Primary energy supply and economic wealth

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Abstract

The purpose of this paper is to analyse the correlation between humankind's energy input measured in terms of primary energy supply and wealth generation measured in terms of gross domestic product (GDP). In contrast to conventional energy statistics we consider energy from biomass, which we estimate by taking a new approach based on society shares, to obtain a comprehensive picture of societal energy supply. Against the background of declining fossil energy resources and restricted natural biomass production, we want to create a more profound view about the known fact that much of humankind's wealth is actually based on the availability of energy. In this regard we undertake a long-term analysis of energy supply and GDP development, disclosing an increasing impact of biomass on GDP. Our results suggest that humanity has embarked upon a non-sustainable path in terms of wealth creation not only based on fossil carriers, but also on the non-sustainable production of biomass.
Keywords: primary energy supply, biomass, economic growth, sustainability.

1 Introduction

Today, humankind faces two major interdependent challenges with regard to energy: On the one hand the exploitation of fossil energy carriers has led to an increase in economic wealth which humankind aspires to maintain. On the other hand the exhaustive use has led to a significant increase of carbon dioxide in the earth's atmosphere. When the energy supply of countries is analysed, it is customary to refer to energy statistics or balances. However, both of these refer to commercial energy only, i.e. to energy that is used in technical devices for the provision of energy services [1].

They most notably include fossil energy carriers like coal, crude oil and gas as well as alternatives such as nuclear and regenerative carriers like water, geothermal heat and solar radiation (Figure 1).

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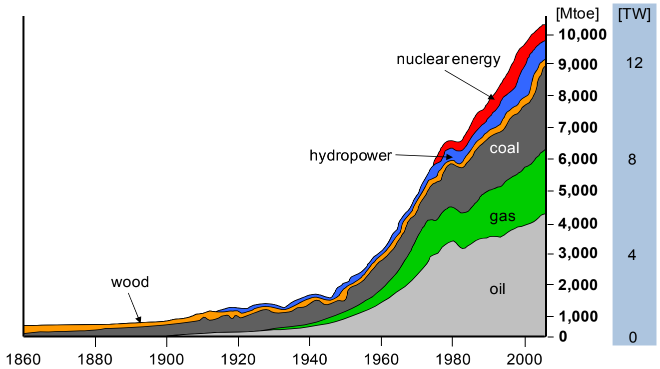

Figure 1: Share of different energy carriers [2].

Considering the development pictured in Figure 1, two issues become apparent. Firstly, it seems like people having lived before 1860 and not having used industrially processed wood had no energy at their disposal. However, this assumption would be incorrect. In order to obtain a consistent picture of a nation's or a society's energy flow, a second dimension needs to be considered: the use of biomass. Biomass has always provided nutritional energy for humans and since the Neolithic Revolution, also for livestock. Moreover, biomass is consumed in form of energy-rich material such as clothes, wooden tools and furniture. Energy statistics and balances only account for the biomass that is directly used as fuel in an industrial manner, or that is converted into fuels, such as charcoal. Therefore, Figure 1 shows a partial representation of humankind's energy use, only. For a comprehensive analysis, energy supply values from energy statistics must be completed with values on biomass supply [1, 3]. Secondly, it is obvious that today a large share of primary energy use depends on the availability of oil, gas and coal. According to several energy scenarios, fossil resources are diminishing. Irrespective of which scenario might come true, there will be a turning point in oil production either in the near future [4] or a few years later in a more abrupt manner [5]. This evokes a set of essential questions regarding our future: What will the next society, evolving from the increasing scarcity of fossil resources, look like? What will be the basis of future society's economic system? What will happen to our economic wealth when fossil resources are exhausted? In order to find possible answers it is crucial to scrutinise the historical development.

Following the term Total Primary Energy Supply (TPES) used by the IEA and OECD [6, 7], we distinguish and denominate the energy used in technical devices Primary Energy Supply – Technical (PES-T) and the natural energy Primary Energy Supply – Biomass (PES-B). The sum of PES-B and PES-T is Primary Energy Supply (PES). We assume supply to be the energy input that enters a societal system; the term is thus comparable to terms used by Haberl [1, 3] and Krausmann et al. [8].

