Energy Intensity and the Environmental Kuznets Curve

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Abstract

During the last decades several scholars have argued that environmental degradation first increases in initial phases of economic growth, and thereafter declines as economic growth enters a certain level in developed economies. This makes environmental degradation form an inverse U-shaped curve, called the environmental Kuznets curve (EKC). Environmental degradation can be measured by different proxies. This paper deals with two, i.e. energy consumption and energy intensity (EI), which again is measured as the ratio between energy consumption and GDP. The relationship of energy consumption and energy intensity to economic growth can thus, serve as tools to examine whether an EKC exists.

Hence, this paper presents continuous series of energy consumption, energy intensity and gross domestic product for the Norwegian mainland economy 1835-2019. These are thereafter utilized in order to examine the possible existence of relative and absolute environmental Kuznets curves (EKC).

The time series are established by drawing on available data, and annual figures for the period 1835-2019 are presented for the first time. They depict a development which reflect that EKCs exist. The paper also offers a polynomial regression model to investigate into the relationship between environmental degradation, measured by energy consumption, energy intensity and economic growth expressed as GDP per capita. It concludes there is clear evidence of both relative and an absolute EKC-relations between environmental degradation and economic growth, with 1975 as relative and 2002 as absolute turning points.

Key words: Environmental Kuznets curve, energy intensity, energy consumption, economic growth.

JEL-classification codes: O1, O11, O13, O44, N5, N53, N54, Q01, Q34

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Introduction

During the last three decades the consequences of economic growth on the natural environment has gained increasingly concern. The main reason for this is basically that economic growth doesn't seem to represent sustainable development.

Several fields of research have been engaged in this problem, e.g. economics, economic history, environmental history and ecology. Due to the considerable fear of climate changes one has mainly focused on the use of fossil energy and thereby air emissions of CO2 (Minde and Grytten, 2004; 9-16).

During these years the debate among scientists has evolved to become more mature and nuanced. How to measure the effect of economic growth and environmental pollution, what kind of sources one should use, and methods for calculations have developed rapidly (Rothman, 1998; 177-194).

A central issue is how economic growth impacts a sustainable environment development. One may ask three key questions:

1. Is economic growth a threat to sustainable development?
2. Can economic growth be a solution to sustainable development?
3. Can it be that economic growth up to a certain stage has a negative impact on the environment, and thereafter a positive impact?

If the answer to the first question is yes, and there is no diminishing marginal pollution as economies move up the wealth leather, the environment will not survive if economic growth continues. The implications of this could only be to change economic and industrial policy in a direction which reverses economic growth or concentrates on green growth in a steady state. The alternative would be a global breakdown.

If the answer to the second question is yes, then economic growth is the solution to the environment problems. If the answer to the last question is yes, then economic growth as an has a negative effect on the environment until the effect is reduced as the economy reach a certain wealth level. Then we deal with the so-called environmental Kuznets curve (EKC) (Stern, 2004; 1419-1439; Dinda, 2004; 431-455).

An important focus in environmental and economic history during the last decades has been to try to find out whether economic growth follows an EKC or not. Is there any evidence that suggests that economic growth in the long run could be a solution and not a hinderance to sustainable development? This implies that production should be first less energy intensive of non-sustainable fuel, and thereafter the use of non-sustainable fuel should fall.

The purpose of this paper is to map a possible EKC for the Norway mainland economy for the period 1835-2019. This is basically done by mapping energy intensity (EI), i.e. how many units of energy is used to produce one unit of gross domestic product (GDP) at different levels of wealth. If the EI during the time series first is increasing and thereafter gradually decreasing, we will map an inverted U-shaped curve, which is an EKC. The paper focus on the mainland economy of Norway, i.e. offshore oil and gas extraction are excluded both in the EI and the GDP series, as they will serve as noise in the historical time series. Including the petroleum industry would have made it impossible to present the underlying trends in these important parameters of sustainable development. Thus, it is considered an external factor to our analysis.

Concept

The EKC-hypothesis rests on an empirical relationship between wealth and pollution. From an economic theory approach this relationship can be explained as a combination of technical development and preferences (Kriström, 2007; 77-90). At the same time several dynamic parameters become exogenous in such models, e.g. the question of which factors that impact preferences and if the preferences are cointegrated with the technical development. In addition, these models are general, as they don't take into account how the environmental preferences are channeled: through political, self-regulation, technological or free market channels.

