Large scale societal transitions in the past

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Large scale societal transitions in the past

Marina Fischer-Kowalski, Daniel Hausknost (UNI-KLU)

Abstract

WP 201 takes a historical perspective in analysing past systemic social-ecological transition processes. The research paper (MS 27) emerging from task 201.2 explores two major energy transitions of the past: the transition to the use of fossil fuels (e.g. starting with coal in the UK in the 17th century, and continuing in the rest of the world with coal and oil since). How was this transition linked to major institutional transformations, frequently paved by revolutions? We statistically demonstrate how similar processes occurred in many countries, and accellerated over time. In contrast to more common approaches, we do not focus on the introduction of particular technologies, but on the gradual substitution of biomass as the key source of energy by fossil fuels, and also on the increase in the amount of economically available energy. Beyond the common indicator TPES (total primary energy supply) we use and expand our historical database that countains the indicator DEC (domestic energy consumption). DEC encompasses, beyond TPES, also the energy converted by human and animal nutritional intake. We analyse the role of revolutions for the respective energy transition statistically and are able to identify statistical breaks in population growth, energy consumption and economic growth linked to the occurrence of revolutions. We compare trajectories of European and Non-European countries, and we compare countries in which the transition to the use of fossil fuels was marked by revolutionary processes with countries where this was not the case. Particular attention is paid to the phase of the transition in which revolutions have occurred, and the impact this shock had on the further course of the energy transition and on economic growth.

The second marked transition analyzed occurred in the mature industrial economies in the early 1970s, in association with the first and second oil price shocks. In practically all mature industrial countries, there was triggered a termination of the steep incline of metabolic rates in favour of a fairly stable per capita level of energy and materials consumption, while economic growth continued. We investigate the policy responses in key policy areas coping with these "shocks" and achieving a reduction of biophysical growth while maintaining growth in the economy and employment. We employ a number of different methods for this analysis: we investigate long time series data statistically to explore at what time and in what sequence certain trends changed. On the other hand, we explore policy analysis literature for a number of countries qualitatively.

Finally, we synthesize what can be learned from such macro societal transitions: what role do external shocks, structural change and energy policies play? Which lessons are to be learnt from past transitions in order to be in a better position to manage the transition ahead of us?

Contribution to the Project

Milestone 27, the research paper emerging from task 201.2, will explore two major energy transitions of the past: the first is the transition to the use of fossil fuels (e.g. starting with coal in the UK in the 17th century, and continuing in the rest of the world with coal and oil since). How was this transition linked to major institutional transformations, frequently paved by revolutions? We will demonstrate how similar processes occurred in many countries, and accellerated over time: while the transition in the UK took some 300 years, in took less than 100 years for Japan not much more than 50 years for China. In contrast to more common approaches, we will not focus on the introduction of particular technologies, but rather on the gradual substitution of biomass as the key source of energy by fossil fuels, and also on the increase in amount of economically available energy. We will analyse the role of revolutions for the respective energy transition statistically, trying to identify statistical breaks in population growth, energy consumption and economic growth. We will deal both with European and with Non-European countries, and compare countries in which the transition to the use of fossil fuels was marked by revolutionary processes with countries where this was not the case.

The second marked transition that will be analyzed occurred in the mature industrial economies in the early 1970s, in association with the "first oil price shock". In practically all mature industrial countries, this event somehow triggered a termination of the steep incline of metabolic rates in favour of a fairly stable per capita level of energy and materials consumption, while economic growth continued. How could this change in trends come about, which policy changes happened that may have had an influence? We will investigate key policy areas (energy policy, industrial policy, transport and infrastructure, labour market and financial policies) for a number of countries comparatively. What role did policies play both in coping with this "shock" and achieving a reduction of biophysical growth while maintaining growth in the economy and employment? We will employ a number of different methods for this analysis. On the one hand, we will investigate long time series data statistically to explore at what time and in what sequence certain trends changed. This will focus mainly on Eropean countries. On the other hand, we will explore policy analysis literature for a number of countries comparatively.

Finally, we will synthesize what can be learned from such macro societal transitions: what role do external shocks, cultural shifts and energy policies play? The aim of the paper is to identify lessons to be learnt from past transitions in order to be in a better position to manage the transistion ahead of us.

Keywords:

Academic research, Biophysical constraints, Demographic change, Ecological innovation, Economic growth path, Economic strategy, Energy transitions, Globalisation, Holistic and interdisciplinary approach, Industrial innovation, Industrial policy, Innovation policy, Institutional reforms, Labour markets, New technologies, Policy options, Post-industrialisation, Socio-ecological transition

Jel codes:

Q01, Q02, Q28, Q32, Q34, Q38, Q43, Q48, Q5

Contents

Tables and Figures

Executive Summary

This work package is devoted to „top down“ societal transitions that could be helpful to understand, and guide, an ongoing and future socioecological transition of industrial societies, Europe in particular, away from fossil fuel use, into a new state of a low carbon, inclusive society that provides its citizens with a high and possibly rising degree of wellbeing.

It is definitely easier to understand past transitions than to learn from them for the future. And it is easier to learn from the past what to expect and what not to expect for the future, than to learn what could be actively done about it. The approach we take in this report is situated very much on a “macro“-level, and therefore lends itself for evolutionary interpretations of systemic processes rather than actor and action-oriented lessons. We assume the challenge ahead is a “great transformation“ (WBGU 2011; Polanyi 1944) that industrial societies will undergo, willingly or not, within the coming decades, in the course of this century. This “great transformation“ is part of an ongoing long-term process, and at the same time very different. While in the long course of human history since the Neolithic revolution, the human population on Earth has continued to rise (with only short periods of decline in-between), it may be expected to peak in the 21st century and then start a slow decline (Lutz et al. 2001). While in the long course of human history, the energy intensity of human modes of subsistence has continuously kept rising (Sieferle 1997, Smil 2008, Fischer-Kowalski et al. 2014), a next mode of subsistence will not be positioned on that upward trajectory of human energy control, but deviate from it downwards. Even the (to some degree: diplomatic) newest Global Energy Assessment (GEA 2012) assumes a decline in global energy use, more likely to occur in high consumption industrial than in high population growth developing countries. At the same time, this high-energy-supply historical era of the industrial regime has provided humanity with unprecedented chances to learn and to technically manipulate natural and social processes – not all of this is energy-dependent, and lessons of the past may be used for new purposes. This is why we try to better understand these lessons from the past – even if humanity may never be expected to „manage history“.

In this research report, we deliver two case studies that extend across historical times but are pretty much based upon quantitative data. These analyses bear a provisional character: we report on ongoing research that should become more conclusive while it proceeds. Its service for the WWW4Europe process is to make aware of horizons of risks and opportunities on the one hand, and tough systemic interdependencies on the other hand that should be counted on and escape voluntaristic “interventions“.

Our first case study, “The role of social revolutions in major historical energy transitions“, focusses on the “take off” phase of the historical energy transition, that is on the transition from the biomass based agrarian to the fossil fuel based industrial energy regime. Major societal transitions are typically not incremental, but involve social turmoil and threats to established property and power structures. For a sample of 17 countries (more or less randomly selected for long term data availability) we analyse the transition from an agrarian to an industrial regime in terms of energy, GDP, population growth – and the occurrence of revolutions, across the last four centuries. We reconstruct the beginnings of the fossil fuel regime in the 16th century, with peat in the Netherlands and coal in the UK. While the Netherlands make a fairly protracted but not very tumultuous transition, the English revolution in 1642 is the earliest case in our analysis of revolutions; China and India in 1949 are the latest cases we deal with. We find all revolutions to occur in the very early phases of the transition (with fossil energy amounting to 3-8% of primary energy), irrespective of whether they happen in the 17th or in the 20th century; it is clear that revolutions can only occur if there are collective societal actors in opposition to the incumbent regime, and if they have resources to build upon. What we can also see is that wherever there is a revolution, the energy transition is accelerated. It should be clear that the ambition to compile comparable and reliable energy (and other) data for a time period of at least 50 years before, and at least 50 years after the energy transition, as we had done here, is quite a delicate and labour-intensive endeavour. From the empirical case studies of revolutions between 1642 and 1949 we can learn the following:

- The point in time at which revolutions occur is very early in the energy transition (at a level of 7% fossil fuels in the society's primary energy use, on average).
- With all countries observed, fossil fuel use accelerates over time, and after an early statistical break the gradient of increase is always steeper than before (typical for "take off" situations).
- There is no difference between countries with and without revolution in the gradient of fossil fuel use before the break. Thus the idea that revolutions happen in cases of more rapid change cannot be defended in the light of these data.
- The energy transition gradient after the statistical break is higher in revolutionary countries than in the others. This is an indication that revolutions tend to accelerate the institutional change required to make a shift towards fossil fues use. But the difference is not very large, and the number of cases low, so we do not expect statistical significance for this finding.

What is there to learn from the struggles involved in introducing fossil fuels into a social structure in which practically all energy generation had been land-based, and where a class of landowners dominates both the economy and political power? In analogy, it would require thinking of those collective actors who have strong vested interests in coal/oil/gas use, ranging from oil producing countries across international corporations to the transport sector; next, it would be necessary to think of those collective actors who have an active interest in renewables, maybe also those who badly suffer from fossil fuel use. The analogy is incomplete, though: coal was in most respects a clearly superior source of energy compared to biomass, irrespective of its bad smell and its detrimental health consequences - and therefore very soon every country was forced using it for being able to stay or become competitive. This is not so with renewable energy sources – they may one day become much cheaper, but their services so far are no more convenient than the services of petroleum or gas (and many think they might be much less convenient, e.g. Smil 2013). Thus there will be collective actors who strongly resist the departure from fossil fuels, but it is not so likely that there will be strong collective actors able to drive a social process towards them, let alone incend a revolution. The probably strongest collective actor in favour of an energy transition is science (see Gouldner 1979, Tainter et al. 2006), as large parts of it believe that climate change and resource overexploitation are very real threats to the future of humanity. But its communicative and behavioural style, as well as its dependence on private and public funding, does not make institutionalized science a candidate for a collective “revolutionary force”. Taken all these considerations together, it should not be expected that a next energy transition will take the form of a revolutionary process. Nevertheless it should be expected that this transition will not only rely on technical change, but will need as much institutional change as the transition towards fossil fuels use had required, with or without a revolution.

Our second case study, “The 1970s Syndrome: structural change from rising to stagnating energy consumption in mature industrial economies“, is on the stabilization of energy and materials use in most industrial countries from the early 1970s onward (up to now). We interpret this as a late phase in the long process of industrial transformation and explore what was involved in bringing this change about. This departure from an energetic and material growth path was connected to a certain delinking of economic growth and exergy (Ayres and Warr 2009), a slight reduction of economic growth rates, but not necessarily to a decline of quality of life. It was also connected to an international process of restructuration that offered new opportunities to developing countries which now pull the train of (economic and also biophysical) growth and contributed to reducing global inequalities on the one hand, to global growth of resource use on the other. This case study teaches the lesson that it is possible to live with stagnating (or even declining) levels of resource use; it also teaches the lesson that signs of stagnation provoke strong political reactions: possibly the wave of neoliberalism has to be seen in this light.

Although the per-capita use of energy seems to have stabilized during the past 40 years or so in the industrialised countries, this does not mean that the level on which it has stabilized is sustainable either in environmental terms or in terms of energy security. But it means that the long acceleration phase of per-capita-energy use in industrialised countries has come to an end and that some sort of new equilibrium on a high level of energy and materials use has been reached. The transition away from these high levels has not properly started yet and will require other measures than those which have achieved the stabilization of the upwards curve. According to Grübler (2012), the convergence of developed economies at a high level of energy and resource use does not necessarily point to an impending decline of global energy use, as in a bell-shaped curve, but might suggest a stable plateau.

The key components of the stabilisation of per capita energy consumption in the 1970s and from there on were innovations for energy efficiency (with partly spectacular efficiency increases as there were many “low hanging fruit“) and a reduction of the industrial sector altogether in favour of (less energy intensive) services and by outsourcing energy-intensive industrial activities to other world regions. There were also major efforts at diversifying partners upon which the energy supply depended, away from Near East oil towards Russian gas (which happened also to be a more efficient source for various purposes). These strategies worked to stabilize energy consumption, but will not work to seriously reduce it.

The energy stabilisation can be explained as a mix of price-induced efficiency measures, structural change in the composition of the economy (including out-sourcing of energy intensive activities to emerging economies) and the inception of ‘energy policy’ as a distinct field of political steering and planning. The oil shocks of 1973/74 and 1979 induced a massive increase in energy efficiency primarily in the industry sector. The increased sensitivity to energy prices and possible supply disruptions also led to the emergence of ever more integrated and comprehensive energy policies which were later supplemented and reinforced by environmental concerns such as climate change. Thus we see an accumulation of policy motives for energy saving and energy planning over time with energy security firmly at the core and environmental motives being added later on. The result is that since 1973, when ‘energy’ forced itself on top of the political agenda of the West, it was never deleted from it ever since: the industrialised world remained ‘energy conscious’ for a growing number of reasons. This in itself might provide part of the explanation of why the per-capita energy use was stabilised even though oil prices dropped sharply in the 1980s and only rose dramatically again in the new millennium.

Moving from there to a ‘sustainable’ socio-metabolic regime will require (1) a radical further reduction of energy intensities without fully re-investing the efficiency gains in further growth and (2) a deliberate transition to renewable energy sources even if they do not offer new and cheaper energy services but may be more expensive and possibly less convenient. The energy transition ahead will have to be a transition towards more co-ordinated and societally planned energy services.

1. Introduction

This work package is supposed to report on “top down“ societal transitions that could be helpful to understand, and guide, an ongoing and future socioecological transition of industrial societies, Europe in particular, away from fossil fuel use, into a new state of a low carbon, inclusive society that provides its citizens with a high and possibly rising degree of wellbeing.

It is definitely easier to understand past transitions than to learn from them for the future. And it is easier to learn from the past what to expect and what not to expect for the future, than to learn what could be actively done about it. The approach we take in this report is situated very much on a “macro“ level, and therefore lends itself for evolutionary interpretations of systemic processes rather than actor and action-oriented lessons. We assume the challenge ahead is a “great transformation“ (WBGU 2011; Polanyi 1944) that industrial societies will undergo, willingly or not, within the coming decades, in the course of this century. And this „great transformation“ is part of an ongoing long-term process, and at the same time very different. While in the long course of human history since the Neolithic revolution, the human population on Earth has continued to rise (with only short periods of decline in-between), it may be expected to peak in the 21st century and then start a slow decline (Lutz et al. 2001). While in the long course of human history, the energy intensity of human modes of subsistence has continuously kept rising (Sieferle 1997, Smil 2008, Fischer-Kowalski et al. 2014), a next mode of subsistence will not be positioned on that log-linear upward trajectory of human energy control, but deviate from it downwards. Even the (to some degree: diplomatic) newest Global Energy Assessment (GEA 2012) assumes a decline in global energy use, more likely to occur in high consumption industrial than in high population growth developing countries. At the same time, this high-energy-supply historical era of the industrial regime has provided humanity with unprecedented chances to learn and to technically manipulate natural and social processes – not all of this is energy-dependent, and lessons of the past may be used for new purposes. This is why we try to better understand these lessons from the past – even if humanity may never be expected to “manage history“.

In this research report, we deliver two case studies that extend across historical times but are pretty much based upon quantitative data. This is exceptional (and provokes resistance) in two directions. On the one hand, in economics it is unusual to draw on very long (century-long) timelines to deal with current problems. Economic forecasts and even future scenarios typically have a fairly short time horizon. On the other hand, in the historical sciences, also in social and economic history, it is fairly unusual to operate with systemic concepts and argue with systemic processes – even more so, if they include biophysical variables in an explanatory framing. The WWWforEurope project tempted us and allowed us to expand and solidify our long-term database on demographic, economic and sociometabolic (biophysical) data for a substantial number of countries that now gives us the opportunity to analyse long-term processes in a comparative way. At the same time, these analyses bear a provisional character: we report on ongoing research that should become more conclusive while it proceeds. Its service for the WWW4Europe process should nevertheless make aware of horizons of risks and opportunities on the one hand, and tough systemic interdependencies on the other hand that should be counted on and that escape voluntaristic “interventions“.

