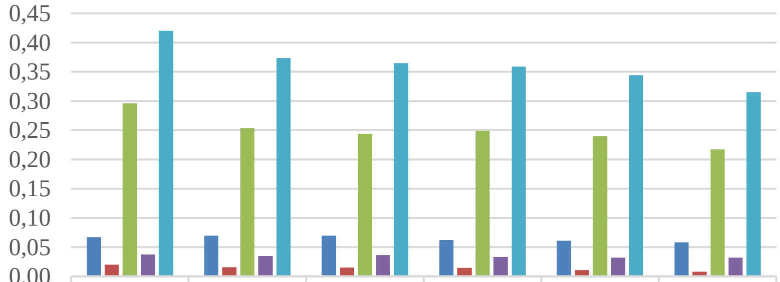


Figure 15 Total water use per user group, 1000 cubic meters. Source: Statistics Sweden, 2015.

Water use in relative numbers is shown in the figure below. From 1990 to 2015, per capita water use has decreased in all categories. Households' per capita water use has dropped by around 15 percent. Per capita water use in the industrial sector and agriculture is a less relevant measure, but if we look at it, we see a decline there as well. In agriculture, it has been halved while the crops, in terms of volume, have gone up significantly.



	1990	1995	2000	2005	2010	2015
Household	0,07	0,07	0,07	0,06	0,06	0,06
Agriculture	0,02	0,02	0,02	0,01	0,01	0,01
Industry	0,30	0,25	0,24	0,25	0,24	0,22
Other use	0,04	0,03	0,04	0,03	0,03	0,03
Total water use	0,42	0,37	0,36	0,36	0,34	0,31

Household Agriculture Industry Other use Total water use

Figure 16 Water use per capita and user group, 1000 cubic meters. Source: Statistics Sweden 2015.

Reduced water use is strategically important, even though we have a relatively good supply of water. Climate change is expected to hit the country unevenly and cause more intense rainfall, increased risk of flooding and pollution of water sources where we collect our drinking water. In the south east of Sweden and on Gotland, there have been periodic warnings of water shortages.

4.3 Resource Productivity

According to data from Statistics Sweden (2016), material consumption per person in Sweden in 2015 was 22.5 tons. This was just over 9 tons more than the EU average in the same year and a domestic increase of about 3 tons from 2000. One of the reasons Sweden has a relatively high consumption of materials is related to the mining industry (Statistics Sweden, 2016).

Statistics Sweden (2019b) examined how Sweden's GDP development has grown in relation to the country's material consumption and then developed a measure for resource productivity. Resource productivity has increased by 19% from 1998 and the highest index value measured was 129 in 2009. Subsequently, resource productivity decreased had declined by 7.4% percentage points by 2017.