The present paper deals with the development of GDP energy intensity (EI), i.e. how much energy is consumed per unit GDP. Energy consumption is not synonymous with environmental pollution. However, it is related to degrading of the environment e.g. via climate changes. Also, energy production is very often based on fossil fuel, with significant omissions of CO2, sulfur dioxide and different air particles. Hydro power on the other hand has a marginal impact on the climate, but might have significant biological disadvantages.

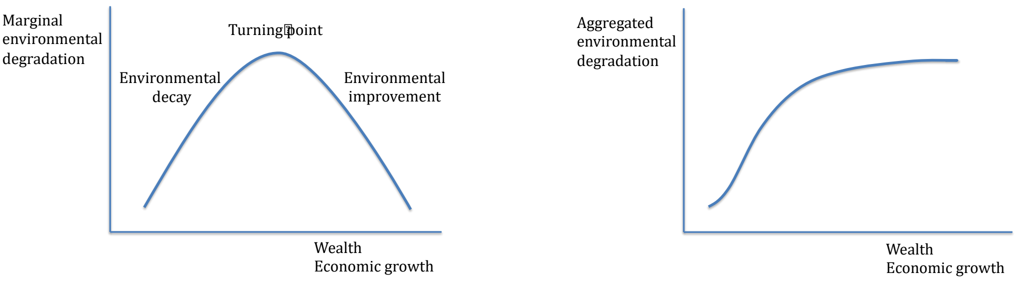
EI is a partial productivity measure. It gives a proxy of degrading of the environment, and thus, a proxy of negative sustainable development (Arrow, 2004; 147-172; Hartwick, 1977; 972-974). Energy is also part of the capital stock. Higher EI then gives higher capital stock, which in its turn might give higher economic growth. Thus, an increase in EI might serve as a negative proxy for sustainable environmental development and a positive proxy for sustainable economic development. Weak economic sustainability is often characterized by a high degree of substitutability between produced capital and natural resource capital, when strong economic sustainability is characterized by an increasing or constant natural resource capital stock, with low substitutability. However, in the long run sustainable economic development is dependent on environmental sustainability.

Theory

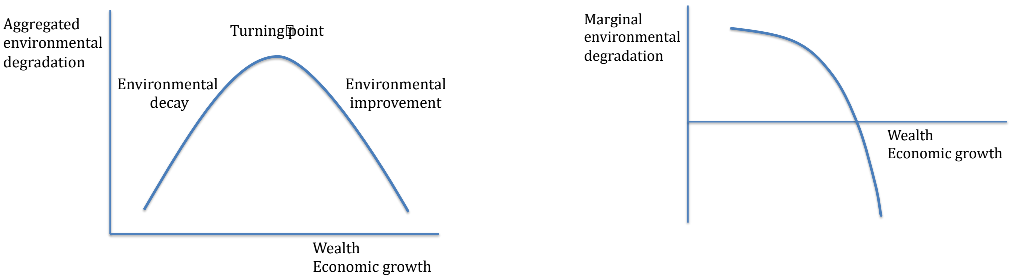
The EKC-theory rests on empirical research, suggesting that economic growth in its early stages causes degradation of the environment. This degradation continues until a certain level of wealth is obtained. Then one might see signs of reduced degradation. Empirically, this is basically mirrored in increasing degradation during takeoff phases of the economy. However, the marginal degradation might be negative, or will become negative at a stage of economic growth. This relationship may indicate that increasing wealth at a stage might reduce even the aggregated level of environmental degradation (Dinda, 2004; 431-455). Theoretically, there is two major forms of the EKC, as described in Figure 1.

Figure 1. Relationship between wealth (economic growth) and environmental degradation in the EKC.

1a. Relative EKC



1b. Absolute EKC



The most common deals with a relative EKC, i.e. marginal degradation to the environment will first increase and then decrease with economic growth. When an absolute EKC, where the aggregated level of degradation first increases with economic growth and thereafter decreases, is supposed to be rare.

A relative EKC relationship implies that economic growth might be a partial solution to environmental degradation, but not sufficient, when an absolute implies that economic growth might be a solution to environmental degradation.

The notion that environmental degradation no longer goes hand in hand with economic growth is called the turning point. This implies that economic sustainability at a certain stage will allow a decoupling of economic growth and environmental unsustainability.

In the literature one may also find the terms weak and a strong EKC. However, these are not always given the same definitions (Kander, 2002;13-16). This paper uses the term strong relationship when the environmental degradation falls with a higher rate than the economic growth, and a weak relationship describes a lower fall in the degradation than in the economic growth. This might be both on a marginal and an aggregated or absolute level.