Our first case study focusses on the “take off” of the historical energy transition, that is, on the transition from a biomass based agrarian to a fossil fuel based industrial energy regime. We investigate this transition for a substantial number of countries across decades and centuries. Major societal transitions are typically not incremental, but involve institutional change, social turmoil and threats to established property and power structures. This, at least, we can demonstrate for the past in this case study. For a sample of 17 countries (more or less randomly selected for long term data availability) we analyse the transition from an agrarian to an industrial regime in terms of energy, GDP, population growth – and the occurrence of revolutions, across the last four centuries. We reconstruct the beginnings of the fossil fuel regime in the 16th century, with peat in the Netherlands (supporting their famous „golden age“) and coal in the UK. While the Netherlands make a fairly protracted but not very tumultuous transition, the English revolution in 1642 is the earliest case in our analysis of revolutions; China and India in 1949 are the latest cases we deal with. Our sample includes 6 countries that made their transition without, and 7 countries that made it with a revolution. We look into the timing of revolutions in relation to the energy transition, we look at the impact of revolutions on population and GDP growth, and we compare the courses taken by countries without to the courses taken with revolutions. We find all revolutions to occur in the very early phases of the transition (with fossil energy amounting to 3-8% of primary energy), irrespective of whether they happen in the 17th or in the 20th century; it is clear that revolutions can only occur if there are collective societal actors in opposition to the incumbent regime, and if they have resources to build upon. What we can also see is that wherever there is a revolution, the energy transition is accelerated. Of course, all this has to be looked upon as a pilot study, and will be continued with a larger sample of countries. It should be clear, though, that the ambition to compile comparable and reliable energy (and other) data for a time period of at least 50 years before, and at least 50 years after the energy transition, as we had done here, is quite a delicate and labour-intensive endeavour.

Our second case study focusses on the “stabilization phase” of the historical transition towards fossil fuel use. Is a continuation of work done within MS 35 on the stabilization of energy and materials use in most industrial countries from the early 1970s onward (up to now). We interpret this as a late phase in the long process of industrial transformation and explore how it evolved. Some of our results were already reported in MS 35; what is new in our present report are additional efforts at understanding which processes were involved in bringing this change about. From a literature review as presented in the report, we come to certain conclusions. Further research involving students‘ qualitative interviews with key Austrian actors in the energy policies of the 1970s as a national case study, or again students analysing energy savings by economic sectors quantitatively across a number of European countries, is still ongoing and has thus not become incorporated in this report. The conclusion from what we know so far is that in the 1970s there was a substantial departure of industrial countries from the path of massive biophysical growth that they had embarked on since the industrial revolution; this had not been recognized as such. This departure was connected to an economic restructuring, but not necessarily to a decline of quality of life. It was also connected to an international process of restructuration that offered new opportunities to developing countries which now pull the train of (economic and also biophysical) growth and contribute to reducing global inequalities on the one hand, to global growth of resource use on the other. This case study teaches the lesson that it is possible to live with stagnating (or even declining) levels of resource use; it also teaches the lesson that signs of stagnation provoke strong political reactions: possibly the wave of neoliberalism has to be seen in this light.

One may question whether there is anything to learn from the struggles involved in introducing fossil fuels into a social structure in which practically all energy generation had been land-based, and where a class of landowners dominated both the economy and political power. In analogy, it would require thinking of those collective actors who have strong vested interests in coal/oil/gas use, ranging from oil producing countries across international corporations to the transport sector; next, it would be necessary to think of those collective actors who have an active interest in renewables, maybe also those who badly suffer from fossil fuel use. The analogy is incomplete, though: coal was in most respects a clearly superior source of energy compared to biomass, irrespective of its bad smell and its detrimental health consequences - and therefore very soon everybody was forced using it for being able to stay or become competitive. This is not so with renewable energy sources – but their services so far are no more convenient than the services of petroleum or gas (and many think they might be much less convenient, e.g. Smil 2013). Thus there will be collective actors who strongly resist the departure from fossil fuels, but it is not so likely that there will be strong collective actors able to drive a social process towards them, let alone incend a revolution. The probably strongest collective actor in favour of an energy transition is science (see Gouldner 1979), as large parts of it believe that climate change and resource overexploitation are very real threats to the future of humanity. But its communicative and behavioural style, as well as its dependence on private and public funding, does not make institutionalized science a candidate for a collective “revolutionary force”. Taken all these considerations together, it should not be expected that a next energy transition will take the form of a revolutionary process. Nevertheless it should be expected that this transition will not only rely on technical change, but will need as much institutional change as the transition towards fossil fuels use had required, with or without a revolution.

2. The role of revolutions in major historical energy transitions.

Marina Fischer-Kowalski, Fridolin Krausmann, Irene Pallua and Markus Heinz

2.1 Introduction

While for a long time in the scientific debate mainly environmental science expert knowledge was invoked to provide remedies for the rising impact of human societies upon the environment, and the issue of social change was merely addressed as the need for ecological modernization, lately there seems to be increasing attention on the potential of a more fundamental social transformation. Most prominently, this is invoked by the debate about global climate change and the need for a transition towards a low carbon society (WBGU and German Advisory Council on Global Change, 2011), but it is also nourished by discussions about “peak oil” (see recently Murphy 2012) and a declining natural resource base (UNEP and International Resource Panel, 2011). Such imminent social and institutional changes are increasingly also addressed in the form of threats: In 2012, the most prominent interdisciplinary science journals each published a special feature on *Critical Perspectives on Historical Collapse* (PNAS 2012), *Human Conflict* (Science, 2012), and NATURE featured on *History as Science* and the predictability of cycles of violence (Spinney, 2012). In a letter to PNAS, Pearson and Pearson (2012) recently stated “usually, we think of transformation to collapse as inadvertent... Positive societal change to new states, such as the global need to transform to sustainable, equitable, low carbon societies, requires deliberate transformation. We call on all colleagues investigating societal change to clarify the attributes and characteristics necessary for societal transformation and resilience for a sustainable future." Such an emergent new scientific agenda brings the somewhat neglected social and historical sciences back centre stage and calls for a much more intimate collaboration on epistemological, theoretical and methodological levels.

We will respond to this challenge by relying on the following assumptions. First, we denote the transition ahead, in its core, to be a transformation of society’s energy system, away from its currently dominant fossil fuels towards renewable sources. This transition some time ahead is inevitable, due to the exhaustibility of fossil fuels. How far ahead, and whether the transition happens inadvertently or by deliberate planning and intervention, is an open question. Second, we presume the major socioecological transition of the past and still ongoing, namely the transition of agrarian to modern, industrial societies, to have at its core also a transformation of the energy system, in this case from a land and biomass based to a fossil fuel based system. This perspective, thirdly, allows us to capture both transitions as different phases of evolution of complex systems, or rather, co-evolution of complex societal with equally complex natural systems.

The distinction between gradualism and transitions is a matter of scale. The focus ought to be on a theoretically and operationally identifiable system that should be self-organizing and sufficiently complex to be in principle able to maintain itself under changing conditions. For such a system, there would be environmental boundary conditions: If they are transgressed, major features of the systems functioning will change. In the extreme case, the system may collapse (if it is an organism, die), or else it may resume its self-organization in a new "state". Both would then be called a transition. The second consideration, again very abstract, is the distinction of stages or phases. The typical model of alternating phases is the so-called S-curve (Rotmans et al., 2001), although other models have also been considered, such as the so-called "lazy eight" (Berkes and Folke, 1998), lock-in situations or system collapse (Tainter, 1988), or "tipping points" in earth systems (Lenton et al., 2008). From the notion of transition, there follows an understanding that no linear, incremental path leads from one state or phase to the other, but rather a possibly chaotic and dynamic intermediate process, or a discrete "jump". One has to be aware, though, that these distinctions are extremely sensitive to the observer's choice of scale. From a wider perspective something may appear as a continuous process, progressing steadily. But from a closer perspective the same process may appear as whimsical, sharply fluctuating. Thus descriptions of processes as transitions or as gradual change do not necessarily exclude each other. One type of process may well be "nested" into the other.

Our choice of scale for identifying transitions will be countries (nation states) on the spatial, and years on the time scale. This complies best to available data, but also to the dominant systems perspective in the historical and social sciences, as well as with the actor's perspective in e.g. international negotiations on climate mitigation.

This essay proceeds as follows: Next, we will address the question of how to operationalize, and specify quantitatively, a country's transition to „modernity". In contrast to the dominant emphasis on technological development (which is chronically difficult to quantify) we focus on the energy transition from a biomass-based to a fossil fuel based energy regime. This gets us into a different time frame (we identify the first take-off phases in the 16th century), and makes us aware of the link between dominant energy sources and interests of social groups.

After explaining our database in chapter 3, we proceed to posing our main questions: what is the time relation between the process of energy transition and the occurrence of social revolutions, irrespective of the historical period in which they happen? Do revolutions matter for the speed of this transition, and do they matter in terms of demographic change and rising incomes? We will present our preliminary findings that suggest fairly close links between energy transitions and revolutions, but also encourage further research with an enlarged database and broader tools of analysis.

2.2 How to measure the transition from the agrarian state to modernity?

Among the host of social, economic and technological changes that mark the transition from an agrarian to a modern society, there is one that stands out as a simple, quantifiable and valid indicator: the use of fossil fuels measured as share in total energy use or as per capita energy flow. There are two interdependent aspects mirrored in this indicator: one aspect is the sheer amount of primary energy made available for use by the social system. The other is distributional: what is the relative share in energy resources from land-based biomass versus fossil fuels? This also has strong social implications: From controlling the supply of energy, collective actors derive economic and political power and cultural influence.

We will illustrate this with data from the two countries that made the earliest transition to the use of fossil fuels – much earlier than anyone would usually date the beginning of the industrial transformation. The Netherlands made the world's first transition to fossil fuels by using large amounts of peat – which is a younger fossil source with much lower energy density than coal, but a very useful substitute for the firewood they had exhausted locally. For the 16th century, the Dutch high fossil energy use of 3-4 GJ/cap, representing about 10% of its domestic energy consumption (DEC) was very uncommon. This cheap energy source and the engagement in trading, shipping and finance (merchant capitalism) rather than manufacturing and agriculture, introduced economic prosperity and the so called Dutch Golden Age. The Netherlands was the most urbanized European country in the 16th century (Centre for Global Economic History, 2013) and had the highest income in 1600 (Maddison 2008). Closely linked to the use of peat in the Netherlands is the Dutch canal system. On the one hand it enabled the draining of peat bogs, and on the other hand it allowed cheap transport of this energy source, making it widely available to the population (Gerding, 2010). From 1650 onwards, the use of peat decreased (figure 1) due to limited opportunities to develop new peat deposits. Increasingly, there were also legal restrictions to peat extraction in order to curb the associated losses of agricultural land.

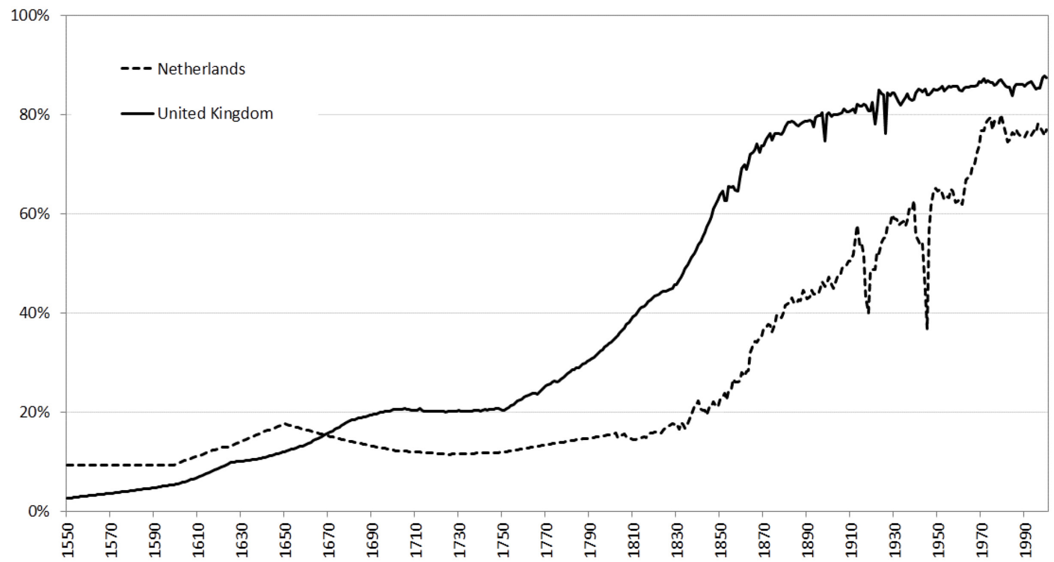
Another important source of fossil energy in the Netherlands was coal, mainly imported from the United Kingdom, but after 1650 restrictive English export policies made coal very expensive and the use of coal declined (Unger, 1984).

For the UK, within the first 300 years of the onset of the transition to fossil fuel use, in this case coal, the primary energy available for society rose 25 fold, indicating an enormously increased action potential[1].

[1] For hundreds of years until the advent of fossil fuels, a rise of available energy depended mainly on population growth: more farmers could generate more harvest – but most of it was consumed by those very farmers. Between 1540 and 1640 mining began at all major English coalfields, and between 1580 and 1660 coal shipments to London rose 25 times (Smil 2008, p.207).

After 1650, the UK challenged the economic hegemony of the Netherlands. Within a few decades, it managed to out-compete the Dutch and triumph also militarily. Much of this happened before the first steam engine was even invented by Thomas Newcomen in 1712. Fossil fuels were used primarily domestically for room heating and cooking; but they allowed the emergence of urban agglomerations and manufacture ("proto-industrialization") in areas where forests were too depleted to sustain a larger population.[2]

Figure 1 **Share of fossil energy in domestic energy consumption in United Kingdom and the Netherlands 1550-2000**[3]



Sources: own calculations based upon Gales 2012, Gerding, 1995, Krausmann et al. 2003, Warde, 2007, Krausmann et al. 2013(see methods section). The comprehensive dataset see with Pallua 2013.Domestic energy consumption (DEC) = domestic energy extraction (DEE) plus energy imports minus energy exports (see Haberl 2001). Domestic energy extraction encompasses not only commercial energy (as measured by Total Primary Energy Supply [TPES]) but also the biomass energy harvested for food and grazed by livestock in calorific units. Thus, it much better represents the primary energy available to pre-industrial societies than the more commonly used indicators.

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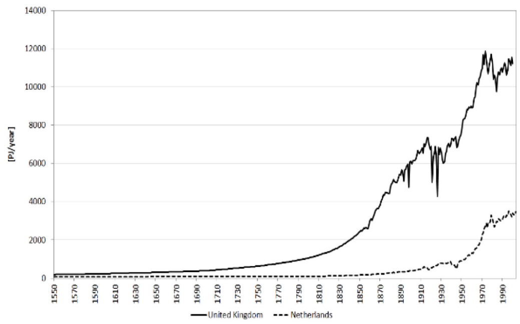
[2] For substantial technological advances before the actual „industrialization", see (Möser, 2004). See also Smil 2008, ch.7, pp. 173

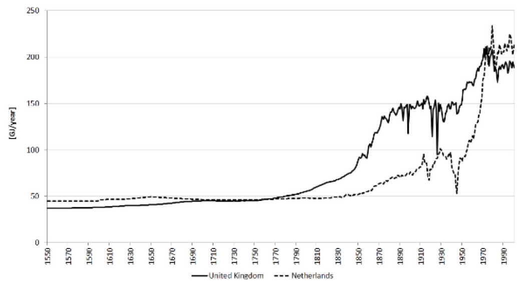
[3] In later years, we also included nuclear energy and imported or hydropower electricity (all „modern" energy carriers) under the header "fossil fuels".

Figure 2 **Domestic energy use (DEC) in the United Kingdom and the Netherlands 1550-2000**

a) DEC (PJ/year)



b) DEC per capita (GJ/cap/year)



Sources: same as Figure 1

Let us now briefly consider the social and distributional aspect of the rise of fossil fuels (Fig. 1). The declining branch, energy from biomass, is clearly linked to the structural position of two (often opposing) collective actors or classes: the landed aristocracy and the peasants. This holds for all agrarian societies, while the degree of autonomy of the peasants, property relations and the interrelatedness of the land owners with the state powers may vary. If the share of land based energy declines, so does – in the long run - the structural position of both aristocrats and peasants in society. Inversely: The use of fossil fuels benefits two relatively new collective actors: urban capitalists (that may be former landed gentry, or originate from lower strata), and wage labourers. The more use of fossil fuels, the more resources to those new classes (even if very unequally so!). This is a very simple equation that may become much more complex under various circumstances – but it is useful to keep the basic interrelatedness of energy sources and social classes in mind.

2.3 How to investigate the link between the energy system transformation and the occurrence / non-occurrence of revolutions: database and methods.