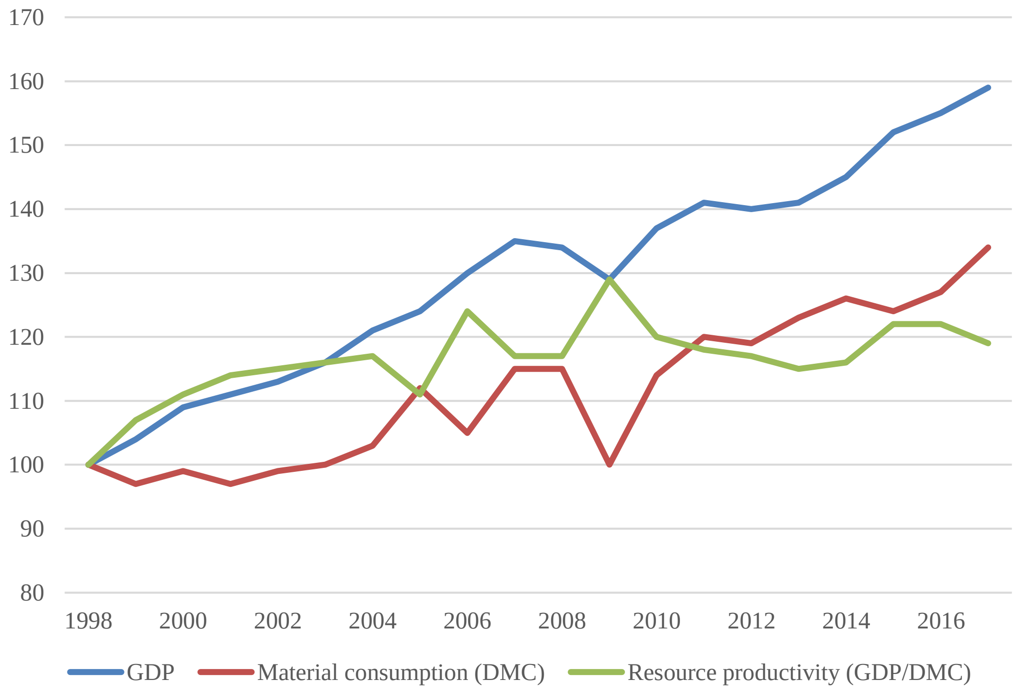


Figure 17 Index material consumption in relation to GDP growth. Source: Statistics Sweden (2019b).

Statistics Sweden emphasizes that the measurement of material consumption only reflects the amount of materials consumed directly within the domestic economy and that the decoupling between GDP and material consumption can therefore depend on more than improved efficiency. Examples of such factors include substitution between domestic production for an increased proportion of semi-finished products and finished products.

3.3. Pollution

In this chapter, we describe how developments have taken place regarding air pollution. The data covers 1990 to 2018. For most types of pollution, we find a steep decline.

3.3.1 Air pollution

The air in Sweden has generally become cleaner since 1990. Of the twenty-six air pollutants that the Swedish Environmental Protection Agency has covered (shown in the graphs below), twenty-four have decreased in absolute terms, while Selenium and PCB have increased in Sweden.

We show the change in air pollution in index form below, i.e. the starting year is 1990, a lower value than 100 means that we emit less than in 1990. Emissions of sulfur dioxide, nitrogen oxides, volatile organic substances, particles, and heavy metals have decreased sharply since 1990. The rate of decline has slowed down in recent years, but this may be explained by the fact that reductions are more easily accomplished when starting from a higher level. For some of the pollutants (three graphs), emissions have fallen by up to 80 percent during the period 1990 to 2018.