So, what is the causal relationship between economic growth and diminishing environmental degradation? One might come up with four major explanations:

1. Technological

   Technical innovations can introduce the way for profitable clean energy, and thus, less environmental pollution.
2. Political

   This implies that the economies have sufficient economic resources for the politicians to take action to reduce environmental degradation.
3. Standard of living

   This implies that consumers become wealthy enough to demand a better and more sustainable development
4. Economic growth

   Economic growth in itself shifts consumption over to more environmentally friendly products and productivity makes cleaner production possible.

The present paper does not focus on which of these explanations that are most plausible. However, we observe that all of them have been decisive for the development. Economic growth and increased environmental pollution have gained increasingly attention by politicians, consumers and business itself. Politicians take measures to improve the environment, consumers demand for environmentally friendly products, and industry seeks to apply more environmentally sustainable technology in production.

Model

To calculate the EI for Norway 1835-2019 we need both data on energy consumption and GDP. Energy consumption is calculated via an EGP-network standard to Joule. Our method takes its departure in the so-called *IPAT-identity*, where *I* is environmental impact, which is influenced by size of population (*P*), wealth (*A*) and technology (*T*) (Chertow, 2000; 13-29) as a tool of analyzing long term energy effects. The method is quite straight forward, as energy intensity (*EI*) is the share of total consumption of energy ($E^C{}_t$) as share of GDP(Y_t) in period *t*:

(1) $$EI_t = E^C{}_t/Y_t$$

Energy consumption in period *t* ($E^C{}_t$) is a proxy of environmental impact ($E^I{}_t$), and is a function of population (*P*) in period *t* (P_t) wealth, which in this paper is GDP (*Y*), and finally technology (*T*) in period *t*:

(2) $$E^I{}_t = E^C{}_t = F(P_t, Y_t, T_t)$$

One can operationalize this relation geometrically, by multiplying the right-side parameters with each other:

(3) $$E^I{}_t = E^C{}_t = (P_t \times Y_t, \times T_t)$$

Furthermore, *EI* can be expressed as an elasticity (EI^e):

(4) $$EI^e = (dE^C{}_t/dY_t) = (E^C{}_{t+n}/E^C{}_t)/(Y_{t+n}/Y_t)$$

Empirical research shows that EI or E^C normally increases when production or GDP (Y) increases. This is called coupling, as expressed in equation (4):

(5) $d(E^C{}_t/Y_t) > 0$

Expansive coupling takes place when energy consumption increases faster than GDP.

(6) $(E^C{}_{t+n}/E^C{}_t)/(Y_{t+n}/Y_t) > 1$

Relative decoupling takes place when

(7) $d(E^C{}_t/Y_t) < 0$

The increase in Y will be larger than the increase in energy consumption:

(8) $0 < (E^C{}_{t+n}/E^C{}_t)/(Y_{t+n}/Y_t) < 1$

Absolute decoupling requires that energy consumption (E^C) decreases when GDP (Y) increases:

(9) $-1 < (E^C{}_{t+n}/E^C{}_t)/(Y_{t+n}/Y_t) < 0$

Absolute strong decupling implies that energy consumption falls more than GDP increases:

(10) $(E^C{}_{t+n}/E^C{}_t)/(Y_{t+n}/Y_t) < -1$

In this paper we pay attention both to relative and absolute decoupling. In sum, we calculate energy intensity as energy consumption relative to gross domestic product per capita for all years 1835-2019. The paper then seeks to find out if we can spot increase in the intensity during the first phase and thereafter falling intensity. If we find such a relationship, it's a sign of increasing marginal environmental degradation in the first period and decreasing marginal environmental degradation in the second period. The paper also seeks to find out if absolute decoupling has taken place by relating energy consumption per capita to economic growth. If energy consumption per capita first increases and thereafter falls relative to economic growth, there is an absolute EKC relation.

In sum, we seek to find whether there was an environmental Kuznets curve for Norway along these parameters for the period and thus, a decoupling of the positive relationship between economic growth and environmental degradation.

Literature review

The EKC-hypothesis stems from empirical research of the relationship between economic growth and wealth on the one hand and environmental degradation on the other hand. In his global history of economic growth Maddison (2007; 352-353) mentions this theme as central to sustainable development. The modern debate started already in the 1960s, and had a takeoff with the book *Limitations to Growth* (Meadows, 1972; Wilkinson, 1973). It was stressed that natural resources one day would end, and thus, economic growth would stop. In other words, continuous growth on the basis of consumption of natural resources is not sustainable. Hence, they suggested a zero-growth scenario as a steady state economy, given that could be sustainable.