In accordance with our theory of sociometabolic regimes (Sieferle 1997, Krausmann and Fischer-Kowalski 2013) we claim to capture the core process of the transition from the pre-modern, agrarian world to modernity by simple variables referring to fossil fuel use. The share of fossil fuels in the societal energy use determines structural social balances, and the amount substantially changes the energy intensity of society, and its competitiveness towards other societies. This gives rise to and presupposes – causality here is not uni-directional, this is a complex systemic process – those complex transformations of society that require detailed historical and social science knowledge to properly reconstruct. These transformations may occur in a piecemeal, stepwise way with only a low level of social and political turbulence, or they may be marked by one or more revolutions that suddenly and radically transform the system of political power. In order to be able to document the full course of the energy transition and to identify the occurrence of revolutions in this process, it was necessary to compile a database of countries with long-term data.

Our country sample was principally guided by data availability, and our ability to reconstruct a full picture of the energy metabolism of this country across time. This implies countries with much research attention devoted to them have been privileged, and countries with a number of complex territorial changes across time, underdeveloped statistical records and little or only recent international attention are underrepresented. This is a substantial bias. What we can say to our favour is that we know of no other long-term study of revolutions, let alone of energy and revolutions, that has a sample size approaching the one we have. In this context, the research presented in this paper has to be seen as a feasibility study and an attempt to gain insights into the relations of energy use and societal transition using this approach, while more conclusive results may be expected for the future on a broader data base.

What do we mean by “long-term data”? Our ambition was to reconstruct each country’s energy system in a timeline that starts a few decades before the onset of fossil fuel use. With the exception of the Netherlands where there was wide-spread use of peat already in the 13th and 14th century (Gerding 1995), the first fossil fuel used by countries is coal. Coal mining was recorded very early on, so that researchers like Etemad and Luciani (1991) and Podobnik (2006) were able to compile databases of extraction and use of fossil energy carriers and other modern energy sources (hydropower for electricity generation, nuclear heat) of reasonable accuracy that we made liberal use of. To calculate the indicator “share of fossil fuels in the total of primary energy use”, we also required data on total energy use: that is, we had to add biomass to modern energy types. Data on biomass consumption were derived from a global database of biomass flows (Krausmann et al. 2013) which provides national data on biomass use for the period 1910-2005. For earlier periods we extrapolated total biomass use on the basis of constant per capita values of 1910 and population estimates. This relies on the assumption that biomass use is growing largely with population and changes in per capita biomass flows are comparatively small.

Table 1 **Sample of Countries and time period of investigation**

Countries with revolution(s)	Time period covered	Year(s) of revolution failed / ***successful***	Year of fossil fuels share in DEC >4%
United Kingdom[4]	1550 - 2000	***1642***	1577
France	1748 - 1997	***1789***, 1830	1825
Austria[5]	1798 - 2005	1848	1837
Germany	1798 - 1997	1848	1836
Russia/ USSR	1800 - 1992	1905, ***1917***	1858
China	1800 - 2000	1911, ***1949***	1920
India	1800 – 2005	***1949***	1913
Countries without revolution			
Netherlands	1550-2000	n.a.	~1500
Australia	1800-1997	n.a.	1882
Sweden	1800-2000	n.a.	1882
Italy	1800-2000	n.a.	1872
Japan	1800-2005	n.a.	1882
United States	1800-2005	n.a.	1823

As to be gathered from table 1, we succeeded in reconstructing long term energy use for 13 countries; in most cases, we managed to cover a time period starting at least 50 years before fossil fuel use took off (we chose the cutting point of a share of >4% fossil fuels, see last column in table 1, because shares lower than that are sometimes hard to identify), and ending fairly close to the present. The countries are described according to their present territory as far as possible; in the case of Austria we also calculated the energy indicators for the country at the time of the transition.

[4] In our sample United Kingdom includes England, Wales and from 1830 Scotland and until 1922 Ireland

[5] Territorial boundaries of today; this is somehow misleading, as the part of Austria that became the Austrian Republic after the first World War was an industrially relatively underdeveloped part of the Habsburg Monarchy.

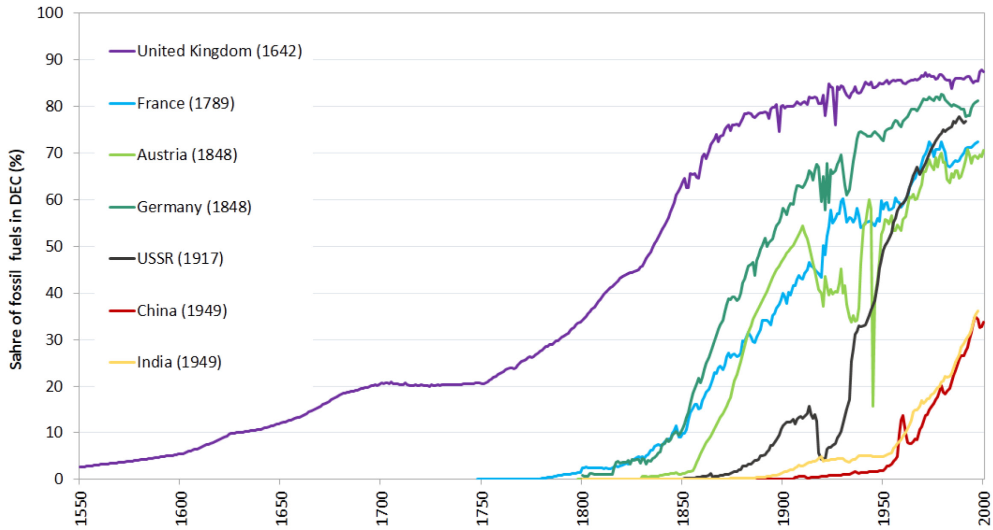
Our sample covers seven countries with and six countries without a revolution. We are liberal and fairly common sense in what we count as a "revolution". In the transitional phase between the agrarian and the industrial energy regime, we accept anything as a "revolution" that resembles an effort at a rapid social and political transformation of society by a bottom-up process aiming at overturning social and political power relations (what Mayer 2010 terms a "social science notion of revolution"). This effort, in contrast to the conception of Skocpol (1979), need not be immediately successful – it may be largely defeated (like the Austrian or German revolutions in 1848). But that it is waged at all speaks in favour of a situation that major actors conceive of as a "revolutionary situation", like some authors (Eisenstadt 1978, Skocpol 1979) call it. So in our analysis, we accept anything as a "revolution" where a serious and historically noted attempt is made to overthrough political power on a national level by movement from below. But if there is more than one such attempt in a particular country, we focus on the one that proved to have been most consequential.

While it used to be quite common to study revolutions as important events in the course of transition to modernity (see the excellent review by Goldstone, 1980), this was to our knowledge never linked to the issue of energy sources and energy regimes. The transition to modernity is usually conceived of as a highly complex process, encompassing urbanization, population growth, technological change, value changes, economic changes (rise of capitalism), new ideologies and interest groups (see for example Tilly 1978) and more. This complexity, as Goldstone (1980, 430) rightly criticises, is very hard to break down to something measurable. A similar fate is shared by approaches focussing on technological change (e.g. Gruebler 1998, 2004). We suggest the share of fossil fuels in a country's domestic energy use to be a very simple, annually measurable and highly valid indicator for the degree of transition to modernity, to industrial society. In particular, it indicates how far the transition to modernity is already progressed at a certain point in time. Fully mature industrial economies all have a share of modern energy carriers (among them mainly fossil fuels, but also nuclear energy and hydropower for electricity generation) between 70% and 80% (Haberl 2001) which they may have achieved at different points in time. The advantage is that for the observed time period, the share of fossil fuels in DEC is a steady variable: for all countries investigated so far, it always rises with time and never declines for more than eventually a few years during periods of major political and economic crisis (see Figure 3)[6].

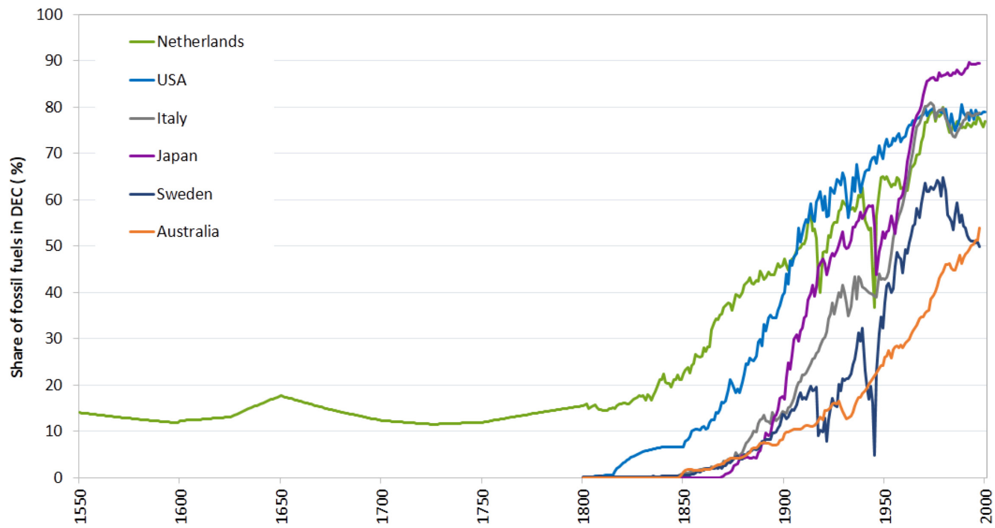
[6] Among our material, there is one exception to this rule: China's „Great Leap Forward" in 1959, an effort at boosting industrialization of the countryside, first led to a massive increase in coal consumption, but then to crisis and famine (see figure 3), and a reduction of coal use for many years.

Figure 3 **Share of modern energy carriers (fossil fuels, nuclear energy and electricity from hydropower) in Domestic Energy Consumption (DEC) from the start of the energy transition up to the year 2000**

a) Countries with revolutions (in brackets: year of revolution)



b) Countries without revolutions

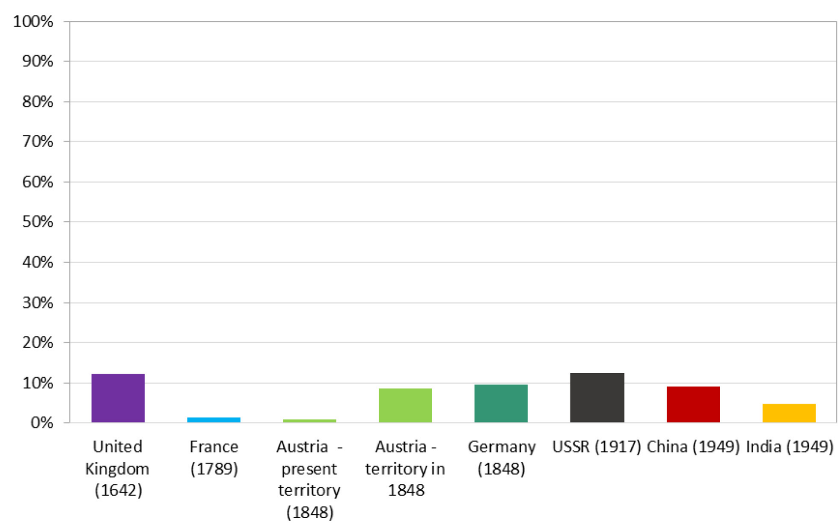


Source: Pallua, 2013 (based on data from Gales et al. 2007, Gerding 1995, Gierlinger und Krausmann 2012, Kander 2002, Krausmann et al. 2003, Krausmann et al. 2011, Krausmann et al. 2013, Podobnik 2006, Singh et al. 2012, Unger 1984, Warde 2007.

2.4 Are revolutions ordinary events in the course of the transition to modernity?

How then does the timing of revolutions fit into the course of the energy transition? If there is a revolution at all, at what point in this process does it take place? Figure 4 displays the share of fossil fuels for the respective year of revolution. Austria is displayed with two values: one for the whole Austrian Monarchy, and one for the territory that after WWI became the Austrian republic.

Figure 4 **Share of fossil fuels in primary energy use (DEC) in the year of revolution**[7]



source: Pallua 2013

There is a very clear-cut result of our analysis: all seven cases investigated fall into a very early phase of the transition. There is no revolution occurring at a time the country does not use fossil fuels at all, and there is no case above a 12% share of fossil fuels. The average share of fossil fuels in the year of the revolution is 8.34%, and the standard deviation for this value is very small (sd = 0.037).[8] Let us put this finding into an appropriate statistical frame: There are about 150 countries worldwide with a population above 500 000 people (to cut off the very minute cases), and out of these, say, 140 are already into the transition. If we further assume that every second country experiences a revolution in the course of this transition process, there would be a universe of 70 revolutions, out of which we captured 7 (in countries adding up to almost half of the world population). Thus we investigated a 10% sample of all revolutions. A hundred percent

[7] In the case of several revolutions in a country, we use the year of the successful one

[8] These values have been calculated using the data for the Austrian monarchy of the time.

of these fell into a narrow 11% range of possible variation[9] of fossil fuel shares. In which range may we expect the "true average" of all revolutions to lie?

We feel we have arrived at quite a solid outcome: Revolutions are part of the course of transition to modernity, and if they occur, they do so very early in the process, in what complex systems transition theory calls the "take off phase" of transition (Fischer-Kowalski and Rotmans, 2009).[10] This observation holds true for events spread across three hundred years of history. At the same time, a substantial number of countries manage this transition without a revolution. We will, in the further course of our contribution, pay attention to what happened in these countries during what we termed the "take off phase" of transition instead.

These findings eliminate some of the ambiguities and uncertainties engrained in what Goldstone (1980) in his brilliant review called the "second" and the "third generation" of theories of revolution. Our findings do not tell anything about the causes and consequences of revolutions, but they give fairly precise information about the timing within the modernization process: they supply the "critical variable" so badly in demand (Goldstone 1980, p.431), and apparently valid across 300 years. Moreover, they link well to what most of these authors think of being essential: a combination of "interest group conflict and resource control" (Goldstone 1980, p.429). This is exactly what a shift in the share of energy implies: a threat to incumbent elites, and a (very real) empowerment of emergent new collective actors that compete with the incumbent interest groups of the old energy regime.

The transition of the energy system towards using fossil fuels provided countries with a huge competitive advantage. More energy and energy carriers of higher density and therefore so much easier to transport, allowed a fully new range of activities: infrastructure construction (roads, canals, mining…). This was particularly relevant in the face of continuous territorial threats, as common throughout history that required sustained military interventions. All enlightened governments seem to have been quite aware of this, and made efforts to secure themselves areas containing coal mines and sought to promote their exploitation.[11]

A transition to the new energy regime, therefore, was a clearly downstream development enforced by interstate competition (at least within Europe). In the wake of the coal age, most

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[9] This assumes that a realistic band of variation of the share of fossil fuels in energy use of a country lies between 0% and 80%. There can hardly be more, as human and animal nutrition cannot be substituted by fossil energy.

[10] But of course, if we think of very different cases like the revolutions in Arab countries in 2009-2012, or anti-colonial uprisings in Latin America, or turns away from communist / soviet rule in 1989 ff, we might come up with different results. This is certainly worth while exploring.

[11] An interesting example of this kind is the War of Succession that involved most European Empires 1740-1748, in which Prussia demanded Silesia from Austria in return for accepting Maria Theresia as Habsburg heiress. This war between Prussia and Austria was exactly about coal, and Prussia's Frederick II immediately after his victory sought to promote legislation that would free coal miners from them being subject to landlords rule. It could be that the military conflicts over the Netherlands of that time between France and Austria also had a background in the – now Belgian – coal mine areas. This might be worthwhile following up with historical data.

state governments struck by enlightenment[12] indeed made efforts to accelerate modernization of their country (often prompted by external threats and competition). But these efforts (modernization of the military, introduction of schooling, coal mining with skilled workers freed from being subject to landlords and their jurisdiction…) typically met with resistance from the part of the landed aristocracy, as they were clearly directed against their interests. They probably did not very much meet the interests of the peasants either.[13] In the absence of a revolutionary movement, it could be a very difficult and slow process to open the pathway towards modernity, even if the state government pressed in this direction, a process that could even be stalled altogether by opposing forces maintaining the status quo.[14]

Revolutions mobilizing the masses in a bottom up process are able to achieve breakthroughs of traditional barriers that go far beyond what orderly governance may achieve. At the same time, they may induce protracted violence, insecurity and lack of governance, and thus a delay of a transition of the energy system. On the other hand, such periods of turmoil may extend over a few years at most, while social deadlocks and blockades of innovations may extend over several decades.

In effect, we should assume, in countries without revolutions, the status quo to be preserved longer and the transition process to the new energy regime to be delayed.

Our next empirical challenge is to establish some insights into what impact revolutions have on the course of the energy transition. He have established above that if they occur, they occur at a similarly very early stage of the process – irrespective of absolute (historical) time.

Figures 5 and 6 give a first visual impression on the course of the energy transition before and after a revolution. For each country, a relative time scale between 50 years before and 50 years after the revolution has been constructed, with the year of the start of the revolution as point zero.

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[12] Even in India, the 16th century saw an enlightened rule that very much resembles counterparts in Europe.

