Long-Term Kaya-Identity Analysis and Prerequisites of a Sustainable and Green Economic Growth in a 2°C World

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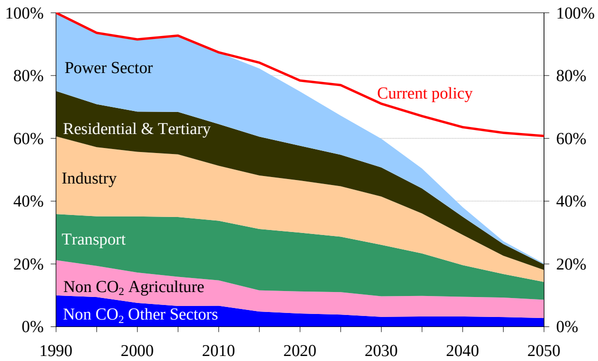
ANALYSIS

1. Introduction

On 9 May 2013, for the first time since measurements began in 1958, the daily mean concentration of carbon dioxide in the atmosphere of Mauna Loa, Hawaii, surpassed 400 parts per million (ppm) (NOAA, 2013). A 400ppm CO_2-concentration of the atmosphere is seen as the lower boundary for reaching a global warming of 2°C with a low probability. Currently, the atmospheric CO_2-contentration is increasing by about 2ppm per annum.

This means, that the upper boundary for the 2°C global warming with a high probability will be reached by around 2040 and 2°C global mean temperature increase compared to the beginning of the industrial revolution may be reached even earlier.

Figure 1:
EU 80 percent GHG-emission reduction pathway
(1990-2050, in t CO_{2e})



Source: EU-Commission (2011).

For keeping the 2°C global warming target, a reduction of global CO_2-emissions by 50% in 2050 compared to 1990 is required. Taking the historical emissions of developing countries and the energy needs of developing countries into account, for the developing countries, this may even mean a 80-95% reduction according to IPCC indications. In 2011, the EU has adopted this emission reduction target and issued a subsequent roadmap (Figure 1) for moving to a competitive low carbon economy in 2050 (EU-Commission, 2011).

With not much more than 12.4% of world CO_2-emissions, the EU initiative is not able to tackle the climate change issue entirely on its own. Major contributions have to come from China and the US. Until today, global CO_2-emissions, however, did not decrease. On the contrary, they increased up to about 34 bn. tons in 2010 (Figure 2), mainly due to growing emissions from China and the US, together accounting for more than 40% of global CO_2-emissions. About 60% of the incremental global CO_2-emissions since 2000 are from China based on economic growth mainly in the export sector. In 2007, China surpassed the US as the world's biggest CO_2-emitter.

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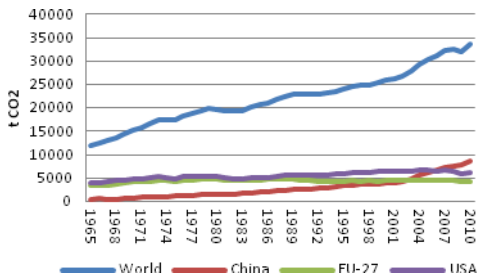
Figure 2:

Development of CO_2-emissions worldwide and in selected countries/regions

(1965 -2010, in t CO_2)



Source: BP (2012).

As the increase of CO_2-concentration in the atmosphere is an accumulative process over hundreds of years since the beginning of the industrial revolution, the industrialized countries also have their historical responsibility. By 2007, the Annex-I countries (i.e. the OECD countries and the transformation economies in Central and Eastern Europe) accounted for 74.8% of the world cumulative CO_2-emissions ($CO_{2,cum}$) since 1750, of which the OECD countries 63.4%. The Non-Annex-I countries (i.e. basically the developing countries and emerging economies in Asia, Latin America, Africa and the Middle East) with a huge increase in population were only responsible for 25.2% of the cumulated emissions, of which China represents 9.2% and India 2.3%. In 2007, however, with 119.7 bn $CO_{2,cum}$, China, already almost exceeded the cumulative CO_2-emissions of Germany (85.1 bn t $CO_{2,cum}$) and France (35.5 bn t $CO_{2,cum}$) together (Oberheitmann, 2010).