Malenbaum (1978) challenged this view by showing that the demand for certain metals fell as proportion to GDP in wealthy countries. Assuming the same development in the future, he drew a picture showing that economic growth did not have to end up in an environmental disaster. Research by Auty (1985; 275-283) confirmed this view. An Intensity of Use (IOU) hypothesis was put forward, suggesting that use of natural resources could be an inverted U-shaped curve along with economic growth. Williams et al (1987; 99-144) and Tilton (1990; 35-76) concluded that even the use of energy could fall along with economic growth in mature economies.

The Kuznets curve was already known as the inverted U-shape between economic growth and inequality, suggesting inequality first increase by economic growth, and after the economy reaches a certain point inequality drops with growth. One of the first studies of the empirical relationship between air pollution and economic growth was carried out by Grossman and Krueger (1991;433-445). During the early 1990s the term EKC was increasingly used also for the relation between environmental degradation and economic growth.

In 1987 the United Nations (UN) launched their report *Our Common Future* (UN, 1987). It was concluded that economic growth could be a solution to poverty. However, the growth had to be ecologically sustainable. Thus, it was imperative that growth should not lead to environmental degradation.

Beckermann (1992; 481-496), Bhagawati (1993; 42-49), Panayotou (1993) and Nemat (1994; 757-773) showed by empirical evidence that this could be possible to obtain. Arrow et al (1995; 520-521) concluded that entering into a mature and wealthy economy would mean more emphasis on service industries and less on manufacturing industry, leading to relative less environmental degradation as economic growth continues. Bruvoll and Fæhn (2005; 34-35) argue that the increase of wealth makes consumers more willing to pay for clean nature, and thus, environmental degradation might decrease with the increase in wealth.

Later research has more focused on the EKC itself, and most scholars doing research into the field find a relationship confirming a relative decoupling between growth and environmental degradation (Harbough, 2002; 541-551; Bimonte, 2005; Ciegis, 2008; 313-335; Mills, 2009; 2087-2095; Uchiyama, 2016; Koilo 2019a; 1-18).

If we see growth convergence in the decades to come, i.e. developing countries will have higher growth rates than developed countries, it is reasonable to believe that they will also enter into an EKC-relationship. Thus, economic convergence might mean environmental convergence. This assumption has been labeled the Double convergence hypothesis (Bimonte, 2009; 2406-2411). However, one has to remember that this will depend on the causal reasons for the empirical tracks of the EKC. If one doesn't find similar environmental focus in the developing countries, they might not enter the turning point as easily as others. This will depend on political, consumption and business attitudes (Stern 2004; 1434-1435; Copeland, 2004; 7-71; Spangenberg, 2001; 175-191).

The energy intensity (EI) of GDP describes the relationship between GDP in fixed prices and energy consumption. Long term trends show a dynamic relationship between the two. One might identify different phases over time. For countries like the UK, Germany, France and the USA the industrialization process was based on coal as energy source. They show a steep increase in domestic EI in the early phase, thereafter a peak followed by a pattern of falling EI. (Schurr, 1978; Smil, 2000; 408-412; Kander, 2013; 4-34; Smil, 2016; 194-197). Fall in EIs can be interpreted as signs of relative or total decoupling of the positive relationship between economic growth and environmental pollution. In many cases energy consumption is considered a proxy for impact on the environment (Stern 2004; 1419-1434). However, such impact varies a lot between energy sources.

Gales et al (2007; 219-253) has shown that per capita energy consumption increased in the Netherlands and Sweden from the mid 1800s to the early 1970s. Kander (2002; 186-195) concluded surprisingly that the EI started its fall relative to GDP as early as the 1800s. She also finds an absolute fall of some important pollution factors. Thus, one. Might depict an absolute EKC. Kunnas and Myllyntaus (2017; 154-189) find a similar pattern for Finland. When Nakicenovic et al (1998) find a long-term decline of EI for the USA. It can be argued that this special pattern for the Nordic countries and the US can be explained by the fact that house heating played an important role in energy consumption even before takeoff of economic growth. Warde (2019; 7-32) points out that the data for the 19th century often lacks reliability, due to courageous assumptions behind the estimations.