[13] We do not agree with Paige's (1975) conclusions about the key role of peasants in revolutions. According to our theory, peasants must take a very ambivalent position towards the energy transition. On the one hand, they share a common enemy with the new urban classes: the landed gentry. This makes them prone to become partners in a revolutionary process. On the other hand, the direction of social change is likely to devalue and in the end almost destroy the peasant's social position as monopoly suppliers of energy to society. They may gain from being relieved from personal dependency on the landlord, and long accumulated debts; but they do not necessarily gain from the introduction of a free labour market, and in the long run they will suffer from the fact that labour productivity, and in effect wages, can progress so much faster under industrial (fossil fuel subsidized) conditions than it ever can progress in agriculture.

[14] Both Skocpol (1979) and Trimberger (1978) have emphasised in their detailed analyses of several cases (China, Russia, Turkey and Japan) that the goals of the states towards modernization of the industrial base were in conflict with the elite class privileges of those societies.

Figure 5 **Share of fossil fuels in domestic energy use (relative time; year of revolution = 0)**

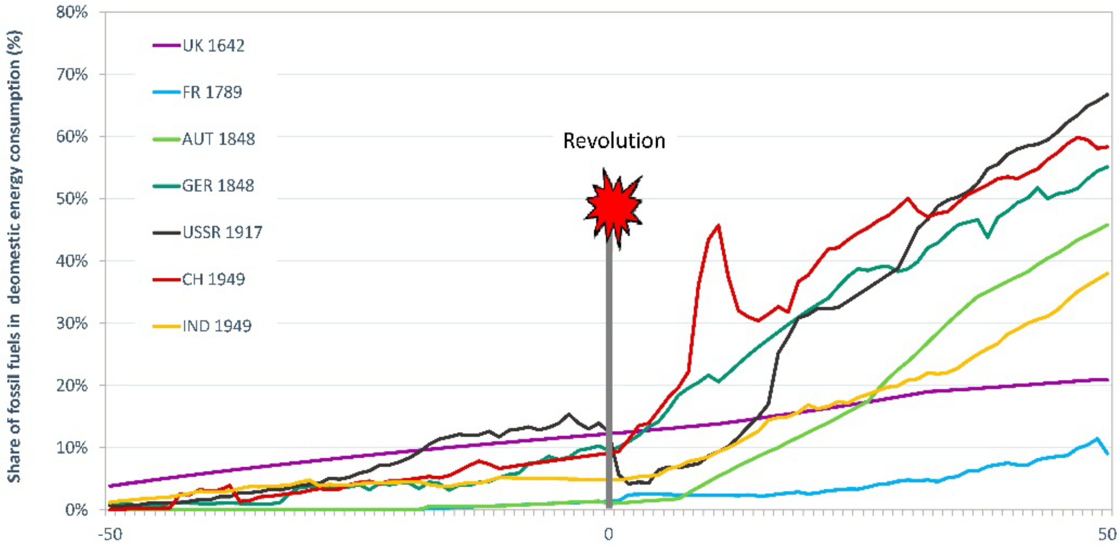
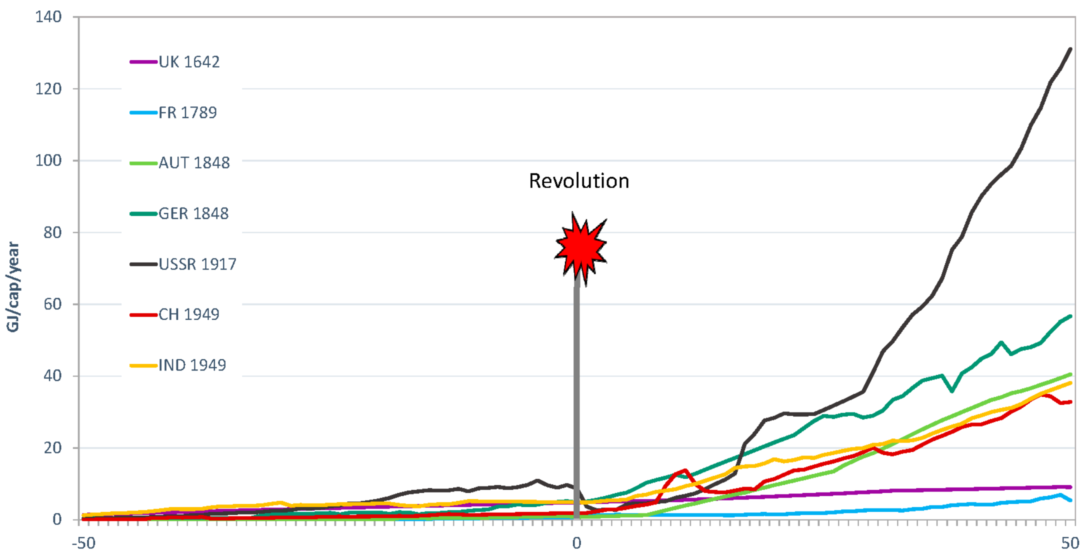


Figure 6 **Fossil fuel use per capita and year (GJ/cap), relative time (year of revolution = 0)**

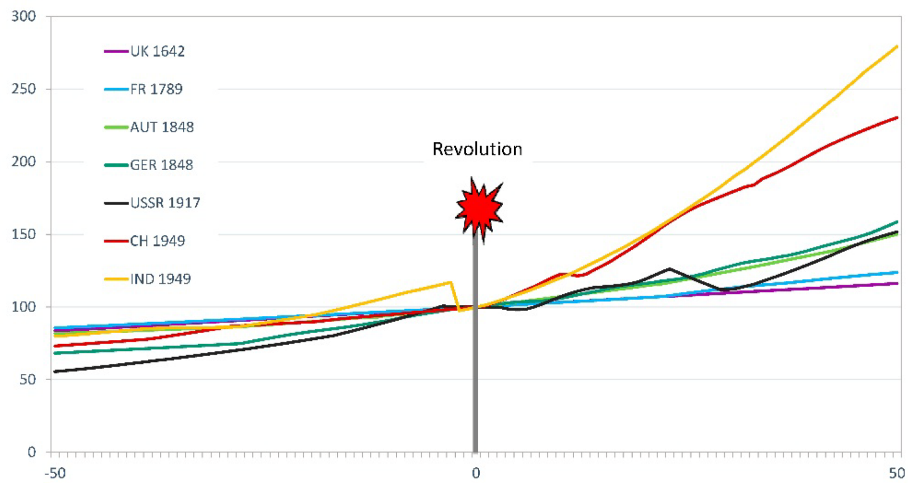


source: Pallua 2013

From simple visual inspection of the trends, one gets the impression that revolutions, often with a time lag of a few years, initiate a phase of steeper incline of both indicators, the share of fossil fuels and the per capita amounts. For some countries this is more pronounced than for others. For example, the UK timeline shows hardly any impact (this could be a methodological artefact because of too few data points in these early years and linear extrapolation in between), and also the timeline for France remains fairly flat (but it started from a very low level at which most countries do not show steep increases). We will need more subtle methodological devices to be able to interpret these similarities and differences (see down below).

Do revolutions also seem to trigger population growth? This was occasionally claimed, and we can provide a similarly superficial optical check for the seven countries we have investigated.

Figure 7 **Population growth before and after a revolution (relative time scale, index of population size at year of revolution = 100)**

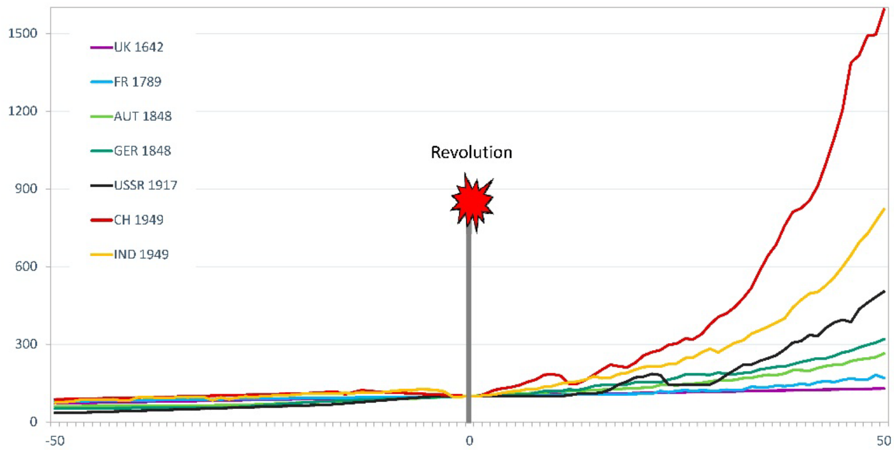


source: population data derived from Maddison 2008.

Upon first impression, it does not seem so as if revolutions made any systematic difference in population growth rates. We presume, for population growth the absolute historical time matters a lot: it makes a difference whether the whole story plays at a time when increased energy availability, for technological and medical reasons, did not make much of a difference neither for mortality nor for the opportunities of contraception, or when there were World Wars with high casualties. But in contrast to the course of the energy transition, revolutions do not seem to have a systematic impact upon population dynamics.

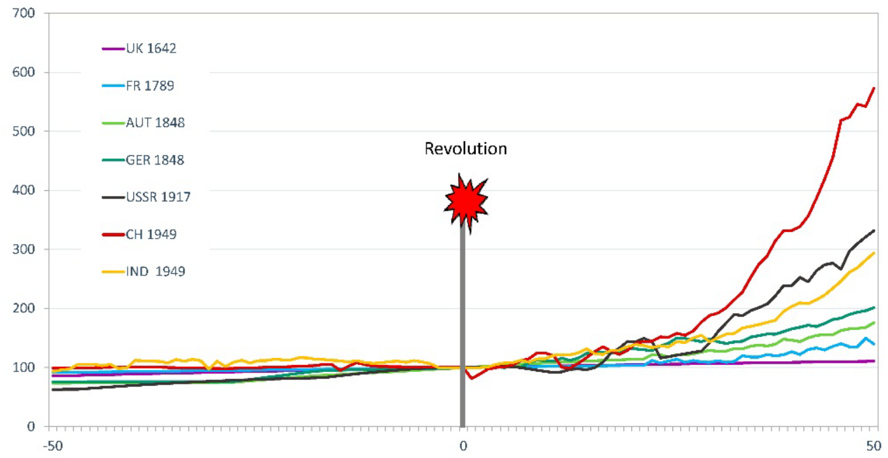
Finally, let us explore the relation to economic activity and income. What we can gather from figure 8 and 9, is a fairly stable situation for the 5 decades before the revolution. Among those 7 countries, there are only two with substantial rises in GDP in the pre-revolutionary phase (Russia and Germany), but both are connected to population growth, so income per capita less than doubled throughout these five decades. With India, China, France and the UK, there have been certain slight fluctuations, but no substantial growth. In contrast, again with some delay, in five out of the seven countries economic activity and income rise substantially in the decades after the revolution. This is most spectacular for China (more so than for India, although both processes happen in the same historical context), and for Russia. The steepness of income growth is directly proportional to the sequence of the revolutions in time. So one may suspect, similar to population, that not so much the relative time, but the absolute time matters. It was much easier to have strong economic growth in the world context of the 20th century than it was in the 18th or 19th century.

Figure 8 **GDP growth before and after the revolution (relative time scale, index value in year of revolution = 100)**



source: income data in Gheary Khamis $, from Maddison 2008.

Figure 9 **Income growth before and after the revolution ($/cap, relative time, index value in year of revolution = 100)**



source: as 8

From these visual checks, one gains certain first impressions that are useful to orient further work. They point in the direction that revolutions certainly do not delay modernization in the sense of decreasing use of fossil fuels and decreasing income, but maybe for a short time period in which there are certain perturbations. Our analysis so far demonstrates that there are certain patterns related to the increasing use of fossil fuels that occur, if not irrespective of the historical period, so at least fairly analogously across historical time. But our analysis so far leaves open if these processes relate to revolutions as events at all. Two alternative interpretations may apply:

(1) Once fossil fuels come into use, this triggers a self-reinforcing process of modernization within and across countries in which the transition to fossil fuels accelerates, energy use and monetary income rise, and a host of other phenomena (urbanization, demographic transition, democratization, mass education and knowledge production …) follows suit. Revolutions are but an early epi-phenomenon of this process.

(2) The same as (1), but revolutions matter. They play a crucial role in removing obstacles to the transition process; they allow for accelerated change and maybe also influence the patterns of change.

In order to decide between these alternative interpretations, more sophisticated statistical analysis is required, in particular also comparisons between countries with and without revolutions, some of which we will present in our next paragraph.

2.5 Do revolutions make a difference in the course of a county's energy transition?

Assuming, as we do, the transition to the use of fossil fuels to be a self-reinforcing process taking its course once it has started, the mathematics of this process should be an exponential function[15]. If it deviates from this exponential form, we should suspect there to be a reason for this to happen. As we can see from our data, the use of fossil fuels is very sensitive to disturbances: wars and crises reflect themselves in these numbers. Revolutions may be considered as one such disturbance.

In a first analysis, we plot 100 years of annual data for each country (50 years before and after the revolution, or 50 years before achieving more than 4% fossil fuels in DEC and 50 years thereafter) in a two-dimensional spread; on the x-axis, there is the total domestic energy use (in PJ/year), on the y-axis, there is the energy use from fossil sources (again in PJ/year).

We then search for the function with the best fit, choosing two pathways: a) an exponential function, and b) linear functions. With the help of the Chow-test (Chow, 1960) we are then able to identify whether there is a significant statistical break in the function, and if there is, we decompose the original linear approximation into two linear functions with an optimal fit. This allows us to identify the point in time when the break occurs, and it allows us to compare the fit and steepness of the two partial linear approximations.

Countries without a revolution[16]

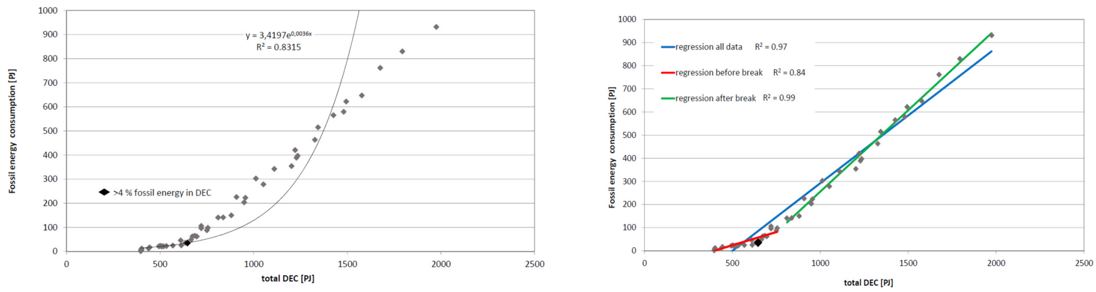
Figure 10 a and b demonstrate our statistical analysis for the case of Japan. Japan has not been through a revolution, but we mark the reference point of >4% fossil fuels in DEC (which Japan achieved in 1882) as an approximation to the typical take-off phase.

[15] If we assume there is some point of saturation, it could also be a logarithmic function – we will discuss that further below. But before saturation is approached, the exponential and the logarithmic function are pretty equivalent.

[16] For the Netherlands as the earliest case, a statistical analysis did not make much sense as observed data points in the 16th and 17th century lay to far apart. From figure 3b it is apparent, though, that the Dutch energy transition, although starting very early, did not accelerate before 1750.

Figure 10 **Japan's transition to fossil fuels between 1832 and 1932. a) observed values and exponential approximation, and b) linear approximations.**

a) b)



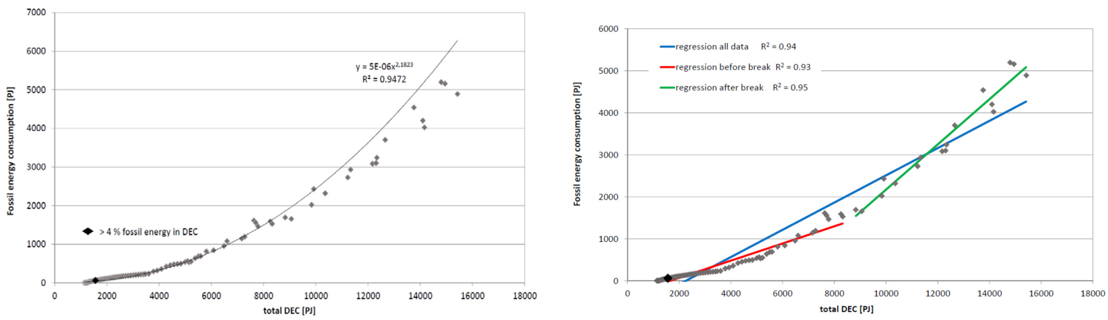
Note: in the vertical axis, there is the amount of fossil fuels in DEC (PJ/year). The black rhomb marks the year in which a share of >4% fossil fuels in DEC was achieved.