Against this background, one of the main driving forces of the global CO_2-emissions is economic development and population growth since the past few hundred years, but not the only one. So, the question is, where do the CO_2-emission derive long-term and how can we cope with the threats to humankind security with a growing world population and development needs.

Aim of this article is (a) to analyze the determining factors of global CO2-emissions on a long time scale since 1800 until today and (b) ask for the prerequisites of a sustainable and green economic growth for the future. Basis for the analysis of the first question is the Kaya-Identity (Kaya, 1990). This ex-post identity (Equation 1) expresses the amount of CO_2-emissions as the product of the following factors: population, Gross Value Added per capita, energy intensity of Gross Value Added and CO_2-intensity of energy consumption. Hence, it is defined as:

$$CO_2 = CO_2/PES * PES/GDP * GDP/POP * POP \qquad (1)$$

with

CO_2 = CO_2-emissions (Mt)
PES = Primary Energy Supply (Mtsce)
GDP = Gross Domestic Product (Mill. Geary-Khamis Dollar)
POP = Population (Mill.)

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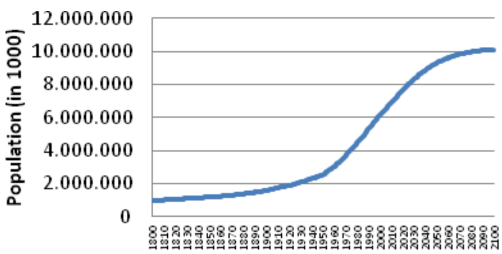
Based on this equation, Chapter 2 analyses the four pillars of the Kaya-indentity on a long-term basis from 1800 until 2010. Chapter 3 analysis the prerequisites of a sustainable and green economic growth for the future taking the increase of energy density of primary energy supply as a prerequisite for economic growth into account and assesses the impact of the promotion of renewable energies on sustainable and green economic growth and the keeping of the 2°C global warming target. Chapter 4 summarizes the article.

2. Long-term Kaya-identity considerations

2.1 Population

In 2012, the Earth's population reached seven billion inhabitants. By around 2050, it is expected to be nine billion, even ten million in 2100 (Figure 3). However, over the past 200 years, world population grew unevenly. In 1811, world population was only one billion and doubled by 1927 to two billion in 116 years. Only 47 years later, in 1974 it doubled again to four million. After 1974, every 12-13 years, an additional billion of world population was added.

Figure 3:
World population
(1800-2100, in 1000)

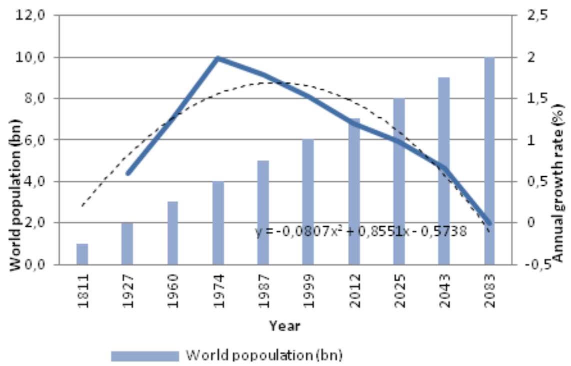


Source: Data 1800-1949: Bolt, J. and J. L. van Zanden (2013). Data 1950-2100: United Nations Population Division, Department of Economic and Social Affairs (2010), MEDIUM scenario.

1974, however, was the peak of global population growth. Since this year, annual growth decreased and world population increased slower than in the past. Following the MEDIUM growth scenario of the UN Population Division, with a world population of 10 billion in 2083, growth rate would be about zero (Figure 4).