As for Norway, little has been done to investigate into the historical energy intensity. However, a pioneer in the area was Stoltz (1955; 50-56) who gave his estimations of the Norwegian EI for the period 1900-1950. Stoltz reported growth in the energy consumption, but a fall in EI for the period. However, he stressed that the period saw a lot of noise due to the two world wars, and severe depressions in the early 1900s, the 1920s and the 1930s. Hence, one should be careful to conclude on the basis of his calculations.

Grimstad (2019; 1-19) later did estimations for the period 1990-2017, and according to him the EI for mainland Norway showed a downward trend from the departure in 1990. Recently Koilo (2019b; 48-65) has studied the relationship between CO2 emissions, energy consumption and intensity and growth of the Norwegian maritime sector. She concludes there is an EKC relationship between the use of energy, CO2 emissions and value-added growth in the Norwegian merchant fleet.

Data

The data for the estimations of the energy consumption is primarily taken from Lindmark and Minde (2018; 157-177), when the historical GDP series are compiled from Grytten (2020; 18-25). The series are presented in Figure 2. As already stated, the paper uses series for mainland Norway. The graphs depict substantial growth in both measures.

However, one can spot that energy consumption is leveling out from around 2000, when GDP continuous its growth. This might be an indication of decoupling between the two.

Figure 2. Historical energy consumption and GDP for Norway

Figure 2a. Energy consumption by source of production in Petajoule, 1835-2012.

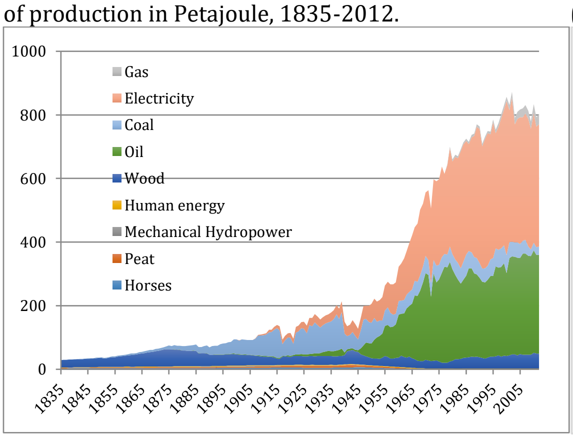
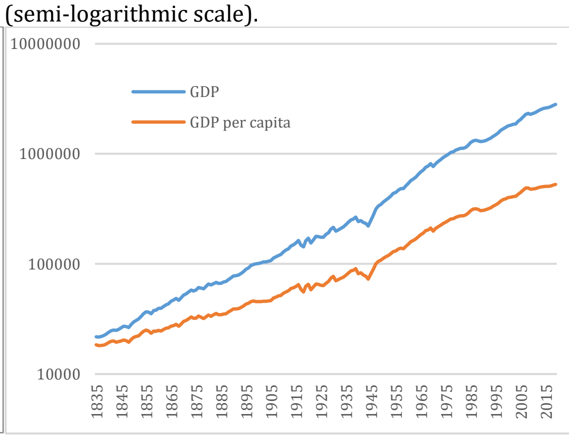


Figure 2b. GDP in 2015-NOK, 1835-2019 (semi-logarithmic scale).



Sources, Lindmark and Minde (2018) and Grytten (2020).

The data on energy consumption are basically taken from governmental papers until the 1870s and thereafter data from Statistics Norway. Both validity and reliability of these records seem satisfactory until 1876, thereafter good and since 1920 very good. Their quality is considered to be of the same high standard as for other Nordic countries, and possibly higher (Lindmark and Minde, 2018; 163-166, Grytten and Minde, 1998; 42-58). Our main challenge is the estimations of traditional fuel, like wood, peat and mechanical hydro energy, which are made on the basis of the calculated energy consumption for commodity consumption and production. Lindmark and Minde also transformed the data from kilowatts per hour (KWH) to Joule (J). They have been transformed to Petajoule (PJ), where 1PJ = 1J ^{x} 10^{15}.

Energy consumption for mainland Norway is reported into nine different sources of production, 1835-2012. Five of these are traditional sources, those are energy from horses, humans, mechanical hydropower, peat and firewood (wood). Four are newer sources of energy, namely coal, electricity, gas and oil. Since 2012 we use energy consumption and EI figures by Grimstad (2019; 1-19) and Statistics Norway. It is not a straightforward operation to link the different sources, due to structural breaks in the data caused my change of definitions. However, by splicing the series by level in 2002 and one arrives at annual series of energy consumption and intensity 1835-2019.