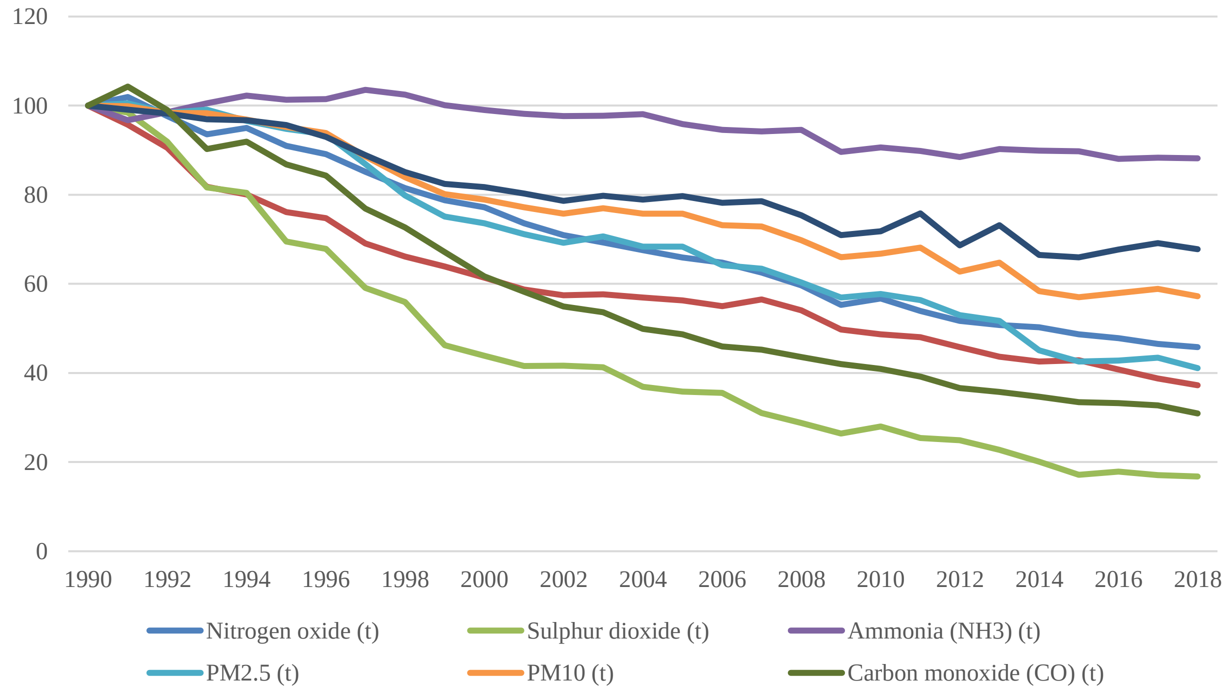


Figure 18 Air pollution, index. Source: Swedish Environmental Protection Agency (Retrieved from Statistics Sweden's database).

Ammonia (NH_3) is mainly emitted from agricultural manure management. One source of the reduction in ammonia is that animal husbandry has decreased since 1990. In 2018, total emissions of ammonia are estimated to be about 53,000 tons, which is equivalent to a 12 percent reduction compared to 1990. Imports of milk and meat also account for a part of the decrease.

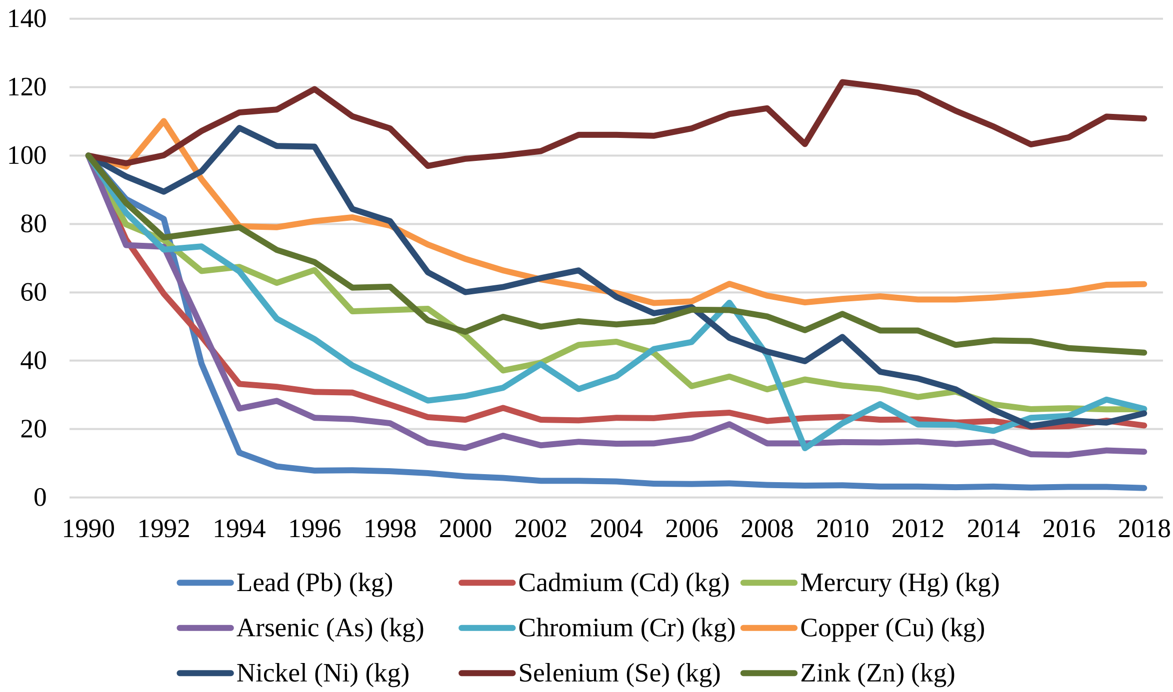


Figure 19 Air pollution, index. Source: Swedish Environmental Protection Agency.