In the case of Japan, the exponential function has a worse fit than a linear function across the whole time period. But there is a statistically significant break in 1929, and a decomposition of the linear function into two linear functions at the statistical break produces an even better fit.[17]

Quite a different case can be made of the United States. For them, an exponential function shows the best fit.

Figure 11 **The course of the energy transition in the United States 1811-1893**

a) b)

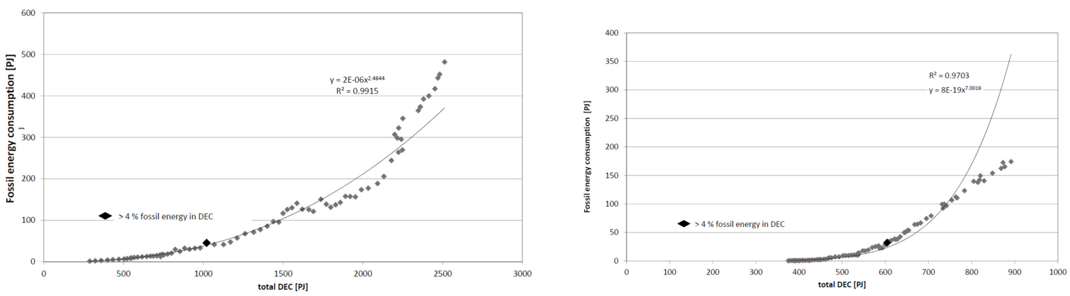


[17] In substance, this confirms Trimberger's (1978) finding that the Meiji Restoration in Japan starting in 1868 that made an effort at modernizing the country and reducing the privileges of the landed elites in favour of a central bureaucracy, was not extremely successful. But maybe this effort came a bit too early, structurally: Japan in 1868 had just 1.4% fossil fuels in its DEC, and it managed achieving 5% within 14 years, which took India 50 and China 30 years. The statistical break in 1929 may well be related to the world economic crisis, after which Japan had a veritable take-off as an industrial economy, with a share of about 30% fossil fuels in its energy system.

In the two further European countries we have in our sample, Italy and Sweden, the exponential function has a very good fit, but the energy transition happens fairly late and slowly (figure 12) – similar to what we have already seen for Japan.

Figure 12 **The energy transition in a) Italy and b) Sweden (timeline 1820 – 1920).**

a) Italy b) Sweden



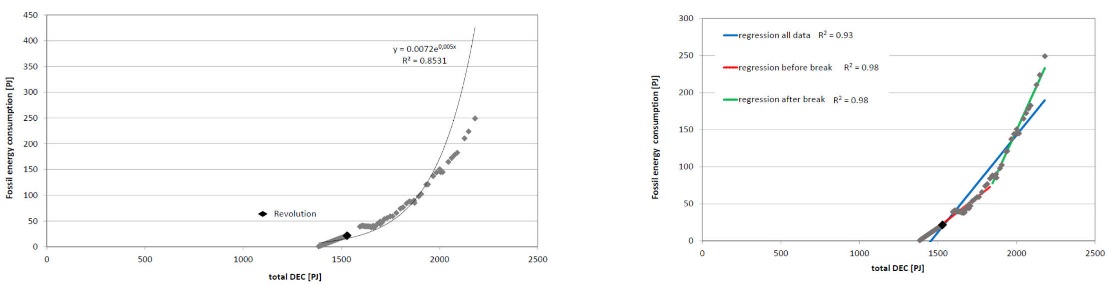
Countries with a revolution

In our sample, we have, two fairly early (UK and France) and two fairly late (China and India) revolutions, two failed revolutions in the time in-between (Austria and Germany) and the Russian revolution in the early 20th century.

For the UK, it is visually apparent that the revolution did not trigger any marked rise in coal use immediately (see Figures 5 and 6). A statistical analysis of the break did not make much sense as observed datapoints for the 16th and 17th lie very far apart (with interpolations in between). The case of France is interesting because it deviates from most others in showing but a small increase in fossil fuel use after the revolution (see figures 5 and 6). The revolution itself occurs early in the energy transition: in 1789, coal amounts just to 2 % of energy use. If we search for the statistical break within the long time period of 100 years (50 before and 50 after the revolution), we find it fairly pronounced but late: in the year 1816.

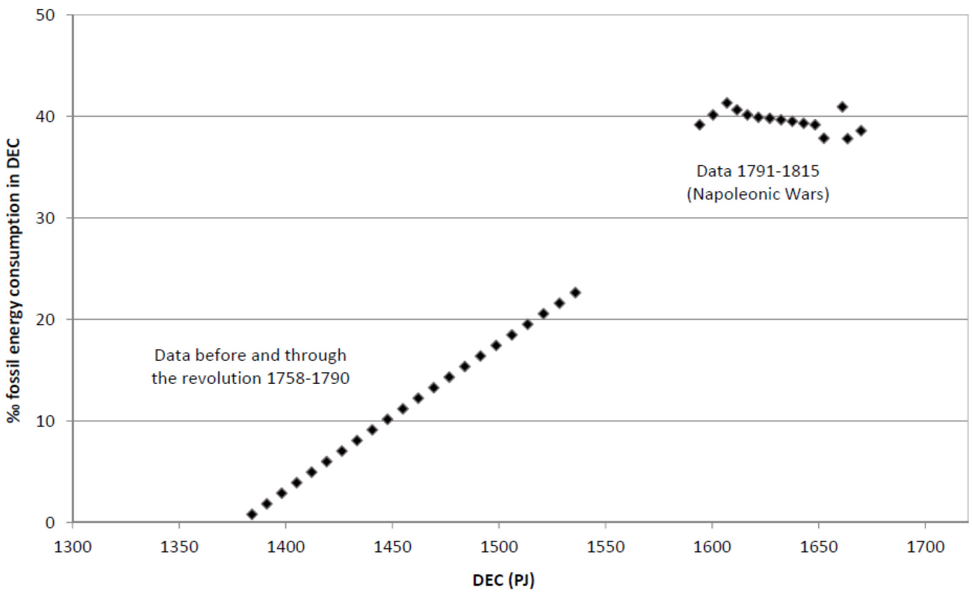
Figure 13 **The energy transition in France in relation to the revolution 1789 (1758-1869)**

a) b)



Apparently, after the French revolution there is a substantial delay of the energetic “kick-off”, which then happens with substantial zest. Why is this so? The statistical break occurs right after the Napoleonic wars and if we look in more detail at the energetic profile of the Napoleonic wars, we find the results presented in figure 14.

Figure 14 **The energy profile of the French Revolution and the Napoleonic Wars (1758-1815)**

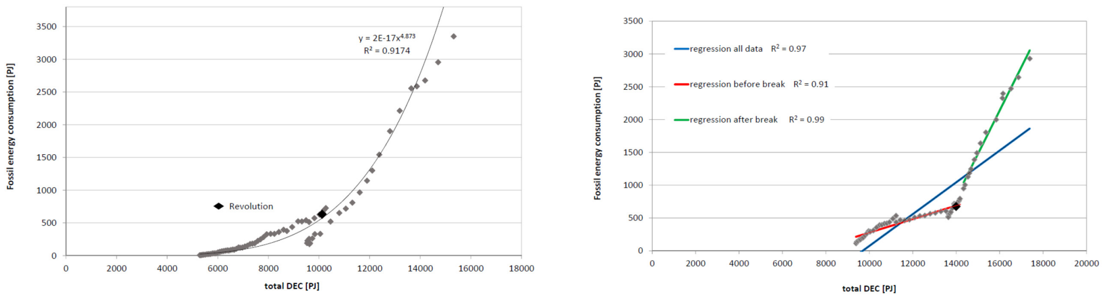


The Napoleonic Wars happen on an enhanced energy level, and on a higher level of fossil fuels. The overall energy level, but not fossil fuel use increases during those years. How can that be? Did Napoleon draw on other nations' coal reserves for fuelling his war? Are data on coal extraction and trade derogated during the war period? This is very hard for us to say. Thus, in effect, we conclude the French revolution does trigger a substantial increase in fossil fuel use, but it shows in domestic statistics only with a substantial delay.

Finally, let us investigate the countries that had their revolutions in the course of the 20th century. There is the Russian revolution in 1917: it occurs at a fossil fuel share of Russia of 6.2%, pretty much with a perfect timing in terms of the take-off of the energy transition.

Figure 15 **The energy transition in Russia 1867 – 1967 in relation to the Russian revolution 1917**

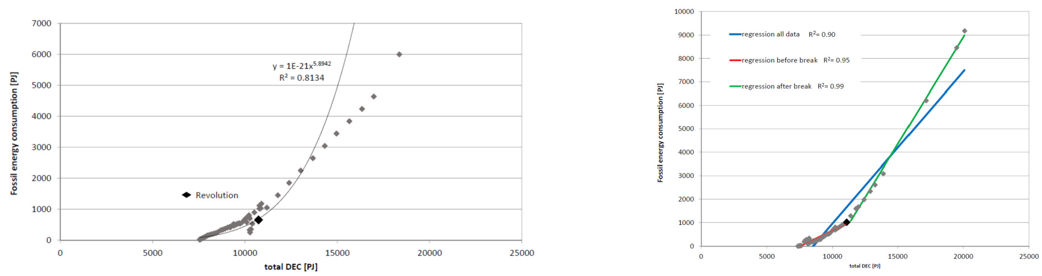
a) b)



In relation to the energy transition in Russia, the revolution is not only just right in time, it is also extremely effective, after a decline that needs to be attributed to WWI, to boost the transition to fossil fuels. The statistically constructed linear approximations show a perfect fit, and the statistical break occurs in the year 1918 – so very close to the date of the revolution 1917.

Figure 16 **The Chinese energy transition and the Chinese revolution 1949 (1899-1961)**[18]

a) b)



The timing of the Chinese Revolution matches perfectly with the energy transition: at 6% fossil fuels in DEC. Again, an exponential function would not fit very well, but in particular the linear regression after the revolution has a very good fit, and the statistical break practically coincides with the revolution (statistical break 1951). In the Chinese course of events, there is an anomaly, though: as was already perceivable in figure 5, a political effort at industrialization of the countryside boosted fossil fuel consumption ahead of 1959 to then break down and decline, only to catch up with its previous track in the late 1960s. The increase in gradient of fossil fuel use is not as marked as in consequence of the Russian revolution.

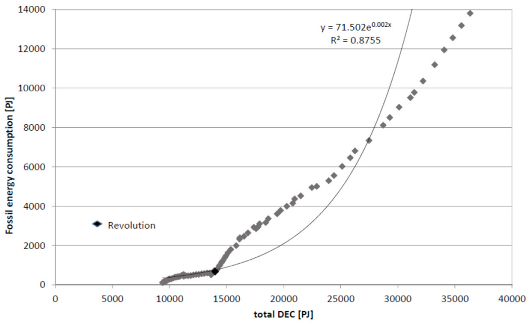
The data for India, in principle, are similar of those of China: An exponential function does not fit very well, and the structural break marked by different gradients of the fossil transition is a bit

[18] In 1959, „the Great Leap Forward“ is started: an effort at rural industrialization. In our data, this triggers substantial structural change that competes statistically with the earlier break. This is why we had to terminate the time series for the Chow test in 1961.

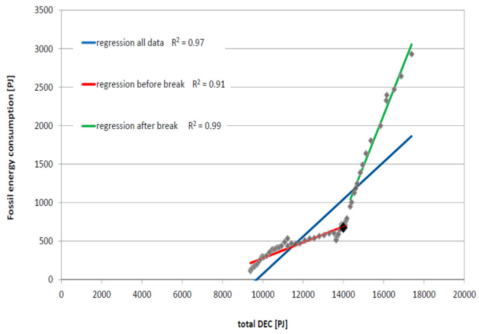
delayed in relation to the Ghandi 1949 revolution, but not very much: it occurs in 1957. Also India waged its revolution quite precisely at fossil energy take off (4.8 % in DEC). Again, like in China, the acceleration of the transition in the aftermath of the revolution is not as marked as in Russia.

Figure 17 **The energy transition in India in relation to the Ghandi Revolution 1949 (time line 1900 – 2000)**

a)



b)



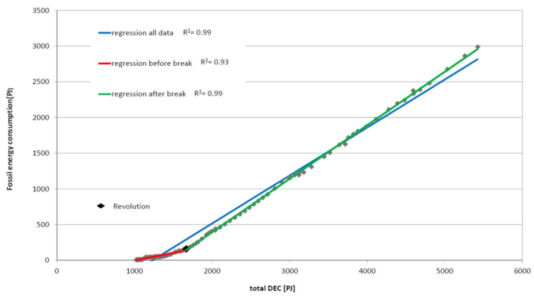
Let us now look at the two "defeated" revolutions in Germany and Austria[19]. Can a failed revolution have an impact upon the energy transition and the course of modernization? Again, both revolutionary attempts occurred at the already well known take-off point: in Germany at slightly above 5%, in the Austrian Monarchy at 9% fossil fuels in DEC. For both countries, an exponential function of fossil fuel rise does not fit well, much less so than linear functions.

For Germany, the statistical break occurs before the revolution (1847), while for Austria shortly after the revolution (1854). This could be taken as an indication that a modernization process was structurally already overdue but blocked by the constellation of social forces. In both cases of course, the revolutionary break and the statistical break in the energy trajectory are very close.

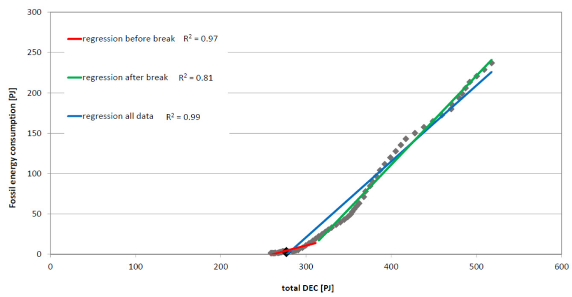
[19] While it is common to regard these revolutions as defeated, this is not quite correct. In the case of Austria, the long overdue liberation of peasants from their debts with the landlords was achieved, and in both cases a major university reform was kicked off that introduced the freedom of teaching and learning ("Lehr- und Lernfreiheit").

Figure 18 **The energy transition of a) Germany and b) Austria in relation to their "defeated revolutions" in 1848 (time line 1798 – 1900).**

a) Germany (statistical break 1847)



b) Austria (statistical break 1854)



After the revolution/statistical break, the energy transition in both countries progresses fast and steadily, while before there had been only slow incline.

After all, what difference do revolutions make?

After all this detailed analysis, it is difficult to tell whether revolutions make a difference for the course of a country's energy transition. Table 2 makes an attempt at assembling an overview of the findings. Some are fairly clear, others less so.

As already demonstrated above, the point in time at which revolutions occur, is very early in the energy transition (at 7% fossil fuels on average), and within the 100 year time span investigated in each case they happen in close vicinity to the statistical breaks in the energy transition (at a time distance of 7.1 years on average). That the time distance is not even smaller is due to the French revolution followed by the Napoleonic wars that created a very special situation.

In countries with revolutions, the statistical break marking the upturn of the fossil fuel share in energy consumption occurs earlier (namely at a fossil share level of 7%) than in countries without a revolution. There the turning point happens on average at 11% fossil share. In the face of the small number of cases, this difference is not significant.

With all countries observed, fossil fuel use accelerates over time, and after the statistical break the gradient of increase is always steeper than before.

There is no difference between countries with and without revolution in the gradient of fossil fuel use before the break. Thus the idea that revolutions might be provoked by particularly fast social change enhancing the tensions in society cannot be defended in the light of these data.

The energy transition gradient after the statistical break is higher in revolutionary countries in contrast to the others. This is an indication that revolutions tend to accelerate social change. But the difference is not so large, and the number of cases low, so we do not expect statistical significance for this finding.

One final observation: In table 2, it becomes obvious how huge the differences between many countries that are pretty much on an equal footing, say, in the year 2000, had been at the beginning of the 20th century. On the eve of the First World War, the future combatants differed in their degree of modernization, and available energy, by one order of magnitude. Across the 20th century, rather than such a process of differentiation as before, a process of convergence took place, in which practically every country converted to a massive use of fossil fuels (and modern energy carriers more generally).