Our data for GDP stems from an ongoing project at the Norwegian central bank (Grytten, 2004; 241-288). By drawing on data from public and private records from the Wedervang Archive of prices and wages, one has established a detailed set of value added for the Norwegian economy during a 200-year period. From 1946 the national accounts by Statistics Norway have been used (Skoglund, 2009). By drawing on these rich sources of data and applying a double deflation technique, i.e. deflating both input and output series to obtain fixed price series, the Norwegian GDP series seem more valid and reliable than most historical national accounts.

The GDP series are calculated in base values from the production side and market values from the expenditure side and the production side inclusive product taxes and subsidies. From 1970 the series split between mainland Norway and the Norwegian economy as a whole. This is due to the offshore oil and gas activity, which is excluded in the estimates for mainland Norway. Thus, we use GDP for mainland Norway from 1970, and before that the general series, which presents the Norwegian mainland economy only, as oil and gas extraction had not started yet.

It is reasonable to conclude that the applied data sets seem quite relevant, valid and reliable for our use, and they should contribute significantly to the quality of this study.

Results

We are now in a position to make relevant estimations of the relationships between EI and GDP as indicators of possible EKCs. Figure 2 already that energy consumption increased slowly until hydroelectricity had its breakthrough after 1905. Due to the two world wars the huge spurt didn't come until the 1950s, it started to level out in the 1990s and reached a maximum in 2002. Thereafter, energy consumption in mainland-Norway stopped its increase or even stagnated. This definitely gives us an idea that we might trace an EKC, not only in relative terms, but also in absolute terms.

In order to come closer to the core of the present analysis it is necessary to look at both energy intensity (EI) and energy consumption per capita during the period of investigation. This is done in Figure 3. The results might be somewhat surprising. In fact, we find an almost constant trend of falling energy intensity, except for the industrialization waves in the 1860-1870s, 1890s-1914 and the 1950s until the early

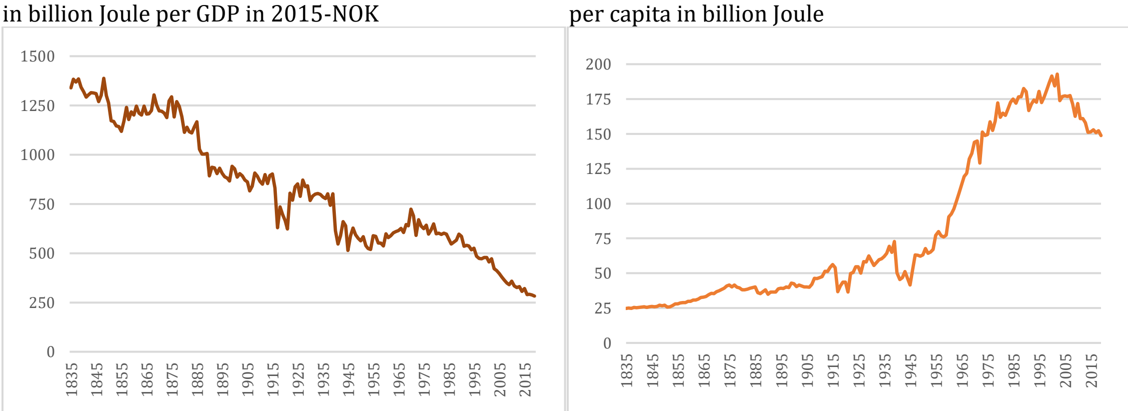
1970s. We also find low EIs during the world wars. This suggests an EKC-relationship with increased environmental degradation during periods of industrialization, and thereafter decreased degradation in periods of less industrialization or even deindustrialization from the mid 1970s. In other words, we find evidence of a relative EKC 1950-2019, which reach its turning point in 1975.

As for energy consumption per capita one finds a clear hint of an EKC. From 1835, and in particular from the early 1950s one finds significant increase in energy consumption per capita and thereafter quite evident stagnation from the first years of the present century. This clearly mirrors the development in EI for this period, which also gives evidence of an absolute EKC curve for mainland Norway since the 1830s until present days with 2002 as its turning point.

Figure 3. Energy Intensity and consumption, 1835-2019.

Figure 3a. Energy intensity in billion Joule per GDP in 2015-NOK

Figure 3b. Energy consumption per capita in billion Joule



Source, Lindmark and Minde (2018) and Statistics Norway (2020).