Already a world population of 5 billion, people began to exceed Earth's recovery potential. If world population reached 9 or even 10 billion by 2050 (in the UN HIGH scenario), we may need more than 3 Earth's to accommodate mankind's demands since the specific economic foot-print per person is growing as well (Green Security Alliance, 2013).

Figure 4:
World population selected years and its annual growth rate
(1811-2083, in percent)



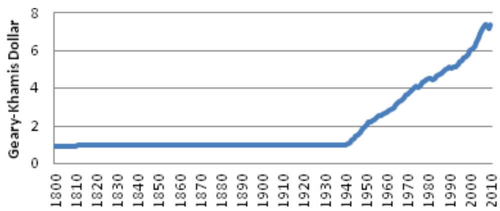
Source: Own calculations based on Bolt, J. and J. L. van Zanden (2013) and United Nations Population Division, Department of Economic and Social Affairs (2010).

As we only have one world, mankind security, which is the security of natural living conditions for the total world population, is at stake. If mankind security is not given, as we know now already for the 7 billion people because of growing observable degradation of human natural living base, then either Earth's carrying capacity will be diminished continuously, or the degradation can be stopped and even be enlarged by introducing a less resources degrading civilization (Green Security Alliance, 2013). Since the events at the Easter Island in the 17th century the process of a civilization collapse cannot be excluded a-priory (Oberheitmann, 2011).

2.2 GDP per capita

According to Bolt, J. and J. L. van Zanden (2013), between 1800 und 1940 world GDP per capita, measured in Geary-Khamis Dollar, i.e. a hypothetical unit of currency that has the same purchasing power parity that the U.S. dollar had in the United States at a given point in time, here in 1990, increased only slowly. Especially after World War II, it grew considerably (Figure 5).

Figure 5:
World GDP per capita
(1800-2010, in 1990 Geary-Khamis Dollar[1])



Source: Bolt, J. and J. L. van Zanden (2013). [1)] Base year 1990.

GDP per capita is the most important driver in the Kaya-identity for the growth of CO_2-emissions as a growth of disposable income increases the demand for energy directly (e.g. for mobility) as well as indirectly through the increase of energy which is needed to produce goods and to provide services being purchased from additional disposable income (Oberheitmann, 2012).

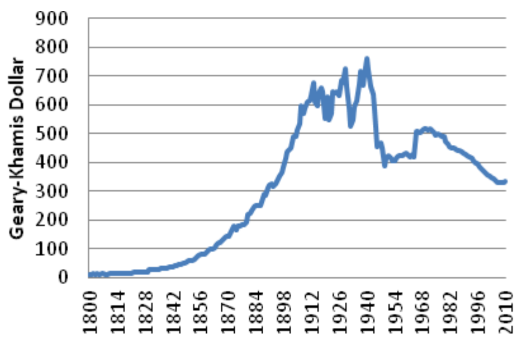
A double-logarithmic regression analysis[1] of these two variables between 1800 and 2010 show a high per capita GDP-elasticity of global CO_2-emissions: one percent increase of global per capita income induces a 2.5% increase of CO_2-emissions worldwide.

This elasticity shows that our economic development has considerable negative side effects on the Earth's carrying capacity. Taking only the needs of China's development needs into account, CO_2-emissions will increase considerably. China currently counts for about 25% of world CO_2-emissions and 16.2% of world GDP, but only has 18.5% of Japan's GDP per capita. Having the same per capita income as Japan, China's CO_2-emissions would at least more than fivefold without any countermeasures taken.

2.3 Energy intensity of GDP

Speaking of countermeasures, the reduction of energy intensity of GDP is currently the main factor for a possible decrease of CO_2-emissions. Since 1880 until the early 20th Century, energy intensity of GDP increased considerably as industrialization took part, especially in the western world. During the times of First World War, subsequent economic depression in the 1920's/early 1930's and Second World War, energy intensity of GDP fluctuated considerably (Figure 6).