2 State of the art

The need to include biomass for a comprehensive energy supply analysis has been recognised by authors like Boyden [9] and Haberl [1, 3, 10, 11] who have estimated per capita values for three typical societies, namely the hunter-gatherer, the agricultural and the industrial society. These societies are subject to different modes of subsistence and are distinguished by their time of appearance in history as well as their energy supply. The authors' per capita biomass values are the basis for our calculation of humankind's biomass consumption and are briefly presented here: Boyden assumes that hunter-gatherers consumed ~10 MJ/day (0.12 kW) per capita in form of nutritional energy. Further on, he estimates the energy consumed in form of firewood to be roughly equal to the energy consumed in form of nutritional energy. Note that firewood is attributed to biomass in this case since its heat would not be included in conventional energy statistics today and it was not used in technical devices. Haberl [3] suggests doubling the amount of food ingested so that losses occurring during food collection and preparation can be accounted for. This arguing lifts the total per capita flow to ~30 MJ/day (0.35 kW/capita). Agricultural societies learned how to produce biomass which provided nutritional energy for themselves and for their livestock. Several studies [3, 10] indicate that the per capita energy flow of agricultural societies amounted to 40-70 GJ/year (1.27-2.22 kW/capita). However, it is to be kept in mind that the power of beasts of burden was, indeed, an extra power source for muscular work that would be done by humans otherwise; but the energy to sustain the animals is accounted for in the indications of biomass use. Although today's industrial societies rely upon the use of fossil energy carriers (compare Figure 1) as well as regenerative and nuclear energy carriers, biomass as nutritional energy and biomass for artefacts must be considered. Haberl [3, 10] assumes a biomass per capita value of at least 70 GJ/year (~2.22 kW/capita). The per capita biomass use in Austria in 1995 amounted to 80 GJ/year (~2.54 kW/capita); a study by Krausmann et al. [8] reveals even higher values for other countries.

As an indication of exact figures is rather out of place given the fact that values depend upon authors' assumptions and different system boundaries, it is plausible to assume a range of probable energy supply. Based on the estimations indicated above, we assume that biomass supply of hunter-gatherer societies ranged from 0.2-0.4 kW/capita, the supply of agricultural societies ranged from 1.2-2.3 kW/capita and the supply for industrial societies from 2.5-3.5 kW/capita. In order to be careful with our indications we have not rounded mathematically, but have enlarged the range to its lower and higher decimal place.

The attempt to estimate total PES-B has been undertaken by authors like Haberl [10, 11] and Krausmann et al. [8]. While Krausmann et al. estimate total biomass flow for the year 2000, Haberl [10, 11] assesses the historical development of total biomass use. For the time span 1800 until today, he multiplies human world population (data from Cohen, 1995) by a constant per capita biomass value of 70 GJ/year (2.22 kW). We assume that he applies this approach to the prior modes of subsistence, too. On the basis of his per capita biomass indications (see above), we thus follow that he allocates 0.35 kW to each hunter-gatherer until the transition to agricultural societies in ~10,000 to ~8000 BC. Furthermore, we presume that he allocates the whole range of per capita biomass supply to the next time period increasing from 1.27 kW in ~8000 BC to 2.22 kW in 1800. Since 1800, the per capita biomass use has remained the same amounting to 2.22 kW, as mentioned above. Hereafter, we will refer to the results of Haberl's approach as PES-B Disruptive Leaps, since the entire population is being shifted to subsequent societies.

Following this approach we have reconstructed the development in Figure 4, using different population data [12, 13], though. However, we argue that this approach, estimating total biomass use through the allocation of average per capita values to the entire population, neglects the complexity of today's societal composition. The entire world population has not been living in industrial standard since 1800; in contrast, the number of people living in non-industrial societies has been increasing due to reasons that are discussed in chapter 4. We argue that the earth accommodates all three typical societies, each having a characteristic quantity of energy at its disposal. In order to account for them, we present a new approach based on society shares.