Polynomial regression test

In order to examine the relationships between energy consumption and economic growth in more depth one might look at statistical relationships between the two variables. Hence, we present these as plot diagrams and estimate polynomial regressions in order to make estimations of trends in the data. The polynomial regression model of order *m* is established according to equation (11), where *y* denotes the estimated value at *i*, when *x* denotes the regression parameters of the model, when *ε* is the disturbance term:

(11) $$y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \beta_3 x_i^3 + \cdots + \beta_m x_i^m + \varepsilon_i$$

where (i = 1, 2, 3, ..., n).

This can be expressed in a matrix form:

(12) $$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_1 & x_1^2 & \dots & x_1^m \\ 1 & x_2 & x_2^2 & \dots & x_2^m \\ 1 & x_3 & x_3^2 & \dots & x_3^m \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_n & x_n^2 & \dots & x_n^m \end{bmatrix} \times \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_m \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

When using pure matrix notation one can express each of the four parameters and factors in equation (12) as in equation (13):

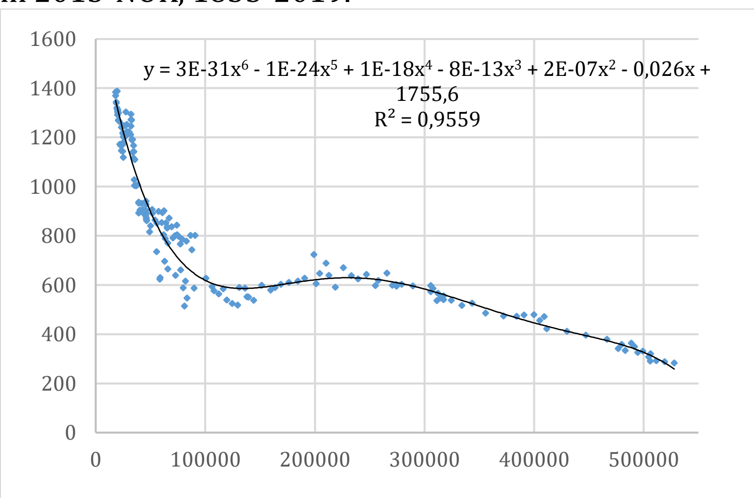
(13) $$\vec{y} = \mathbf{X}\vec{\beta} + \vec{\varepsilon}$$

Here $\vec{y}$ is a response vector, $\mathbf{X}$ a design matrix, $\vec{\beta}$ a parameter vector, and $\vec{\varepsilon}$ a random error vector. The vector of estimated polynomial regression coefficients ($\hat{\vec{\beta}}$) using OLS estimation would be:

(14) $$\hat{\vec{\beta}} = (\mathbf{X}^{\mathrm{T}}\mathbf{X})^{-1}\mathbf{X}^{\mathrm{T}}\vec{y}$$

In the present analysis the dependent variable y is energy consumption per capita or energy intensity, when, the explanatory variables x is GDP per capita. One is now able to run tests according to the model. The results are presented in Figure 4.

Figure 4. Energy Intensity in billion joule vs GDP per capita in 2015-NOK, 1835-2019.

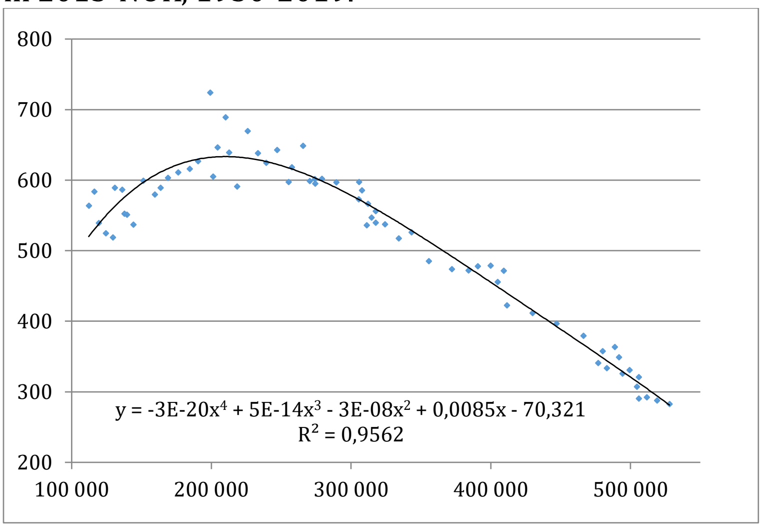


Sources, Lindmark and Minde (2018) and Grytten (2020).