Figure 6:
World primary energy intensity of GDP
(1800-2010, in t sce per Geary-Khamis Dollar[1])



Source: Own calculations based on Bolt, J. and J. L. van Zanden (2013), Oberheitmann (2010) and BP (2012). 1) Base year 1990.

After the Second World War, energy intensity of GDP decreased until the late 1960's. With the first oil crisis in 1974 and economic downturn, energy intensity first increased and then decreased continuously. Since the

[1] If both sides of the equation are expressed in logarithmic form, the regression coefficient can be interpreted as an elasticity. An elasticity expresses the percental impact on the dependent variable of a one percent increase of the independent variable.

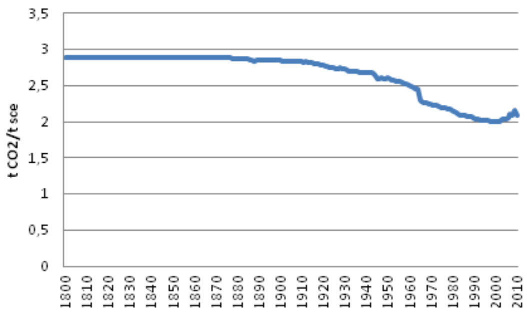
world financial crisis and economic turmoil in 2008, Figure 6 shows a slight increase of energy intensity of GDP again.

A double-logarithmic regression analysis of global energy intensity of GDP and CO_2-emissions between 1800 and 2010 show that one percent decrease of global energy intensity of GDP induces a 1.5% decrease of CO_2-emissions worldwide. This means that the global reduction of energy intensity of GDP can compensate 60% of the worldwide CO_2-emission increase due to the growth of global per capita income.

2.4 CO_2-intensity of primary energy supply

Since 1800, global CO_2-intensity of primary energy supply decreased due to a shift from coal to oil and natural gas as well as the promotion of hydro power and the introduction of nuclear and modern renewable energy sources mainly for electricity generation (Figure 7). Since 2001, there is a certain renaissance of coal due to the increase of coal demand in China leading to a slight increase in CO_2-intensity of world primary energy supply.

Figure 7:
CO_2-intensity of World Primary Energy Supply
(1800-2010, in t CO_2/t sce)



Source: Calculations based on data from Oberheitmann (2010) and BP (2012).

Especially the promotion of renewable energies, such as undertaken by the German Federal Government aiming at restructuring the domestic energy demand mix ("Energiewende") or the massive investments in China into renewable and nuclear energy will lead to a long-term further reduction of global CO_2-intensity of primary energy supply.

To achieve a 80-95% reduction of CO_2-emissions in the EU and other developing countries until 2050 can finally only be achieved with a dramatic turn to renewable energies. The strategy, however, should be as follows:

a) First, saving energy wherever possible. The easiest CO_2-emission reductions are those which do not occur in the first place relative to the business-as-usual. This may count for 10% of the global CO_2-emissions to be reduced.

b) Second, decreasing energy intensity of GDP as much as possible. This can save about 60% of the global CO_2-emissions (see above).

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c) Third, reduce the remaining CO_2-emissions with renewable energies and only use this form of energy for necessary economic growth.

3. The increase of energy density as a prerequisite of global long-term sustainable economic growth

Looking into the long-term future, the question is how to assure a sustainable economic growth for 10 billion people on Earth in 2050 and even way beyond that. As described above, renewable energies are the main form of energy for the necessary economic growth of the future. This development may be the path for the energy supply of the next 100 years.

Imagine, however, at one point of time the world societies develop further technologically and e.g. concrete plans are developed to enable manned spaceships leaving our solar system. Such technologies need a significant increase of energy density. Energy density is the energy content per physical unit of energy, e.g. per kg standard coal equivalent (sce) or per m^3. The lunar missions in the late 1960's and early 1970's were fuelled with kerosene and solar photovoltaic panels for electricity generation. This however, is not concentrated enough for fast and long space voyages in a small or large spaceship.