3 Concept

As mentioned above, we assume a range rather than exact per capita values. Furthermore, we presume that all three societies coexist today. Figure 2 represents PES values taking reference to the PES-B ranges as well as to the transition periods in which energy supply increased.

Hunter-gatherer societies live on the basis of a sustainable collection of biomass that is as good as constant (0.2-0.4 kW/capita). As they harvest the biomass they need without caring for the reproduction of it [3], they live in an "uncontrolled solar energy system" [14]. In contrast, agricultural societies are characterised by being producers of biomass. During the transition from hunter-gatherer to agricultural societies, the latter learned to convert natural ecosystems into agrarian systems, cultivating land and breeding livestock.

This production of biomass [10] has considerably increased per capita PES-B to 1.2-2.3 kW. Industrial societies live on the basis of a non-sustainable exploitation of fossil resources causing a significant increase of per capita PES. While per capita PES-B amounts to 2.5-3.5 kW, per capita PES-T reaches 2.5-12.5 kW.

The graph we have drawn in Figure 2 roughly represents historical transitions of the most advanced societies within and between modes of subsistence to higher energy levels in terms of PES. For hunter-gatherer and agricultural societies we assume that their most advanced societies had the most sophisticated technologies at hand, thus employing the highest possible amount of primary energy. These most advanced societies were in a position to find "answers to challenges" [15]. For industrial societies today, the graph shows a vague mean value relating to the given PES range since the range of the subsequent future society cannot yet be determined. It is quite certain that the

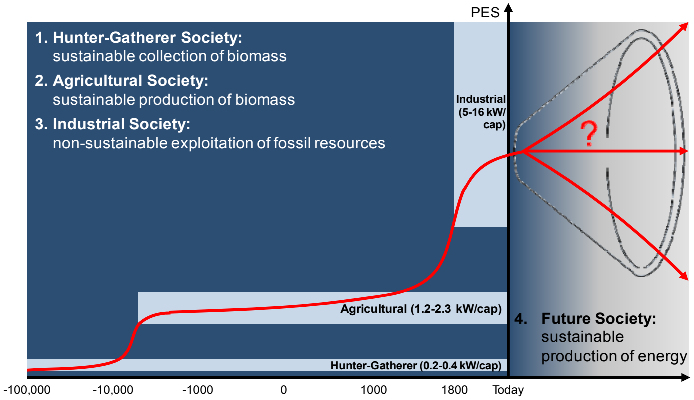

Figure 2: Primary energy supply (PES) in different societies [7, 9, 10].

future society will depend on the sustainable production of energy. The mode of production and the amount of production remain to be seen.

Figure 2 is the starting point for our estimation of total PES-B. The per capita values are based upon indications from literature (see above); from the derived ranges we calculate a mean value for each type of society and estimate the number of people living in each society share (chapter 4). These two figures are multiplied and aggregated to a total value. After comparing our new approach and Haberl's approach (chapter 5), we juxtapose PES-B and PES-T and evaluate their individual relation to GDP in a final step (chapter 6).

4 Population, societies and PES-B

First of all, we visualise the development of population growth in Figure 3. It took four million years to exceed the threshold of one billion people around the year 1820. In the 1960s, earth accommodated three billion and in 1999 six billion people [12, 16]. Today, our planet accommodates more than 6.7 bn people. This enormous growth has been supported by the transition from nomadic hunter-gatherer to sedentary agricultural societies, growing crops and surmounting the every-day struggle to meet their energy requirements to survive. During the last decades, growth has also been supported by today's senescent population which exists due to higher life expectancies, which, again, are based upon better nutrition, medication, sanitation and technological devices that ease physical labour.

In order to assess the total amount of humankind's PES-B in chapter 5, we first calculate a per capita mean value. It is based upon the range of per capita PES-B that we deduced from different indications in literature. As the range refers to the most advanced societies within each mode of subsistence we use a 2:1 weighting scheme in favour of the lower value to obtain an adequate value. This approach thus also considers those societies that do not (yet) belong to the most advanced ones, rendering a more precise value. Following this method, the per capita mean for hunter-gatherer societies amounts to 267 W, for agricultural societies to 1,567 W and for industrial societies to 2,854 W.