Lead has seen the largest reduction, over 95 percent. The decline can probably be explained by the fact that in 1995 a lead ban was introduced for all vehicles.

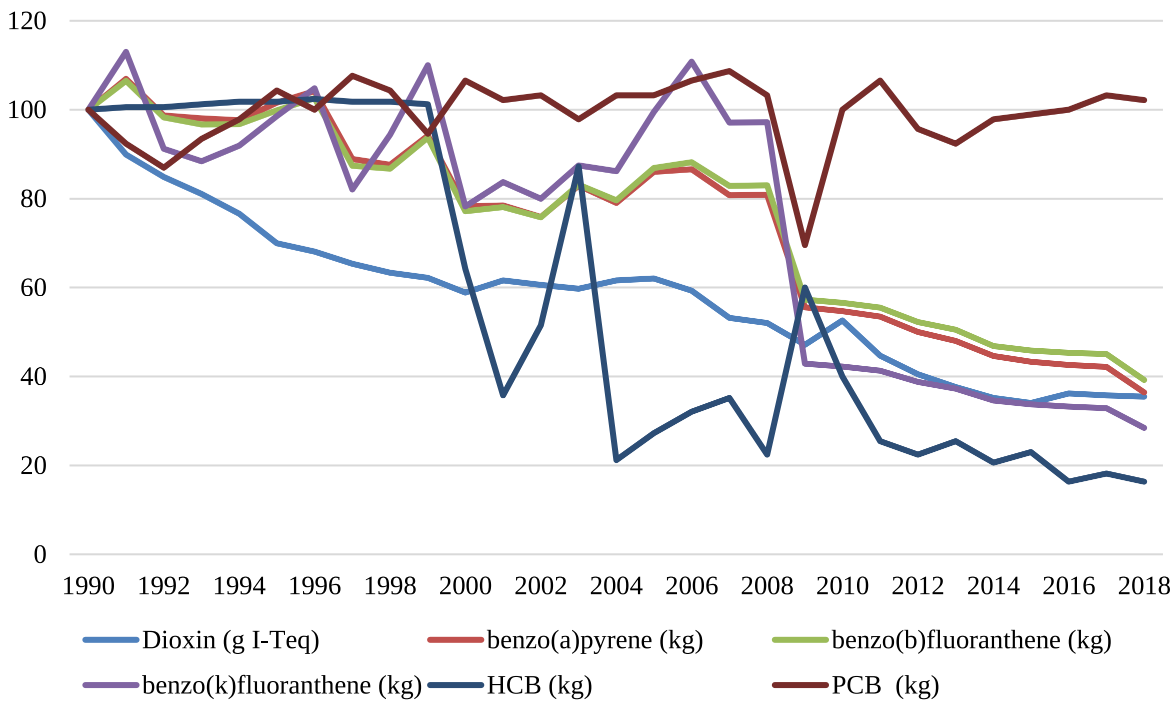


Figure 20 Air pollution, index. Source: Swedish Environmental Protection Agency.

3.3.2 Sulphur oxide

Sulphur oxide is one of the pollutants that has experienced a significant decline. In 2018, Sweden's total emissions of sulfur dioxide (SO_2) were just over 17,000 tons. Emissions have decreased by up to 80 percent compared with the 1990 level of emissions.