Table 2: **How do revolutions relate to the energy transition? Do they make a difference?**

	year of statistical break	deviation from year of revo-lution	% fossil fuels in DEC in year of revolution	% coal/fossils in DEC at stat. break	gradient before break	gradient after break
countries with revolution						
UK 1642	1648	6	12%	13%	0.37	0.54
FR 1789	1816	27	2%	5%	0.16	0.47
AUT 1848	1854	6	1% (9%)[20]	7%	0.28	1.10
GER 1848	1847	-1	10%	10%	0.21	0.75
RUS 1917	1918	1	13%	6%	0.28	0.72
China 1949	1951	2	9%	11%	0.26	0.91
India 1949	1957	8	5%	7%	0.10	0.53
average		**7**	**7.43%**	**7.67%**	**0.24**	**0.72**
countries without revolution						
AUS	1865	n.a	n.a	2%	0.02	0.12
Italy	1906	n.a.	n.a.	20%	0.39	0.89
Sweden	1877	n.a.	n.a.	5%	0.10	0.51
Japan	1898	n.a.	n.a.	17%	0.23	0.70
USA	1877	n.a	n.a	19%	0.28	0.54
average		n.a.	n.a.	**13%**	**0.20**	**0.55**

2.6 Summary of where we stand

As stated before, this has been an exploratory analysis into the relation between transitions of societies' energy regimes and major social transformations. Both conceptually and empirically, we engaged in unconventional pathways and provided preliminary tests of their fruitfulness.

[20] Austrian monarchy of the time

In particular, we waged an alternative interpretation for the transition to "modernity": We suggested not to focus on technological change (which has chronically been difficult to reliably and comparatively quantify), but to focus on the transition from a biomass-based to a fossil-fuels based energy regime instead. For this, we presented two specific indicators: the share of fossil fuels among societies' primary energy use, and primary energy use per capita. The parameter "primary energy use", to make sense for periods before the industrial transformation, needs to be adjusted by including food for humans and feed for animal livestock to so-called Domestic Energy Consumption (DEC). If we use this information, we obtain reliable quantitative indicators on an annual basis informing about each country's stage of transition to "modernity". Our findings suggest that globally the first "take off" into the fossil fuel regime happens in the Netherlands and the United Kingdom, and it happens much earlier than the usual dating of the industrial transformation suggests. The take-off starts in the 16th century, pretty much at the same time when the humanities date the start of the modern age, and well over 100 years before Newcomen invents the steam engine.

In the next chapter, we expose our long-term database of the energy transitions of 13 countries and explain our interest in social revolutions as markers of this energy transition, irrespective of when in history this takes place. Chapter 4 then displays our main findings. Firstly, the transition to a fossil fuel regime may take place with or without a social revolution; but if there is a revolution, it happens exactly in the take-off phase of the transition, when fossil fuels have a share of about 7% in the total primary energy use. This makes sense insofar as there need to be new collective actors interested in and already empowered by a regime transition in order to wage a revolution. The observation holds for historical events as distant as the UK revolution in 1642 and the Chinese revolution in 1949. A first visual inspection of the long-term data shows that after a revolution has taken place, the transition to fossil fuels and to higher income accelerates, while the demographic transformation seems not to be directly related.

Chapter 5 makes use of more sophisticated statistical means (identifying statistical breaks) to analyse both the coincidence of timing of revolutions with energy take off phases, and to explore what difference it makes whether the energy transition is marked by a revolution, or whether it occurs socially more incrementally. The findings suggest that revolutions accelerate the energy transition (even if this may happen with a delay of a few years); countries without revolutions develop later and more slowly. In view of the small sample of countries that became part of this analysis, and the ambiguity of some findings, further research is strongly encouraged.

The situation the world confronts now, namely another energy transition away from fossil fuels, and possibly a transition into a lower level of societal energy use, is likely to create about as much turmoil as we have seen during the last energy regime transition. It will require further data collection and analysis to be better able to understand a downturn of the energy system rather than an upturn. What we can see so far is that in the highly industrialized countries, the rapid incline of the energy system towards more and more fossil energy has more or less come to a halt in the early 1970s. In view of the heterogeneity of transition processes in time periods we have documented in this contribution, such synchronization is a new phenomenon that requires particular methodological attention and a new global rather than country wise approach.

3. The 1970s Syndrome: Structural change from rising to stagnating energy consumption in mature industrial economies

Marina Fischer-Kowalski, Daniel Hausknost, Dominik Wiedenhofer, Fridolin Krausmann and Nikolaus Possanner

3.1 Introduction

The research presented here figures in a number of different contexts. On the "applied" side, it is part of a European research project WWW (Welfare, Wealth and Work for Europe), and supposed to supply historical experiences in re-directing economic and biophysical growth in ways potentially useful for informing future policy interventions. On a more fundamental level, it is part of our efforts at understanding the – as we term it – sociometabolic transition from an agrarian mode of societal reproduction to an industrial, or as we prefer to see it, a fossil-fuel based mode, and possibly also beyond such a mode. Here we build on a long-standing intellectual cooperation with R.P.Sieferle (e.g. 1990) and on his understanding of sociometabolic regimes as being based on the societal energy sources and conversion technologies. The "1970s syndrome" we report on here is an important element in this chain of transitions, and makes terminological reference to C.Pfister's widely cited "1950s syndrome". Pfister's book appeared in 1995 and resonated widely: he found the year 1950 to constitute a structural break between "industrial" and "consumer society" and described the take-off of mass consumption and its environmental side-effects. The quantitative data we present confirm his diagnosis, but they go beyond: they show this period as a phase in a longer transition process, a phase that ends in the early 1970s, to give way to sociometabolic stagnation in mature industrial economies. Finally, we probe into the role of agency in emergent change of complex systems. While we share a systemic view as our overarching perspective (Fischer-Kowalski & Weisz 1999) based upon Godelier's (1986) dictum that society changes because it changes nature, and this provokes new responses, a more actor-oriented perspective seems expedient when discussing ways out of a planetary deadlock of a potentially catastrophic dimension. In other words: the question is whether and to what extent the systems dynamics of the current energy regime can be deliberately influenced by purposive agency. Still, this inquiry is in a preliminary stage, and our efforts at finding causal clues for the structural change we observe in the 1970s have not yet been very conclusive.

3.2 The socio-ecological perspective on transition and the sociometabolic accounting framework

The socio-ecological approach builds upon certain theoretical premises and choices when studying society-nature interactions over long time scales. Starting from a systems theory approach, it analyses the behavior of evolving systems conceived as self-organizing and sufficiently complex to maintain themselves under changing conditions. In the cases we analyze here, these systems are national economies or societies respectively, interpreted as hybrid socio-metabolic systems, interacting with biophysical systems in the natural environment. Society itself is seen as a structural coupling of a communication system (Luhmann 1995) with biophysical compartments (such as: a human population, livestock, and physical infrastructure). The social metabolism serves to maintain and reproduce these biophysical compartments within a certain territory (Fischer-Kowalski and Haberl 2007), and is organized by society through its communication systems such as the economy. How social metabolism is organized is historically variable, and equally has variable impacts upon the environment. We follow Sieferle (Sieferle 2001) in calling historically evolving distinct patterns of society-nature interaction “socio-metabolic regimes” [21] rooted in the energy system a society depends upon, that is the sources and dominant conversion technologies of energy (Fischer-Kowalski and Haberl 2007).

A socio-ecological transition, then, is a transition between socio-metabolic regimes. Sieferle distinguishes between the socio-metabolic regime of hunting & gathering, the agrarian and die industrial regime. These regimes differ greatly in their social metabolism, both qualitatively and quantitatively (see table 2 for the agrarian and the industrial regime).

Table 2 **Typical metabolic profiles of agrarian and industrial socio-metabolic regimes (see methods section for the definition of the indicators used in this table)**

Parameter	*Unit*	*Agrarian regime*	*Industrial regime*	*Factor*
Energy use (DEC) per capita	[GJ/cap/yr]	40 – 70	150 – 400	3 – 5
Material use (DMC) per capita	[t/cap/yr]	3 – 6	15 – 25	3 – 5
Biomass (share of DEC)	[%]	>95%	10 – 30 %	0.1 – 0.3
Agricultural population	[%]	>90%	<10%	0.1
Population density	[cap/km²]	<40	<400	3 – 10

Source: Krausmann et al. 2008

During the transition between the agrarian and the industrial regime, per capita domestic energy consumption (DEC) and domestic material consumption (DMC) multiply by a factor of 3 – 5. In that process the importance of biomass as energy source decreases from a share of over 95% in DEC to around 10 - 30%, when fossil fuels have become finally dominant. Absolute biomass consumption, though, does not decrease, as it is strongly linked to population size in the form of food demand (Steinberger, Krausmann, and Eisenmenger 2010), and the regime transition is associated with a demographic transition triggering strong population growth and urbanization. Population densities increase by a factor of up to 10, while the share of agricultural population decreases sharply, from over 90% to below 10% (Krausmann, Fischer-Kowalski, Schandl, and Eisenmenger 2008; Krausmann, Schandl, and Sieferle 2008).

We use data derived from material- and energy flow accounting (MEFA, see Haberl et al. 2004; Fischer-Kowalski et al. 2011; Fischer-Kowalski 2011) to investigate structural change in the long term trends of resource use during the socio-ecological transition and to test the

[21] This is a different use of the term regime than, for example, in the Dutch transitions management theory which describes a transition as interference of processes at three different scale levels: macro, meso and micro. The scale levels represent functional relationships between actors, structures and working practices that are closely interwoven. A regime is typically located at the meso level. The approach assumes that transition dynamics do not start in one place but at different locations at different scale levels. Only when these dynamics modulate (have a similar direction), can a scaling up effect emerge as a necessary condition for achieving a transition (for further discussions see (Fischer-Kowalski and Rotmans 2009)).

hypothesis of a stabilization of resource use in industrial economies in the 1970s ("1970s syndrome"). MEFA allows calculating the resource use indicators domestic material consumption (DMC) and domestic energy consumption (DEC) which measure apparent consumption defined as domestic resource extraction + imports – exports.

In contrast to conventional measures for primary energy consumption (e.g. TPES) which only account for technical or commercial energy carriers, DEC is a more comprehensive measure which also includes all primary biomass used by society: all feed for livestock and plant based food for humans. DEC also accounts for electricity from hydro- and nuclear power as primary energy in the form of hydropower and nuclear heat. That is, it takes the conversion efficiency of hydro and nuclear power plants into account (Haberl 2001).

DMC measures the socio-economic use of all materials (except for water and air), typically distinguishing four main material groups: biomass, fossil energy carriers, non-metallic minerals and ores and metals. Accounting principles and estimation procedures are highly standardized and summarized for example in (Eurostat 2009) and (Fischer-Kowalski et al. 2011). We use four long term DMC series available from the literature: USA 1870-2005 (Gierlinger and Krausmann 2012), Japan 1879-2005 (Krausmann, Gingrich, and Nourbakhch-Sabet 2011), UK 1870-2005 (Schandl and Schulz 2002) and Austria 1960-2010 (Statistik Austria 2011). For the statistical analysis of structural breaks presented below we draw on a compilation of long term time series data on DEC for 10 countries with data available for the period 1945 to 2000. In addition to the USA, Japan, UK and Austria (see above), DEC series are available for Germany, The Netherlands, France, Sweden and Italy. These series are based on published data (e.g., Podobnik 2006; Kander 2002; Gales et al. 2007) which have been updated and extended (e.g. for lacking biomass components) to calculate DEC (Pallua 2013), with biomass data from Krausmann et al. 2013.

3.3 The 1970s syndrome as latest phase in the long course of the industrial transition

The transition process from the agrarian to the industrial regime may take several centuries, or it can happen much faster; across this variable time span, fairly similar patterns of pre-development, take-off, acceleration and eventually stabilization can be identified. We demonstrate this for the high-income OECD economies UK, USA, Austria and Japan.

The primary example for the transition from the agrarian to the industrial regime is of course the United Kingdom, which as a forerunner, took approximately 350 years (Wrigley 1988; Sieferle 2001; Krausmann, Schandl, and Sieferle 2008). Already in the 16th century the use of coal began to spread, gradually substituting for dwindling wood supplies and allowing for heating growing urban centers and textile manufacturing. Much later, with the diffusion of the iron - steam engine - railroad complex (Grübler 1998), we can see the well-recognized take-off of industrialization in the more common sense of the word, and a first acceleration phase from the mid-19th century onward[22] (Figure 19). The early take-off and acceleration take a fairly similar course for all three indicators shown in Figure 19: for energy consumption, material consumption and for GDP (all indicators per capita and year). A next phase established itself after World War II (WWII), marked by the expansion of the oil – steel - auto cluster, together with electricity (Ayres 1990a; Grübler 1998; Ayres 1990b). This also marked a take-off of mass consumption and can be looked upon as "the" acceleration phase of the industrial transition (termed "1950s syndrome" by Pfister (2010)), with rapid biophysical and economic growth. But in the 1970s this phase seems to have ended and a per capita stabilization at high levels set in (Figure 19).

For the USA the end of the Civil War (1861-1865) marked the take-off phase, with coal, steam and steel-based industrialization and the expansion of the railway system (Figure 19). After the Great Depression and with Roosevelt's "New Deal" and the war economy, the acceleration phase began in the USA, which also lasted until the 1970's. During that period material use (DMC) grew by 3.3% annually and DMC per capita more than doubled, from 13t/cap/year in 1932 to 29t/cap/year in 1970. Per capita energy use (DEC) increased by a factor of 1.6, from 306 GJ in 1930 to the peak of 484 GJ in 1979 (Gierlinger and Krausmann 2012). In the case of Austria the transition took off in the second half of the 19th century (Figure 19 and Krausmann, Schandl, and Sieferle 2008). Because of the availability of wood in rural and iron producing regions, biomass continued to play an important role as heat source until the acceleration phase of the post WWII period, when oil based industrialization, post-war reconstruction and mass consumption led to an exponential increase of materials and energy use. As in the other mature economies, the 1970s are the period in which resource use stabilized, while economic growth continued (Figure 19).

The case of Japan is highly interesting because of the fast pace of the transition and because Japan is one of the few cases where absolute decoupling of economic growth from materials use has been observed (Krausmann, Gingrich, and Nourbakhch-Sabet 2011). Japan remained in the agrarian regime for much longer than the other cases presented here, and only with the end of the 19th century a pre-development and eventual take-off in the mid-20th century can be identified (Figure 19). Japan never experienced a strongly coal-driven phase of its metabolism, but started the steep acceleration of its metabolic transition directly into the oil-age after WWII, with most of the rapid increases of energy and materials use happening in the three decades until the 1970s (Figure 19).

Interestingly not just for these four countries, but also for most high income countries of the capitalist Western system the 1970s marked a turning point towards stabilization of per capita energy and materials use, while GDP continued to rise. This change in trend is so marked that it even shows in global resource use: Both global energy and material use per capita stabilize at a high level between the early 1970s and the late 1990s, after two and a half decades of fast

[22] One should be aware that the numbers shown in Figure 19 and 20 refer to per capita metabolism. Simultaneously, from about 1720 onwards, there was a huge population growth; by eliminating the effect of population growth, we get the impression of a stagnating system in the first half of the 20th century – UK's economy as such, though, was growing both physically and economically during this period.

growth (Krausmann et al. 2009;Fischer-Kowalski 2011). From the late 1990s onward, though, the metabolic and economic rise of “emergent” economies dominates the global energy and materials consumption trend, inducing another phase of steep incline, while the mature industrial economies keep stagnating.

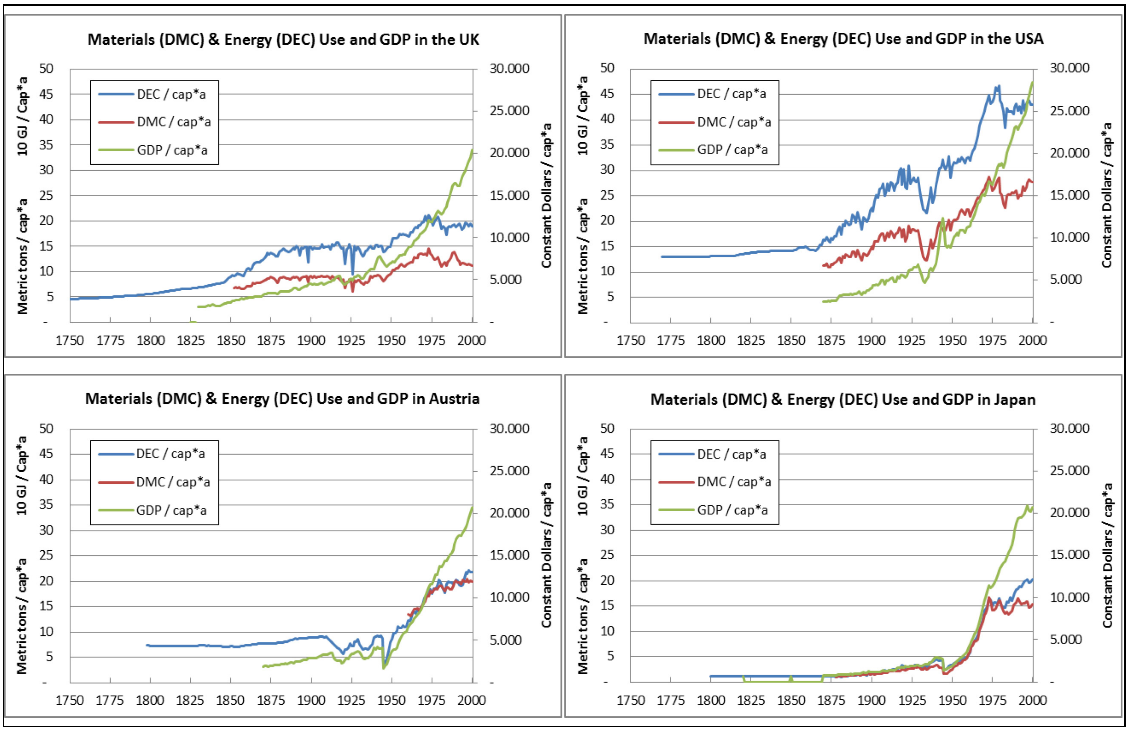


Figure 19: The socio-metabolic transition in the UK, USA, Austria and Japan, from 1750 – 2000

sources: Krausmann, Schandl, and Sieferle 2008; Pallua 2013; Gierlinger and Krausmann 2012; Krausmann, Gingrich, and Nourbakhch-Sabet 2011 and Maddison 2008 for GDP and population estimates. Domestic energy consumption (DEC) in 10 GJ/cap/y, domestic material consumption (DMC) in t/cap/y and GDP in international constant 1990 Gheary Khamis Dollars. All numbers are expressed as per capita values. Including population growth effects would show even more marked accelerations and increases of energy and materials use as well as GDP.