Secondly, we estimate the share of people living in one of the three modes of subsistence. We use total population data from Maddison [12, 16] and Kremer [13] and subtract the number of people living in non-industrial standards. This number is based upon indications from various sources (see Figure 3). We assume that all people lived as hunter-gatherers until ~8000 BC, when first agricultural farming developed. Some three thousand years later it became the staple of life for most people on earth. In the 19th century, many agricultural societies became superseded by industrialism and since then earth has been accommodating three different societies.

Assigning the three societies to energy classes, the industrial society corresponds to the upper class. Today ~1.7 bn people or ~25% of world population belong to this upper class, having an average per capita PES-B of 2,854 W. The share of people living in industrial societies increased with the spread of industrialisation across the world. It augmented significantly after ~1950 when industrialisation reached Latin America and Asia. Since ~1990 the share has increased again, mainly because millions of people in China and India shifted into industrial society. The amount of people living in agricultural societies increased mainly due to high growth rates in these regions, caused by the need for many children to assist in the fields. Cultural habits and beliefs as well as higher life expectancies in many regions are also reasons for population growth. People in agricultural societies belong to the middle class, having an average per capita PES-B of 1,567 W (today ~3.9 bn people or ~59% of world population). The number of people living from the same energy amount as hunter-gatherers has increased substantially mainly due to the urbanisation process, accelerating in the second half of the 20th century when people migrating into cities could only take refuge in slums [17]. Today, more than a billion people live in slums, i.e. in intolerable housing conditions with no or little access to safe water and sanitation as well as with a lack of secure tenure and durability in housing [18]. These people subsist more or less as hunter-gatherers because they live from hand to mouth by collecting food. Usually, they have no or little extra energy at their disposal.

In fact, we assume the energy use of slum hunter-gatherers being equal to the energy use of original hunter-gatherers, also included in Figure 3. Two typical hunter-gatherer groups are the Bushmen and the Pygmies, and the number of these "foragers" has been estimated to ~400,000 [19, 22]. Hunter-gatherers, having as good as no supplementary energy to nutrition, firewood and clothes available for use (today ~1.1 bn people or 16% of world population), belong to the worldwide lower class. They have an average per capita PES-B of 267 W (compare Figure 3).

Two things must be pointed out here: Firstly, the classification into upper, middle and lower class does not include any valuation or judgement about the people living in one of these classes. Secondly, our indication about the number of people living in each society is a rough estimate.

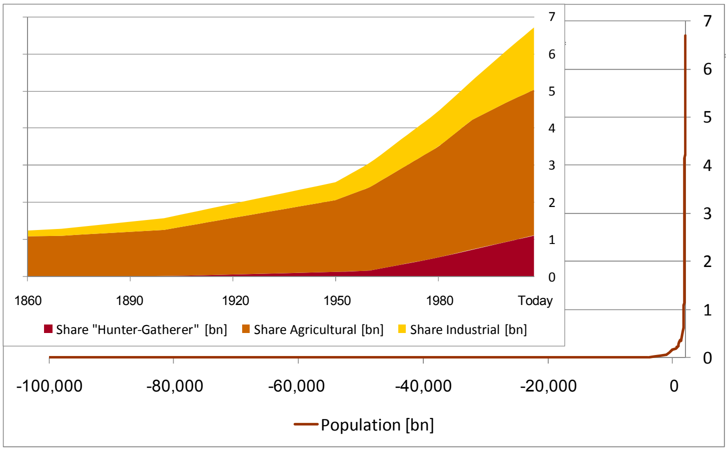

Figure 3: Population growth [12, 13] and society shares [12, 17, 19–22].