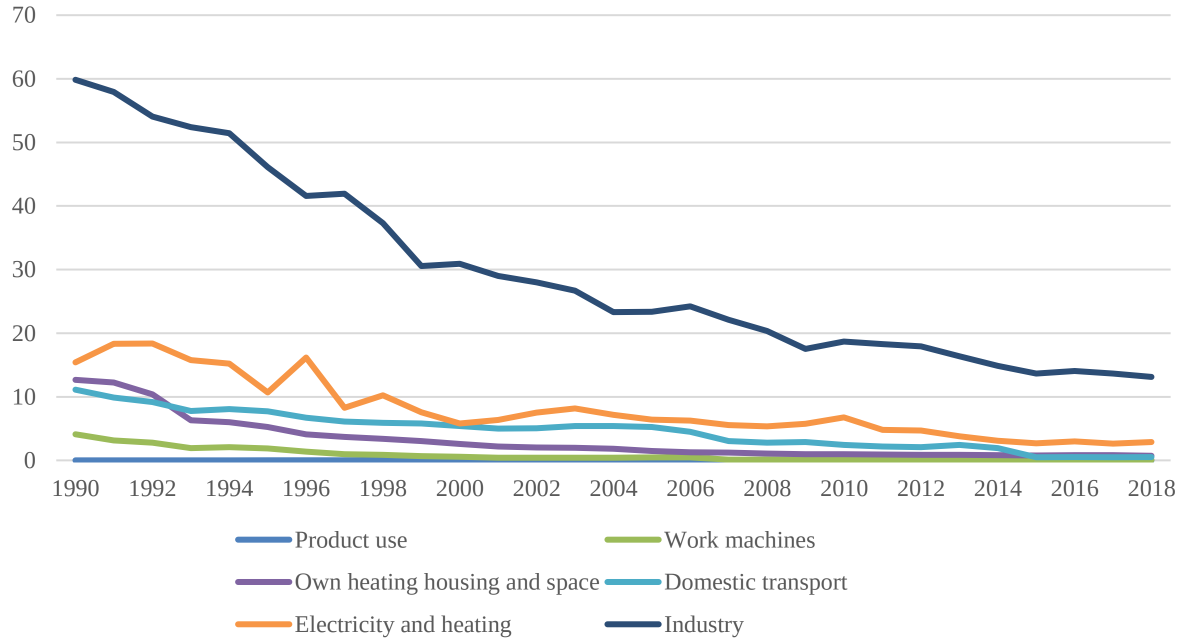


Figure 21 Air pollution of sulfur dioxide emissions. Source: Swedish Environmental Protection Agency.

Precipitation of sulfur has several negative environmental effects such as acidification of soil and water. If acidification becomes severe, sensitive animals and plants will be affected, especially in lakes and streams. Sulphur emissions also affect the quality of drinking water and damage cultural heritage when buildings and monuments are subject to corrosion due to the sulfur. The Swedish emissions of SO_2 into the air have mainly come from the consumption of sulfur-containing fuels such as coal and fuel oil. Sweden is also affected by the emissions of sulfur dioxide in other countries.

Emissions from industrial sectors have fallen sharply since the 1990s. Industrial emissions have decreased by 78 percent since 1990, both from incineration and processes. The reduction has been due, among other things, to fuel changes, for example by replacing oil with high sulfur content by oil containing less sulfur and increased use of biofuels. The increase has not slowed down in recent years, between 2017 and 2018, emissions fell by 4 percent. Emissions for domestic transport have fallen by 95 percent since 1990.

Electric and district heating contributed about 17 percent of sulfur dioxide emissions in 2018. The largest contribution came from the combustion of solid biofuel containing sulfur. Incineration of waste, peat and coal and oil also contribute, but to a lesser extent. Emissions have fallen sharply - by 81 percent since 1990.

6. Discussion

We have in the previous sections gone through many emissions, production, and natural resources. The overall picture is that we get more for less. In most of the variables we have studied, we have found an absolute decrease in emissions, and thus a relative decline also follows.