3.4 Patterns of industrial stabilization in the 1970s: a statistical analysis

Why does such a stabilization of industrial metabolism happen in the 1970s? As it is one of the few generally accepted principles of causality that causes must precede effects, we attempt a first step towards clarification by identifying the time when exactly this structural break occurred, not just for the four countries previously described in their long range development, but for 10 industrial economies (Austria, France, Germany, Italy, Japan, Netherlands, Sweden, United Kingdom, USA and the USSR; see Figure 20).

For 9 out of the 10 countries investigated, there happens a significant structural break in the time series during the years from 1966 to 1979 (Figure 20). The only exception is the USSR: it shows nearly linear increases of per capita energy use until its collapse in 1991. In our case, we are only interested in those trend breaks that lead from a steep increase (the acceleration) towards a stabilization. We arrive at a cumulative frequency distribution of significant breaks across time as shown at the bottom of Figure 20.

The single most frequented year for energy downturns is 1979, the year of the second oil price spike. Else, there is no uniform pattern: half of the countries experience downturns in 1970, in 1973 and in 1974, and the rest is fairly scattered across the Seventies. For Sweden the first break period ranges from 1968-71, a second one from 1978-80. In the UK the first breaks are from 1971-75 and again from 1978-79. In Japan 1973-80 is an entire period of structural change. For France, 1972 can be identified, with 1979 as the second break. In the Netherlands only in 1974 a significant break occurs. Finally the USA show a strong period of change from 1977-80. So except for maybe the second oil price shock there was not one single external signal to trigger the trend change in energy use, but an extended period of change.

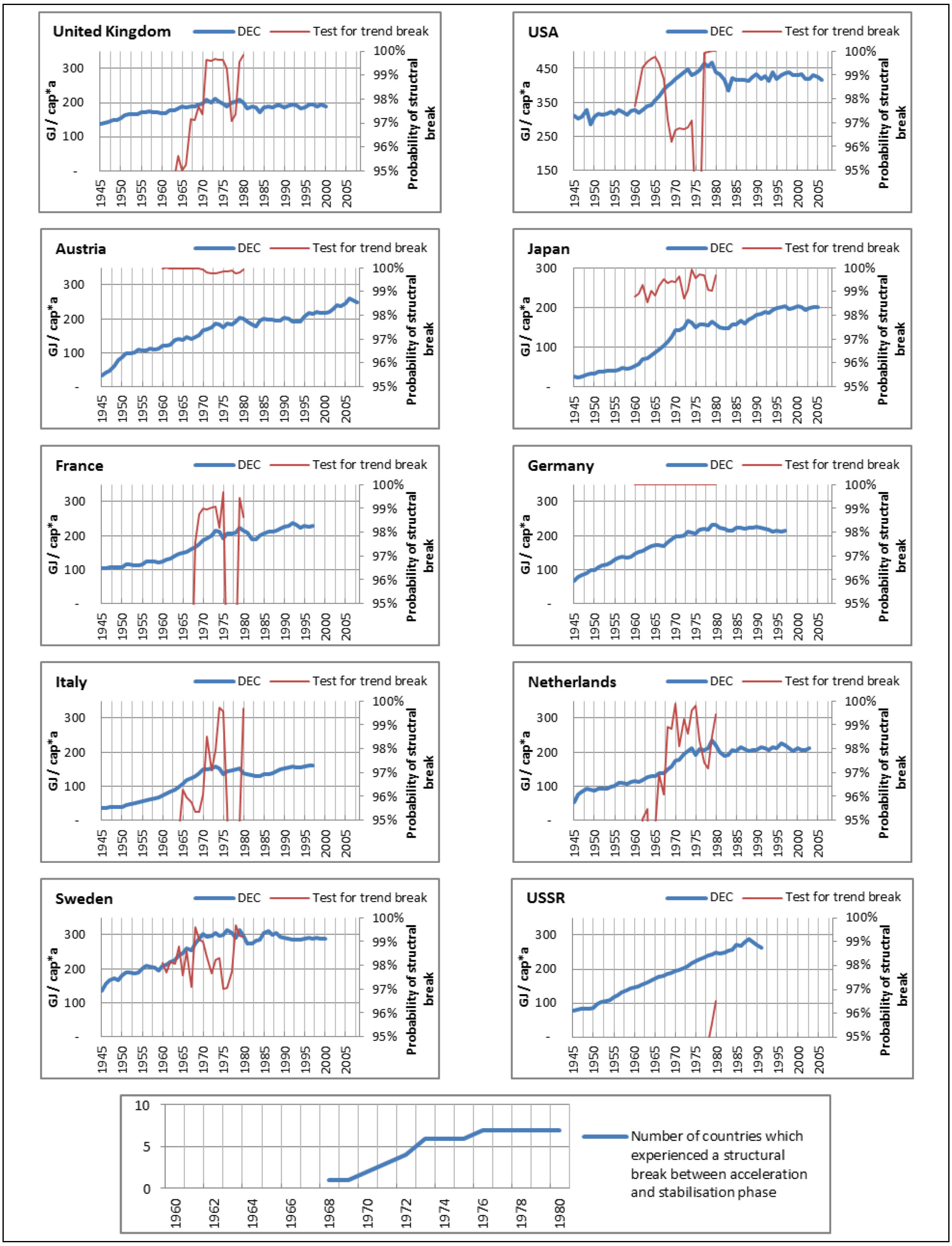


Figure 20: The timing of structural breaks between the acceleration and stabilization phases of the socio-metabolic transition.

Time series for per capita domestic energy consumption (DEC) are presented with the same scaling of 0 – 350 GJ/cap*a, except the USA which is shown at 150-500 GJ/cap*a. On the second axis we show the statistical probability of a structural break occurring in the respective year (Chow test), marked within the figures in red lines.

So from our statistical analysis, we can draw the following conclusions. Our initial thought experiment to look at the industrial regime as a long-term transition process of energy (and materials) use has proven as fruitful empirically. For the few countries where sufficiently long data series for resource use are available we could demonstrate an S-shaped transition curve, across 150-350 years. What is even more surprising and could be demonstrated for several more countries is the observation that in high income industrial countries the 1970s marked the beginning of a stabilization phase of energy and material consumption per capita, while income growth continued (albeit on a lower level than before the 1970s). Our efforts to identify the exact timing of the turn away from the preceding trend towards ever higher per capita energy and materials consumption are not entirely conclusive yet, as we find turning points scattered across the 1970s. This could be an indication that no single cause – such as the first and/or second oil price shock – has triggered this lasting structural change. Nevertheless, oil price shocks must have played an important role in inducing stronger efforts at increasing energy efficiency of businesses, of cars, and in the residential housing stock. Other potential causes, such as increased outsourcing of production processes into developing countries and a shift towards service economies and later in particular information and communication technologies (ICT) are going to be further explored. A much bolder interpretation would be that of endogenous system change; an historical opening for the pre-development phase of a next socio-ecological transition, another "great transformation" (Polanyi 1944; German Advisory Council on Global Change (WBGU) 2011).

3.5 The 1970s Syndrome: Exploring possible explanations

In what follows we will assess possible explanations for the plateauing of energy (and material) consumption in industrialized countries during the 1970s, based on a review of relevant literature. The question that interests us most is to what extent this '1970s syndrome' can be attributed to endogenous factors (like structural change in the composition of the economy, efficiency gains due to technological progress or market responses to increased energy prices), and to what extent it is the result of exogenous influences in the form of active political intervention into the energetic metabolism of industrialized societies. We do not aspire to quantify these different influences. But what we can achieve here is to get a better picture of the different factors that were at play in this complex process and to arrive at a rough estimation of the relative weight of the factors in explaining the overall process.

The findings of our literature-based research suggest that the main drivers of the stabilization of energy use were endogenous but that these endogenous processes were significantly reinforced and accelerated by political measures to improve energy efficiency, reduce waste energy and ultimately reduce the overall energy intensity of mature economies. These policy measures were first devised in the early 1970s in response to the oil price increases, but have been continued until today under changing motives: while the prime motive in the 1970s was energy security, it changed in the 1980s towards general environmental concerns and economic competitiveness and has been reconfirmed with efforts at mitigation of climate change since the early 2000s.

Each factor at work in stabilizing the energy and materials use seemed to have dominated a different phase of the stabilization process. For example, the main savings in the 1970s stemmed from the overall decrease in economic output due to the recession in 1974-75 and a slow recovery in the following years as well as from the spontaneous response mainly of the manufacturing sector to cut waste energy and diversify energy supply, resulting in a relatively steep decrease of energy intensity. Meyers and Schipper (1992), for example, stress that 'much of the easy-to-cut "energy waste" was trimmed between 1973 and the early 1980s' and that 'many inexpensive technical improvements' were made in these early years. Thus, the proverbial 'low-hanging fruit' were all plucked early on, enabling large energy savings in a very short period of time.

These efficiency improvements were not reversed after the crisis but led to a lasting effort in the economy to reduce energy dependency and energy waste. The efficiency and energy conservation programs implemented by the end of the decade, however, only started contributing significantly to the stabilization of energy use throughout the 1980s and thereafter, as they mostly concerned new building standards for space heating and insulation as well as efficiency standards for cars and appliances which get replaced or refurbished only at a relatively low annual rate. Energy politics in the 1970s was primarily motivated by concerns over energy security and had little to do with environmental concerns. But the 1973 oil crisis made once and for all clear that fossil energy is a finite resource and that energy was no longer available at no cost (Issawi 1978).

The 1980s were characterized by the convergence of a few factors: first, the second oil crisis of 1978 led to an even more pronounced economic downturn after which OECD economies never fully recovered to pre-1970s growth. Hence, the slower average annual growth rates after the oil crises (1973-98: 2.7%) as compared to the high average growth rates between 1950 and 1973 (4.5 %) have to be taken into account as an important structural factor for the stabilization of metabolic rates (Colitti and Baronti 1981; Geller et al. 2006). The second factor characterizing the 1980s was rapid changes in the overall structure of the OECD economies. This meant a shift away from heavy industry and towards the service sector and light manufacturing, which both have much lower energy intensities. An interesting question with regard to these structural changes concerns their global effects on metabolic rates: to what extent is the energy saved in deindustrialization and outsourcing reimported (as "virtual" or "embodied" energy) to the OECD countries in finished products from emerging economies? To what extent is the stabilization of energy use in the advanced industrial economies owed to the outsourcing of energy-intensive activities and the re-importation of the resulting commodities? Unfortunately these questions, however important, cannot be answered within this paper.

Compared to the 1970s, energy politics in the 1980s was less motivated by the quest for energy security than by the motive of competitiveness (following the new belief in market forces that was becoming hegemonic in the 1980s), and also environmental concerns (Finon 1994). From the 1990s onward, a certain consolidation of different factors into an overall societal trend to energy saving can be observed: on the one hand, structural change and a comparatively modest economic expansion are ongoing, and on the other hand efficiency gains through technological change and government-led steering efforts are continuing to further decrease the energy intensity of advanced economies. Now, energy efficiency and energy conservation have turned into firmly established societal goals that have diffused into all sectors of the economy and segments of society. Although economic growth and increasing prosperity are still the main objectives of the political systems, it is clear that these aims have to be achieved at an ever higher level of energy efficiency.

This trend is being continued and even exacerbated in the first two decades of the new millennium. Governmental programs to save energy and to stimulate energy efficiency in all societal sectors are now motivated by the mitigation of climate change. The return of high energy prices (driven by a high crude oil price) since about 2005 conceivably compounds these tendencies: after a peak in 2008 at over 140 US$ and a slump during the financial crisis that followed, oil prices have continuously hovered at around 100 US$ or above (as compared to about 40 US$ before), stimulating substitution processes away from heating oil towards biomass in some countries (e.g. Austria and Scandinavian countries) and pushing the car industry to produce more fuel efficient cars.

In sum, our findings suggest that the stabilization process we term the ‘1970s syndrome’ is the result of the cumulative and mutually reinforcing effects of several factors. Some of these factors, like technological efficiency gains and structural change, have been there long before the first oil crisis had hit, but they were amplified and synchronized by the systemic realization (both in the economic and in the political realm) of the finiteness of energy resources and by the political responses to this realization. Policy measures were developed to purposefully reduce the energy intensity of the economy and eventually to reduce its carbon-intensity. We generally confirm the observation by Finon (1994) that the policy responses of the 1970s were primarily motivated by concerns over energy security, that the 1980s saw a relative loss of interest in energy policy while measures aiming at efficiency were still en vogue and that the 1990s witnessed a revival of energy policy, driven by environmental concerns that are, in the new millennium, clearly centering around the global problem of climate change. These different motives of energy policy over the past decades are not mutually exclusive but reinforced each other so that a lean, energy-efficient economy is a top priority for policy makers today for reasons of energy security, competitiveness and environmental concerns.

In what follows we will have a closer look at some of the individual factors that contributed to the 1970s syndrome. We will first discuss structural change and efficiency gains, before turning to the policy responses in various OECD countries.

3.5.1 Structural change

The indicator most commonly used in the literature to describe the relationship between economic activity and energy use is *energy intensity*, which is the energy necessary to produce one unit of economic output (Rühl et al. 2012). Energy intensity does not give any information about per capita energy use or total energy use of an economy. For example, as long as the rate of decline in energy intensity is smaller than GDP growth, the total energy use of an economy will still increase. This is precisely what typically happens in industrialized economies: from a certain point in their development, their energy intensity declines, but this decline is usually outpaced by their economic expansion, thus leading to an overall increase in energy use. From the early 1970s onward, however, these two rates seem to converge in most OECD countries, leading to the stabilization of overall energy consumption.

The energy intensity of an economy typically follows a bell-shaped curve. In the period of industrialization, with ever more energy-intensive activities (like iron and steel production) being added to the economy, overall energy intensity increases. At a certain point, when the industrial sector growth slows down 'as the need for energy intensive infrastructures and urbanization projects declines' (ibid.), the continuous efficiency improvements in production will outweigh the negative energetic effects of industrial expansion. Ultimately, the composition of the industrial sector typically shifts from heavy and energy intensive sub-sectors toward light manufacturing and 'the composition of economic activity tends toward the tertiary or service sector, driven by the changing structure of demand and higher income elasticity for services' (ibid.). The energy intensity of the UK, for example, already peaked in the 1880s, that of the US around 1910 and that of late-developing Japan around 1970, however at a much lower absolute level (Rühl et al. 2012: 113). These changes correspond to what can be gathered from Figure 1 (although the values for energy intensity are not explicit in this figure).