5 Primary Energy Supply (PES)

In this chapter, the two different approaches that have been disclosed thus far are compared. On the one hand, we have Haberl's approach in which he multiplies per capita biomass values by entire world population to derive total PES-B (see chapter 2). On the other hand, we have our approach calculated by explicitly considering the share of people living in each mode of subsistence in the course of time (in correspondence with Figure 3) and multiplying it by the weighted biomass values used by each society under consideration (see chapter 4). Following Haberl's approach, PES-B has been slightly increasing since the introduction of agriculture in ~8000 BC and crossed the value of ~1 TW between 1500 and 1600. With industrialisation spreading across the world from ~1750 until ~1950, total biomass use increased from ~1.67 TW to ~5.62 TW. Today, following Haberl, humankind uses ~14.88 TW.

In contrast, our approach yields lower total values. Total PES-B reached the value of ~1 TW between 1700 and 1750. From 1750 until 1950, PES-B rose from ~1.19 TW to ~4.44 TW. Today, humankind uses ~11.23 TW. However, our value for the year 2000, namely ~10.14 TW, is quite comparable to the value of ~10.9 TW for global biomass supply calculated by Krausmann et al. [8]. Haberl's approach delivers a value amounting to ~13.51 TW.

Figure 4 visualises the different results. Haberl estimates total biomass supply by allegedly allocating average per capita values to the entire world population. We try to overcome this deficiency of simplification by assessing the number of people living in one of the three modes of subsistence to gain more accurate values.

Still, to provide a comprehensive picture of humankind's PES, PES-T needs to be disclosed as well. Technical energy provision became significant when large-scale mining was developed extensively in the UK in the late 18th century. In the course of the 19th century, coal became the main source of primary energy

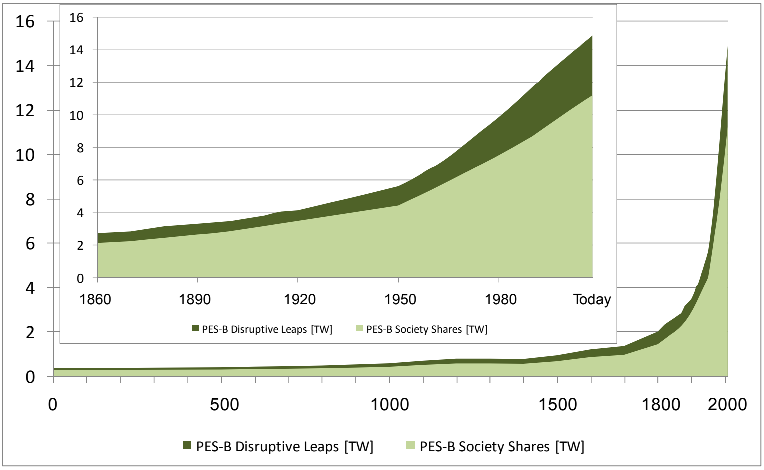

Figure 4: PES-B Disruptive Leaps and PES-B Society Shares [10, 12, 13, 16–22].

and is responsible for the increase in PES-T until ~1950. While humankind used only ~0.1 TW in 1860 in form of technical energy, PES-T amounted to ~2.6 TW in 1950. Since then, fossil energy carriers have gained increasingly more weight in the world's energy portfolio and have driven PES-T to ~10 TW in 1980 and up to ~13 TW in 2000. Some irregularities are seen in the 1970s and early 1980s due to the oil crises and the Gulf Wars. Today ~90% of the demand for technical energy is accommodated by coal, gas and oil; humankind uses ~16 TW. This means that since the beginning of the comprehensive exploitation of fossil energy carriers in the 1950s, PES-T has increased ~6-fold. With regard to hunter-gatherer societies that have lived on zero PES-T for hundreds of thousands of years, it becomes obvious how extraordinary the development of the last century, or even more specifically of the last 60 years, has been (compare Figure 1 and 5).

6 Energy and GDP

This chapter is devoted to the analysis of energy supply in relation to GDP. Figure 5 illustrates the development of PES combined with the development of GDP growth, expressed in 1990 International Geary Khamis Dollar ($).