The measuring point, of course, plays a role. In most cases, this is governed by data availability. From the beginning of the 20th century until the 1970s, emissions and population increased.

Many of the emissions did not even exist in the early 1900s. In most cases, there is data from the early 90's. Sometime before the 1990s, we can assume that there is a peak for many environmentally hazardous emissions, but that an awareness of them and a work to bring them down should have begun a few decades before. For example, IPCC was founded in 1988.

That we can get more for less is fascinating. That we can get extremely much more for less is fantastic. Below we discuss several things that contribute to technology development.

6.1 Legislation

An example of how legislation has been used to improve the environment is the ban on lead in gasoline. This meant that the air presence of lead has almost disappeared in Sweden today compared to the early 1980s. The lead ban seems to have been announced far in advance and been on the international agenda as well. This should have made the transition relatively painless once it took place. However, the legislation was preceded by several decades of conflicts regarding the danger of using lead in gasoline.

In addition, a large and growing literature has argued that environmental legislation leads to technological development. This connection has been called the Porter Hypothesis after Harvard Professor Michael M. Porter. The Porter hypothesis argues that well thought-out environmental legislation can strengthen a company's competitiveness if it has a positive impact on the pace of innovation, which in turn can outweigh the costs that the legislation entails. Porter said that the environmental debate had mistakenly regarded environmental legislation as a trade-off between private costs and social benefits. To see environmental legislation in this way, according to Porter, missed the dynamic effects that regulations can create, in the form of innovations that benefit the company, the country's competitiveness, customers and the environment.

The Porter hypothesis immediately received a lot of attention, not least if you put the attention in relation to how little evidence Porter initially gave for the hypothesis. However, the reasoning was further developed in 1995 by Porter and van der Linde (page 97):

> *"The notion of an inevitable struggle between ecology and the economy grows out of a static view of environmental regulation, in which technology, products, processes and customer needs are all fixed. In this static world, where firms have already made their cost-minimizing choices, environmental regulation inevitably raises costs and will tend to reduce the market share of domestic companies in global markets".*

The authors cite several examples. First, Japan, which introduced a recycling law, which led to Hitachi changing the design of its products. Hitachi managed to reduce the number of components in a washing machine by 16 percent and in vacuum cleaners the number of components was reduced by 30 percent. Second, the US introduced a regulation that forced the American company 3M to reduce the amount of chemical solvents in its products by 90 percent by 1995.

Today, there is a large literature on the so-called Porter hypothesis and the interaction between technological development and competitiveness. The exact links are not yet clear and it should be pointed out that stricter environmental requirements have often been preceded by a certain technological development and when it has been found possible to remove an environmentally hazardous substance, legislators have been able to make changes without the industry becoming too critical. It is sufficient here to note that legislation can have positive effects both in the form of removing environmentally harmful substances and by creating stronger incentives for technological development.

6.2 Investments in Research and Development

A research article by Ryan Wiser and Dev Millstein outlines what the benefits have been to society by the US government's efforts in research and development in wind power. The US state invested a total of $ 3 billion in the period 1976 - 2017. As in the fishing example above, the development of technology has created ripple effects. Net profit is estimated at $ 31.4 billion in the medium scenario and significantly positive in the more conservative scenarios.

Imagine that dozens of companies get access to the technology for free. This means that they can sell their product cheaper, which benefits consumers. Other sources of profit for society are that there are a lot of inventions that can be used in areas other than wind power.

Within all technology areas, there are various sources of potential future cost reductions. Technological development opens for new processes, learning curves optimizes existing processes, learning-by-doing, economies of scale spread fixed costs and raw material prices for necessary inputs all affect the final cost of a technology / process. Which of these factors is most important varies between different technologies. The rapid cost reduction on, for example, wind power has primarily been achieved through optimization of existing processes, while cost reductions for solar cells have rather occurred through research-driven technological development (Grafström, 2017, Grafström et al., 2017).