The relationship between EI and GDP per capita in fixed prices seem to be, something similar to a N-shape, which often is the case for the historical development in modern economies. One initially observes a falling EI-curve, due to substitution from wood and peal to cleaner energy. Then, one finds possible evidence of the EKC as the economy goes through substantial industrialization and growth, until the development in EI levels out and falls. As for mainland Norway, it seems as the initial fall ends at a GDP per capita level of 130.000 in the early 1950s, and then the increase continues until a per capita GDP level of 220.000 in the mid 1970s, both figures in 2015-NOK.

One should look at a smaller sample to illuminate a possible EKC. Thus, we apply the model on the period 1950-2019, using independent data series for this period by estimating for these limited years only. The results are shown in Figure 5. The estimated polynomial regression line along with the plot diagram evidently gives evidence of a relative environmental Kuznets curve for the Norwegian mainland economy on the basis of the relationship between economic growth and energy intensity for the period 1950-2019. Following both the energy intensity and per capita consumption along a timeline, one finds 1975 as the exact turning point.

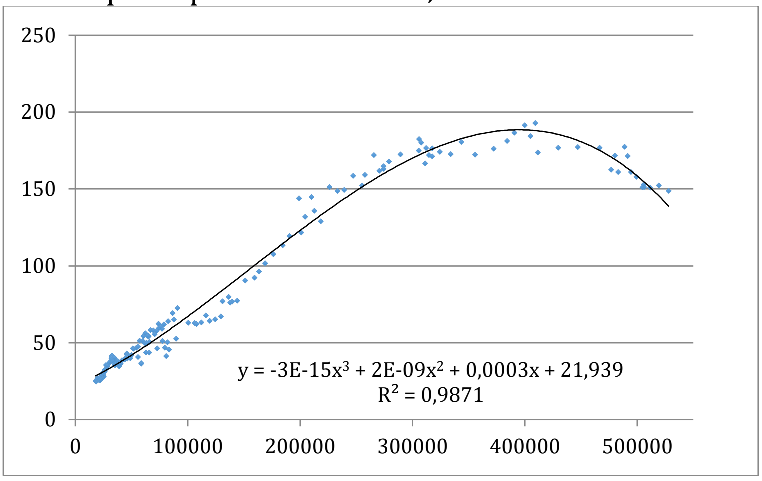
Figure 5. Energy Intensity in billion joule vs GDP per capita in 2015-NOK, 1950-2019.



Sources, Lindmark and Minde (2018) and Grytten (2020).

Finally, in addition to the relative, one may also trace an absolute EKC. To find out whether such a relationship exists it is natural to plot the relationship between energy consumption per capita and GDP per capita for the period under investigation, and run the polynomial regression model on these data. The results are reported in Figure 6. The polynomial regression line clearly depicts that the entire period 1835-2019 represents an absolute EKC curve with a turning point or decoupling during the first years of the 21st century.

Figure 6. Energy consumption per capita in billion joules
vs GDP per capita in NOK-2015, 1835-2019.



Sources, Lindmark and Minde (2018) and Grytten (2020).

As for all the tests done within this regression model, we find a very satisfactory R^2, i.e. the estimated regression lines explain between 95.59% and 98.71% of the development. Thus, it should be evident that the historical development of the EI along with economic growth for mainland Norway gives evidence of an EKC, both in relative and absolute terms.

Conclusions

The present paper seeks to investigate possible relationships between environmental degradation and economic growth. More precisely it aims at examining whether it exists an environmental Kuznets curve for energy consumption in Norway at some time during the period 1835-2019. We investigate the EKC in two dimensions. Firstly, we look at a relative EKC. This is measured by the relationship between energy intensity (EI) and gross domestic product per capita. This is done by establishing annual series of energy intensity, i.e. energy consumption divided by GDP in fixed prices for the entire period. Secondly, we look at an absolute EKC, measured by energy consumption per capita compared to GDP per capita.

The data are compiled from research into historical series of energy consumption and GDP, spliced with more recent data from Statistics Norway. By looking at the time series of EI, one finds an evident negative trend in the series, meaning that EI is falling during the period. For the period 1950-2019 one finds a clearly inverted U-shaped curve. This implies there is a relative EKC for Norway for this latter period with a turning point and decoupling from 1975.

Looking at energy consumption per capita one finds a similar inverted U-shaped curve for the entire period, and in particular for 1945-2019. This means there is an absolute EKC with a turning point and decoupling from 2002.

The paper finally offers a polynomial regression model to test relationships between energy intensity and energy consumption on the one hand and GDP per capita on the other. These tests clearly confirm that one finds both a relative and an absolute EKC for Norway.

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