Worldwide GDP increased only slightly from Nativity until 1400; from ~0.07 T$ (T$ = 10^{12} $) to ~0.2 T$. By 1750 GDP had increased to ~0.5 T$. With the start of the Industrial Revolution spreading across Europe and reaching North America, GDP had more than doubled by 1860, amounting to ~1 T$. A larger rise was achieved between 1860 and 1950 when GDP quintupled, reaching ~5.3 T$ in 1950. An even greater augmentation occurred in the period between 1950 and 2008, when GDP grew 11-fold, amounting to more than 60 T$ in 2008 [12, 23, 24].

The economic growth in the last two centuries is indeed extraordinary and unique in human history. While it certainly must be acknowledged that physical and social technologies, like the assembly line and the market, for instance, accelerated economic evolution and thus prosperity [25], a great deal of this development is based upon the input of technical energy. PES-T and GDP rising almost synchronically, clearly illustrates that this massive multiplication of GDP is based upon "energy slaves", namely machines powered by fossil fuels such as crude oil, gas and coal. It can be stipulated that today's value creation rests upon these fossil fuels.

However there seems to be a break of the high synchrony between the development of PES-T and GDP around 1980. The impact of PES-B in relation to PES-T on GDP seems to have increased substantially. Have the oil crises in the 1970s shown the world its dependence upon oil, triggering off a trend towards a more efficient fossil energy use? It is indeed interesting to note that although PES-B was gradually rising after Nativity due to the development of more sophisticated artefacts and techniques to work the soil, sustain the soil's fertility and enhanced productivity [26], people did not produce more economic value in terms of GDP. GDP started to rise considerably after 1750 – the beginning of the Industrial Revolution and exploitation of fossil fuels. The world, so it appears, waited for fossil energy carriers to be exploited in order to develop an economic system which seems to enable endless economic growth. Does the decoupling of GDP and PES-T mean that much economic value is actually created through increased trade with biomass? Sophisticated tools and machines, elaborated techniques, as well as chemical additives such as fertilisers have enabled humankind to produce as much plant biomass destined for nutrition as never before. Rising incomes of millions of people in fast-growing developing economies changed consumption patterns, triggering an increased demand for a wider variety of food, causing higher intra-industry trade and ultimately being recorded as economic exchange, increasing GDP. Advances in transportation technology over the past 30 years have enhanced global trade of high-value food products [27]. Industrial fishing and deforestation are economic activities that increase GDP. Industrial livestock farming does not only produce much of the biomass that is traded, but also requires enormous amounts of biomass to feed the animals, especially in industrialised countries where overfeed is standard. Indeed, today more than half of humankind's PES-B is used to feed livestock [8]; however, the efficiency of the energy transfer from one trophic level to the next usually amounts to less than 20% [28]. This means that much of the biomass' energy content gets lost in transit. Against the background of hunger and diminishing land, biomass could be used more efficiently if the demand for meat by so many people was reduced [29]. The anticipated future population growth combined with many people's pursuit of a living standard in which the consumption of meat and a variety of other products is customary, sharpens this issue. This trend of increasing biomass production and consumption during the past 30 years, however, is non-sustainable.

Much of today's biomass production is only possible through the extensive employment of fossil energy. Thus PES-B's increasing impact on PES may be

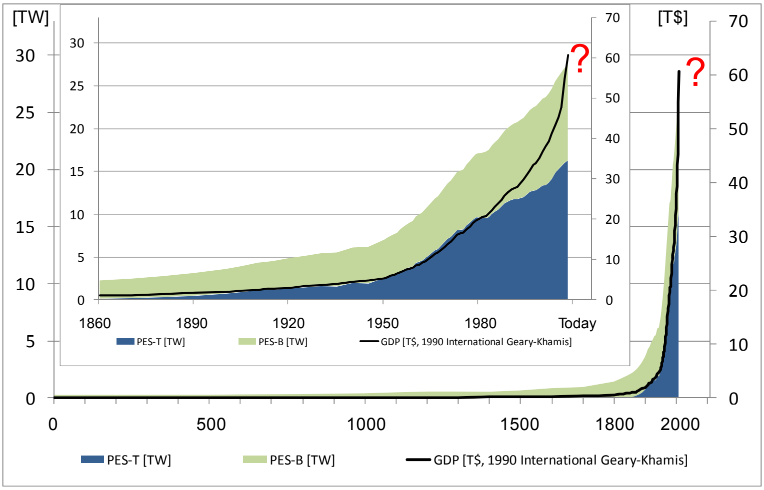

Figure 5: PES-T, PES-B and GDP [7, 11-24, 30, 31].