7. Conclusions and directions for future research

The purpose of this report is to show how emissions and use of natural resources in Sweden have changed over time, and to relate these to economic development. The results are encouraging in the sense that we generally get more out of less. We hope that this report will contribute to a more in-depth and fact-based analysis if the present state, without diminishing the major challenges that exist for that matter.

We found that, especially around environmentally and health-hazardous emissions, enormous progress has been made in the sense that we emit less. At the same time, we can fly more, drive longer and generally consume less carbon dioxide. The results in this report are important since we have high environmental goals and the results show that we can get rapid reductions in harmful emissions while our prosperity is still growing.

This does not mean that issues related to sustainability should be downplayed, or that the transition towards sustainability is complete. On the climate issue, this is clearly not the case. At present, we (the earth's total population) are moving further away from the climate target, and at an ever-faster rate. According to the International Energy Association, carbon dioxide emissions in 2018 are estimated to have increased by 1.7 percent, to 33.1 billion tonnes. Other organizations have even higher estimates.

The report does not aim to distinguish or highlight which factors have contributed to the development described. We can see that a combination of appropriate environmental legislation and related technological development has made a difference over the past decades. We welcome further research into the interplay between those factors.

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Swedish Environmental Agency – Flygresor per personhttps://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Flygresor-per-person/

Swedish Environmental Agency: Konsumtionsbaserade utsläpp av växthusgaser i Sverige och andra länder

https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-konsumtionsbaserade-utslapp-Sverige-och-andra-lander/

Sveriges Miljömål. Flygresor per invånare: http://www.sverigesmiljomal.se/miljomalen/generationsmalet/flygresor-per-invanare/

Figure 1, 2 - GDP per CO2

SCB nationalräkenskaperna https://www.scb.se/hitta-statistik/statistik-efter-amne/nationalrakenskaper/nationalrakenskaper/nationalrakenskaper-kvartals-och-arsberakningar/pong/tabell-och-diagram/diagram/bruttonationalprodukten-bnp-real-bnp-och-real-bruttonationalinkomst-bni-ar/

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Figure 3, 4 – Consumption based emission from foreign and domestic use

Swedish Environmental Agency: https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-konsumtionsbaserade-utslapp-Sverige-och-andra-lander/

Figur 5, 6, 7, 8 – Emissions domestic transport

https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-utslapp-fran-inrikes-transporter/

https://www.ekonomifakta.se/fakta/energi/energibalans-i-sverige/anvandning-av-fossila-branslen/

Figure 9, 10 – Air flights

Swedish Environmental Agency. Antal flygresor per invånare. https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Flygresor-per-person/

Sveriges Miljömål. Antal flygresor per invånare. http://www.sverigesmiljomal.se/miljomalen/generationsmalet/flygresor-per-invanare/

Växthusgasutsläpp från den svenska befolkningens flygresor https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-utslapp-fran-den-svenska-befolkningens-flygresor/

Figure 11, 12, 13, 14 – Fuel use

Svenska petroleuminstitutet, volymer: https://spbi.se/statistik/volymer/

Svenska petroleuminstitutet, volymer drivmedel https://spbi.se/statistik/volymer/volymer-drivmedel/

Genomsnittlig bensin diselanvändning Sverige – Swedish Environmental Agency: https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Bransleanvandning-for-bensin--och-dieselbilar/

Bensin diesel i bilar effektivitet, Swedish Environmental Agency: https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Bransleanvandning-for-bensin--och-dieselbilar/

Figure 15 Electricity use

Swedish Energy Agency: https://pxexternal.energimyndigheten.se/pxweb/sv/%c3%85rlig%20energibalans/%c3%85rlig%20energibalans__Total%20anv%c3%a4ndning%20av%20energivaror/EN0202_5.px/

Figure 16, 17, 18 – Water use:

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Figure 20, 21, 22 – Air emissions

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Figure 23 - Sulfur

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