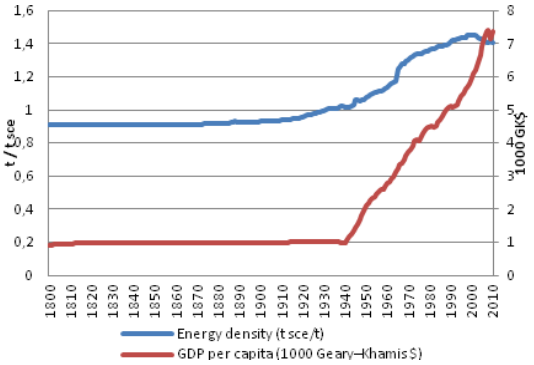
Physically, mass itself is the greatest energy source. Albert Einstein (1879 - 1955) formulated the equivalence of matter and energy: E = mc2 (Einstein, 1905). In this equation, m = ρV, where ρ is the mass per unit volume, V is the volume of the mass itself and c is the speed of light. The energy of mass, however, can only released through the processes of nuclear fission, nuclear fusion, or the annihilation of (some or all of) the matter in the volume V by matter-antimatter collisions. Against this background, current research take nuclear fission, nuclear fusion and matter-antimatter collision into view as possible spaceship fuels.

With 20 TJ/kg, Uranium 238 has a more than 440,000 times higher energy density of compared to jet kerosene (44.1 MJ/kg). Against this background, nuclear fission could be a feasible spaceship fuel, but the problem of radiation is not solved and maybe never will. Nuclear fusion is the physically opposite process to nuclear fission. Here, two or more atomic nuclei join together to form a single heavier nucleus. This fusion is usually accompanied by the release of huge quantities of energy. Nuclear fusion e.g. powers the sun, the H-bomb and experimental devices examining fusion power for electrical generation. Until now, the controlled production of nuclear fusion power is not technically feasible.

In particle physics, antimatter is the extension of the concept of the antiparticle to matter, where antimatter is composed of antiparticles in the same way that normal matter is composed of particles. In antimatter-matter collisions resulting in photon emission, the entire rest mass of the particles is converted to kinetic energy. The energy per unit mass (9×1016 J/kg) is about 10 orders of magnitude greater than chemical energy, about 3 orders of magnitude greater than nuclear energy that can be liberated today using nuclear fission (about 200 MeV per atomic nucleus that undergoes nuclear fission, or 8×1013 J/kg), and about 2 orders of magnitude greater than the best possible from fusion (about 6.3×1014 J/kg for the proton-proton chain). The reaction of 1 kg of antimatter with 1 kg of matter would produce 1.8×1017 J (180 petajoules) of energy (by the mass-energy equivalence formula $E = mc^2$), or the rough equivalent of 43 megatons of TNT, more than 3300 times the Hiroshima bomb (WIKIPEDIA, 2011).

These imaginations, currently seem to be more science fiction then reality. Economically, however, this may have huge impact. Double logarithmic analysis of the impact of world energy density on per capita income suggest, that a one percent increase of energy density induces a 4% increase of per-capita income. Figure 8 shows the development of the density of primary energy supply and per capita income in the world between 1800 and 2010.

Figure 8:
Density of World Primary Energy Supply and per Capita Income
(1800-2010, in tsce/t and 1000 Geary-Khamis $)



Source: Calculations on energy density based on data from Oberheitmann (2010), as for hydro energy and other renewable energies material density according to Wuppertal Institute (2011). GDP per capita based on data by Bolt, J. and J. L. van Zanden (2013) and IMF (2013).

A clear positive correlation between these two variables can be seen. One may imagine what impact an energy density by the factor 440,000 or more might have. The current use of nuclear energy however tells, that its introduction does not have such a huge economic impact for now and the side effects (nuclear waste, possible nuclear disasters etc.) can be immense. Hence, a final answer to future energy security is yet to be found.

* * *

Remarks: Opinions expressed in this contribution are those of the author.

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