explained by PES-T being substantially used as a factor of production to produce biomass and as the means for extensive biomass trade. Today, humankind's biomass harvest has already increased to ~15% of global terrestrial net primary production [8]. Neither fossil energy carriers nor biomass can be exploited indefinitely. Human history has exemplified the consequences of societies disrespecting natural boundaries – the destruction of their own living foundation. The fall of past societies (such as the Polynesian people on the Easter Island or the Mayas in Mexico) has been well documented. Can scarcity of fossil energy and excess of humankind's biomass use cause a collapse of one or more of our future societies [32]?

7 Summary and outlook

In this paper we have undertaken a long-term analysis of PES and GDP in order to assess their correlation. As conventional energy statistics only refer to energy used in technical devices for the provision of energy services, biomass use has been included in our analysis to capture a comprehensive picture of humankind's PES. Per capita biomass values indicated by different authors have provided the basis for our creation of per capita PES-B ranges. From these ranges we have calculated the mean value for each typical society and have multiplied it by the number of people living in each mode of subsistence that we have estimated. By allowing for the development of different society shares that evolved in the course of time we hope that we have obtained more accurate values for humankind's PES-B. We have compared PES-B and PES-T to GDP; while the correlation between PES-T and GDP is known, the shift towards higher correlation between PES-B and GDP is surprising. Indeed, an additional statistical analysis reveals maximum correlation between PES-T and GDP from 1860 until 1979. From 1980 until today the correlation coefficient is still very high but, nevertheless, it is slightly lower. Especially during the last decade, the high correlation between PES-T and GDP has shifted in favour of higher correlations between PES as well as PES-B and GDP. We hypothesise that PES-B will have increasing impact on GDP due to the changing lifestyle in fast-growing developing economies.

Since the amount of data supporting this hypothesis is still quite small, this development needs to be observed carefully. Assessing worldwide PES-B is not straightforward as values differ depending on methodological approaches and population data referred to. Concerning our approach, more research on the allocation of society shares is needed. Also, it must be reconsidered whether it is plausible to compare PES with GDP. While GDP might be a reasonable indicator for past and current economic wealth, it is neither necessarily an indicator for human welfare nor for the sustainability of a state's economic performance. Factors that could be considered in the assessment of humankind's sustainable welfare include use and availability of ecological, human or monetary resources, personal contentment and a modest ecological footprint. More research thus needs to be done with regard to the connection between PES and one or more of the indicators mentioned above.

References

[1] Haberl, H., The Energetic Metabolism of Societies. Part I: Accounting Concepts. *Journal of Industrial Ecology*, **5(1)**, pp. 11-33, 2001.

[2] Paeger, J., Eine kleine Geschichte des menschlichen Energieverbrauchs. www.oekosystem-erde.de/html/energiegeschichte.html

[3] Haberl, H., The Energetic Metabolism of Societies. Part II: Empirical Examples. *Journal of Industrial Ecology*, **5(2)**, pp. 71-88, 2002.

[4] Campbell, C. C., The General Depletion Picture, *ASPO Newsletter*, **83**, pp. 1-9, 2007.

[5] Hakes, J., Long Term World Oil Supply, *Conference of the American Association of Petroleum Geologists*, Louisiana, pp. 1-20, 2000.

[6] International Energy Agency (IEA), Total Primary Energy Supply. www.iea.org/Textbase/stats/defs/Tpes.htm

[7] OECD, *OECD Factbook 2009: Economic, Environmental and Social Statistics*. OECD, 2009.

[8] Krausmann, F., Erb, K.-H., Gingrich, S., Lauk, C. & Haberl, H., Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. *Ecological Economics*, **65**, pp. 471-487, 2008.

[9] Boyden, S., *Biohistory: The Interplay between Human Society and the Biosphere*. UNESCO Man and Biosphere Series, **8**, p. 80, 1992.

[10] Haberl, H., Energetischer Stoffwechsel und Nachhaltige Entwicklung. *Natur und Kultur*, **1(1)**, pp. 32-47, 2000.

[11] Haberl, H., The global socioeconomic energetic metabolism as a sustainability problem. *Energy*, **31**, pp. 87-99, 2006.

[12] Maddison, A., Statistics on World Population, GDP and Per Capita GDP, 1-2006 AD. www.ggdc.net/maddison

[13] Kremer, M., Population Growth and Technological Change: One Million B.C. to 1990. *Quarterly Journal of Economics*, **108(3)**, pp. 681-716, 1993.

[14] Sieferle, R. P., *Rückblick auf die Natur, Eine Geschichte des Menschen und seiner Umwelt*. Luchterhand Verlag: München, 1997.

[15] Toynbee, J. A., *Der Gang Der Weltgeschichte – Aufstieg und Verfall der Kulturen*. Europa Verlag: Zürich, 1954.

[16] Maddison, A., *The World Economy – A Millennial Perspective*. OECD: Paris, p. 328, 2001.

[17] Davis, M., *Planet der Slums*. Assoziation A: Berlin, p. 55, 2007.

[18] UN, The Challenge of Slums: Global Report on Human Settlements 2003. www.un.org/Pubs/chronicle/2003/issue4/0403p19.asp

[19] Lee, R. B. & Hitchcock, R. K., African Hunter-Gatherers: Survival, History, and the Politics of Identity, *African Study Monographs*, **26**, pp. 257-280, 2001.

[20] UN-HABITAT, Statistics – Table 4 Slum population projection 1990-2020. ww2.unhabitat.org/programmes/guo/documents/Table4.pdf

[21] UN-HABITAT, 12th Session of the Commission on Sustainable Development. Interactive Discussion On Sanitation and Human Settlements: Meeting Basic Needs in Human Settlements. www.unhabitat.org/downloads/docs/1322_90482_CSD12_3004.pdf

[22] Vidal, J., World Bank accused of razing Congo forests. www.guardian.co.uk/environment/2007/oct/04/congo.forests/print

[23] International Monetary Fund (IMF), World Economic Outlook Database. http://www.imf.org

[24] Nordhaus, W., Do Real Wage and Output Series Capture Reality? The History of Lighting Suggests Not. *The Economics of New Goods,* eds. T. Bresnahan and R. Gordon, University of Chicago Press: Chicago, 1997.

[25] Beinhocker, E. D., *Die Entstehung des Wohlstands - Wie Evolution die Wirtschaft antreibt*. mi-Fachverlag, Redline GmbH: Landsberg am Lech, p. 399, 2007.

[26] Fagan, B., *The long summer: How climate changed civilisation*. Basic Books: New York, pp. 127-145, 2004.

[27] Regmi, A. & Gehlhar, M., Consumer Preferences and Concerns Shape Global Food Trade. *Food Review*, **24(3)**, pp. 2-8, 2001.

[28] Campbell, N. A., *Biologie*. 6. Auflage, Spektrum Akademischer Verlag: Heidelberg and Berlin, p. 1439, 2003.

[29] Goodland, R., Environmental sustainability in agriculture: diet matters. *Ecological Economics*, **23**, pp. 189-200, 1997.

[30] Etemad, B. & Luciani, J., *World Energy Production 1800-1985*. Librairie DROZ: Geneva, p. 262, 1991.

[31] Romer, R. H., *An Introduction to Energy Physics*. W. H. Freeman and Company: San Francisco, p. 599, 1976.

[32] Diamond, J., *Collapse. How Societies Choose to Fail or Succeed*. Viking: New York, 2005.