A focus on energy intensity thus suggests that at some point on the downward slope of the bell curve, a certain maturation of the economy is achieved where population growth is minimal and economic expansion moderate but technological change and changes in the composition of the economy (i.e. structural change) are still driving down the overall energy intensity of the economy. This is when energy use per capita stabilizes. The bell curve in energy intensity is thus shaped by two factors: structural change and technological efficiency gains. Structural change refers to the changes in economic activity and shifts of activity between and within sectors, but also the outsourcing of activity to other parts of the world economy. For example, the rise of the steel and automobile industry in Japan and Korea in the 1970s and 80s has contributed to excess capacity in those industries in the mature economies of North America and Europe. As a consequence, total capacity in the U.S. steel industry fell by 38% and total employment fell by about 50% (Jensen 1993). An example for structural shifts within a sector would be the pulp and paper industry, whose energy-intensity was affected since the 1980s by shifts in production between energy-intensive pulp and finished paper goods (Meyers and Schipper 1992). Some also suggest that during the 1960s a certain saturation in stocks and infrastructures played a role in the peaking of energy use in mature economies. For example, Rühl *et al.* (2012: 112) argue that at a certain point, 'the need for energy intensive infrastructure and urbanization projects declines'. Similarly, Meyers and Schipper (1992: 465) argue that 'structural change in economic activity and maturation of physical infrastructure have contributed to decline in the energy/GDP ratio'.

However, the saturation argument only holds for the manufacturing sector at first. While it seems plausible that the demand for energy-intensive infrastructure 'peaked' in the 1970s in mature economies and that the manufacturing sector started to transform from heavy industry to light manufacturing in the 1960s, 'structural change' worked in the opposite direction in the residential and transportation sectors for another twenty years or so. In the residential sector, 'increases in home floor area, heating equipment, and appliance ownership raised energy use by about 40% in the United States and by about 60% in other [OECD] countries' during 1970 and 1990 (Meyers and Schipper 1992: 494). Also, the 'increase in the share of passenger travel in automobiles and airplanes' raised energy use considerably (ibid.). Thus, 'structural change contributed to reductions in energy use only in manufacturing' (ibid.). Nonetheless, structural change away from the energy-intensive industries (most notably iron and steel) accounted for about one-fourth of the decrease in aggregate energy intensity in the seven large OECD countries studied by Meyers and Schipper (1992: 473), which underlines the overall importance of the manufacturing sector in the energy intensity of an economy.

More important than structural change, however, were the efficiency improvements through technological progress, as Meyers and Schipper underline. According tom them, '[d]ecline in energy-intensities at the industry level [i.e. through efficiency gains] was the major force pushing aggregate intensity downward' (1992: 473).

3.5.2 Efficiency gains

Most authors agree that energy efficiency improvements played the key role in bringing the energy intensity of OECD economies down in the years since 1973. Again, some of these improvements were 'spontaneous' reactions of the economy to the higher energy prices, some were simply the continuation of ongoing technological progress and some were triggered, amplified or even forced by government programs. At any rate, '[w]ithout energy efficiency improvements, the OECD nations would have used approximately 49% more energy [since 1973] than was actually consumed as of 1998', as Geller et al. (2006: 556) show. According to their calculations, actual energy use of 11 selected OECD nations was at 80 exajoules (EJ) in 1973 and rose 'only' to around 100 EJ by 1998, while it would have risen to around 150 EJ without efficiency improvements (ibid.: 560). Confirming the above assessment by Meyers and Schipper, that the low-hanging fruit were plucked early on after 1973, they state that primary energy intensity fell most rapidly after the two oil price shocks: 'Between 1973 and 1983, the fall in primary energy intensity averaged 2.2% per year. After 1983 and until 1990, TPES (total primary energy supply)/GDP declined at a more modest average rate of 1.3%/year.' (Geller et al. 2006: 557). After that, the decline slowed further until it somewhat accelerated around the turn of the millennium.

Part of the efficiency gains generated in the 1970s and 80s is attributable to an ongoing diversification of energy sources that has started in the 1960s and was accelerated by the first oil price shock. This meant that fuels were used more efficiently (for example, space heating with coal declined and was substituted by oil and gas, which deliver heat more efficiently), and that new sources of energy were developed (most notably, nuclear energy and natural gas) that allowed for a more specialized and thus efficient fuel mix (Rühl et al. 2012: 109; Colitti and Baronti 1981: 236).

Efficiency gains again had the greatest total effects in the manufacturing sector: in the seven OECD countries studied by Meyers and Schipper, aggregate manufacturing energy intensity fell a remarkable 40% between 1973 and 1988. While manufacturing value-added rose at an average rate of 2.3% per year, energy use fell by 1.2 % per year (Meyers and Schipper 1992: 473). The largest intensity reduction was in chemicals (37%), as compared to 32% in building materials and 27% in pulp and paper and in iron and steel (ibid: 473-474). This gives a taste of the enormous potential for efficiency improvements that remained untapped before the 1973 oil price shock and of the role the manufacturing sector played in bringing overall energy intensities down.

This is all the more impressive if one compares the savings in the manufacturing sector with the very modest achievements in the transport sector. Although technical progress – partly driven by government policies, as will be discussed below – was considerable also in increasing the energy efficiency of cars, trucks and airplanes, these gains were more than offset by the enormous increases in per capita miles driven and flown. Indeed, between 1970 and 2000, 'neither the transport intensity of the economy nor the carbon intensity of transport has been reduced', as Tapio *et al.* (2007) point out. This means that as the economy in the EU-15 (which were studied by Tapio *et al.*) grew a staggering 91% in the 30 years between 1970 and 2000, so did transport and so did its reliance on fossil fuels (ibid. 446). Thus, while overall energy use between 1960 and 2000 in the EU-15 increased only moderately (by around 30%), energy use in transport skyrocketed by around 350%. Again, without efficiency gains in engine technology and automobile design the increases in energy use in the transport sector would have been even higher, but even with the efficiency improvements realized they were enormous.

In the residential sector, the two factors energy improvement and structural change constituted countervailing trends that ultimately all but leveled each other out. On the one hand, quite impressive efficiency improvements were achieved since the early 1970s, many of which resulted from government policies that established new codes for the thermal insulation of buildings and new technical standards for heating equipment. In Germany, for example, such thermal insulation ordinances reduced heating energy consumption per unit of floor area about 30% between 1978 and 1993 (Geller *et al.* 2006: 566). On the other hand, as mentioned above, structural change towards increased floor area, heating equipment and appliances ownership raised residential energy use in the OECD considerably (up to 60% in some cases). This structural change was the consequence of more disposable income per household and of smaller family units. The aggregate of both countervailing trends was a relative stabilization of overall residential energy use in the OECD, which was about the same in 1988 as in 1973, despite a 10% growth in population (Meyers and Schipper 1992: 485). However, there were regional differences: while final residential energy use per capita declined by 15% in the United States, since the average floor area and appliance ownership had already been very large in 1973 and therefore the efficiency gains had a higher absolute impact, the same energy use increased by 10% in Europe and by 46% in Japan, as these parts of the world had more to catch up in those terms.

3.5.3 Exogenous factors: policy responses

The immediate reactions of governments to the first oil price crisis of 1973 were driven by concerns over energy security. Emergency measures like car-free days, the introduction of summer-time and of fuel-saving holidays in winter (e.g. in Austria) had little or no measurable effect on energy consumption, however (Edler 2013). Only the more comprehensive measures directed at the manufacturing and residential sectors that were developed in the years after the crisis started to affect the overall energy regime of the oil consuming countries. As noted above, it was mainly the energy efficiency policies that contributed to the decline in energy intensity over the past 40 years (Geller *et al.* 2006: 556). In the years directly following the first crisis, energy plans and programs were devised that had the two-fold objective of reducing total energy demand and dependence on oil imports. These programs, together with the more spontaneous reactions by industry to cut energy waste in their immediate domains, helped bring the energy issue onto the agenda of companies and households and helped reduce energy waste that was hitherto not regarded an issue. But these early gains in energy efficiency were also countervailed by governments' aim to substitute coal for oil where possible. The EC issued a directive (75/405/EEC) to restrict the use of oil in power generation. According to this directive, new power generators were prohibited to run on oil and were therefore encouraged to use coal as a fuel. This led to a significant revival of coal in the 1970s, at least in power generation, but also in industries like cement production (Finon 1994: 6). It is interesting to note, however, that despite these policies the share of coal in total energy use has decreased during the 1970s (Colitti and Baronti 1981: 250), which can only be explained by the structural changes away from heavy (and coal-based) industry like iron and steel towards services and light manufacturing. On the supply side, the focus of governments was on diversification of energy sources by developing non-oil sources like nuclear power (in particular France, Sweden, Germany), natural gas (the UK and Norway developed new fields in the North Sea and the Netherlands started to export gas from their Groningen field), and renewables (Austria, for example, further developed its hydroelectric power capacities).

Interestingly, most energy policies aiming at efficiency improvements were elaborated and enacted only in the second half of the 1970s or around 1980. In Austria, for example 'not much happened in the phase 1973-79' in terms of energy policy, as Edler (2013: 17) points out. A reduction of total primary energy consumption only became a goal of Austrian energy policy in the government's Energy Report in 1984 (ibid: 28). In the Netherlands, too, energy saving only became a top priority after the second oil crisis in 1978, which was reflected in the second Energy White Paper of 1979 (Verbong and Geels 2007). In Japan, the *Law Concerning the Rational Use of Energy* was enacted in 1979 (Geller *et al.* 2006: 561). By comparison, the USA acted relatively early and passed their Corporate Average Fuel Economy (CAFE) standards for automobile fuel efficiency in 1975, a law on national building energy efficiency standards in 1976 and the Public Utility Regulatory Policies Act (PUPRA), which pushed utilities towards combined heat and power generation, in 1978. This comparatively more active stance of the

U.S. might be explained by their higher starting levels of energy consumption, combined with a growing dependency from oil imports[23]. This made political action on automobile fuel efficiency an urgent issue and might have stimulated a more proactive approach in other energy fields as well.

The efficiency standards adopted in many countries led to impressive energy savings, especially in appliances and space heating. In Japan, the average electricity use of new refrigerators declined by about 15% between 1979 and 1997, while at the same time the average refrigerator size increased by approximately 90% (Geller *et al.* 2006: 561). The EU measures on appliance labeling and efficiency standards reduced the average electricity consumption of new refrigerators and freezers by 27% between 1990 and 1999 (ibid: 568). And the thermal insulation ordinances adopted in Germany reduced heating energy consumption per unit of floor area by about 30% between 1978 and 1993 (ibid: 566).

Overall, our assessment is that energy policy played an important role in curbing per capita energy use since the 1970s, but that it could not have done so on its own, that is, without endogenous trends of structural change, saturation, and decreasing energy intensities. Energy policy played the role of a catalyst, in that it seized the occasion of the oil price shock to put energy on the agenda once and for all, and to make energy efficiency and energy conservation a standard objective in almost all policy fields. The motives behind this shift – energy security, competitiveness in the global market, environmental goals and climate protection – converged at some point and present the common rationale of the current ideology of ‘green growth’ and a ‘green economy’. The purported aims of these buzzwords are much more comprehensive and far-reaching than such a stabilization of per-capita resource use on an unsustainably high level, however. They allude to a wholesale transition of the global economy toward a low-carbon, environmentally sustainable type of by not much different to those that were employed over the past thirty years to ‘green’ the inherently ‘grey’ fossil energy regime of ours. But can this work?

3.6 Conclusions: Learning from the Seventies?

Although the per-capita use of energy seems to have stabilized during the past 40 years or so in the industrialised countries, this does not mean that the level on which it has stabilized is sustainable either in environmental terms or in terms of energy security. It simply means that the long acceleration phase of per-capita-energy use in industrialised countries has come to an end and that some sort of new equilibrium on an unsustainably high level of energy and materials use has been reached. The transition away from these high levels has not properly started yet and will require other measures than those which have achieved the stabilization of the upwards curve. Or, as Arnulf Grübler (2012) puts it, ‘[a] discomforting observation is that since the mid-1970s rates of change have significantly slowed down, coming almost to a standstill, which creates an unfavourable baseline for the much needed next energy transitions’. According to

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[23] „Peak Oil“ in the United States occurred in 1973 (Fouquet 2010)

this view, the convergence of developed economies at a high level of energy and resource use does not necessarily point to an impending decline of energy use, as in a bell-shaped curve, but seems to suggest a stable plateau at unsustainable rates until this unsustainability will eventually force a decrease in metabolic rates – which might then come in the form of socio-ecological collapse (Tainter 2007).

To try to bring overall energy consumption down to the level necessary to combat climate change with the same policy tools that were used to stabilise it at the current level (a focus on efficiency in a growth-oriented system, on energy security to provide further growth and on outsourcing energy-intensive activities to other world regions) will not work. There are at least two main reasons why the lessons from the past are not sufficient to plan for the future: for one, while the Industrial Age led to ever more efficient technology allowing to produce a dollar worth of goods with ever less energy, it also led to an explosive growth in production, consumption and trade. Efficiency gains are inherently eaten up and overcompensated by growth since what they do is in fact reduce input factors of production and therefore allow more of the same to be produced with the same inputs. The first reason is therefore that in a growth-based economy at least part of the efficiency gains will be re-invested in further economic expansion (rebound effect)

The second (and related) reason has to do with the expansive nature of previous energy transitions: In an analysis of 14 past sectorial energy transitions Roger Fouquet found that 'for a new energy source to become dominant, the energy services (such as space and water heating, powering machinery and appliances, passenger and freight transport, and lighting) it provided had been cheaper than the incumbent energy source' (Pearson and Fouquet 2012; Fouquet 2010). 'That is, generally, where the energy transition succeeded, the cost of producing the service […] was lower than for the incumbent source' (Pearson and Fouquet 2012: 2). Hence, energy transitions in the past were successful when they offered better and cheaper energy services and thus stimulated new fields of consumption and new economic activity. Coal provided much more and cheaper energy services than biomass; oil provided new and better services than coal at least in transportation (which it revolutionised), electricity again provided a range of new and improved services, etc. And all that led to an overall expansion of the industrial energy regime. Hence, 'historical experience suggests that energy transitions have been characterised by major increases in energy consumption. […] Thus, even a major shift towards low carbon energy does not guarantee that the global economy will reduce fossil fuel consumption. Instead, such a shift may simply promote overall greater energy consumption' (ibid).

The policies of the 1970s and thereafter reinforced an endogenous trend to curb the exponential growth of the fossil energy regime at least in per capita terms. Their era represented the final phase of the socio-ecological transition from the agrarian socio-metabolic regime to the industrial socio-metabolic regime. Moving from there to a 'sustainable' socio-metabolic regime will be a different question altogether. It will require (1) a radical further reduction of energy intensities *without* re-investing the efficiency gains in further growth and (2) a deliberate energy transition that does *not* offer new and cheaper energy services but that has to put up with more expensive and possibly less convenient and fewer energy services. The energy transition ahead will have to be a transition *downwards* in terms of overall utility and services; it will be a transition toward more selective, more coordinated and societally planned energy services. As long as this is not properly understood, policy makers will still hope to achieve a sustainability transition by stimulating efficiency improvements for ‘green growth’. To learn from the seventies therefore means, first and foremost, to realize that the quest to radically de-carbonise the world economy is not compatible with the quest to stimulate further growth, green or otherwise.

References

Ayres R. U., 1990a. Technological Transformations and Long Waves. Part I. Technological Forecasting and Social Change, 37:1-37.

Ayres R. U., 1990b. Technological Transformations and Long Waves. Part II. Technological Forecasting and Social Change, 36:111-137.

Ayres, R. U. and B. Warr 2009. The economic growth engine: How energy and work drive material prosperity. Cheltenham, UK and Northhampton MA, US: Edward Elgar.

Berkes, F., Folke, C., 1998. Linking Social and Ecological Systems. Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge.

Centre for Global Economic History (2013) The Clio-infra database on urban settlement sizes: 1500-2000 [http://www.cgeh.nl/urbanisation-hub, accessed 2013-09-02].

Chow, G.C., 1960. Tests of Equality Between Sets of Coefficients in Two Linear Regressions. Econometrica., 28 (3), 591-605.

Colitti M., Baronti,P. 1981. Energy Policies of industrialized Countries. Energy, 6:233-262.

Cottrell, F. 1955. Energy and Society. The Relation between Energy, Social Change, and Economic Development. New York, Toronto, London: McGraw-Hill Book Company.

Edler E., 2013. Politischer Einfluss auf sozialökologische Transformationen: Österreichische Energiepolitik zwischen 1970 und 1990. Master thesis: Institute of Social Ecology, Alpen-Adria Universität Klagenfurt.

Eisenstadt, S.N., 1978. Revolution and the Transformation of Societies: A Comparative Study of Civilizatons. Free Press, New York.

Etemad, B., Luciani, J., 1991. World Energy Production 1800-1985. Librairie Droz, Geneve.

Eurostat, 2009. Economy wide Material Flow Accounts. Compilation Guidelines for reporting to the 2009 Eurostat questionnaire (Version 01 - June 2009), European Statistical Office, Luxembourg.

Finon D., 1994. From Energy Security to Environmental protection: Understanding swings in the energy policy pendulum. Energy Studies Review, 6:1-15.

Fischer-Kowalski M., 2011. Analyzing sustainability transitions as a shift between socio-metabolic regimes. Environmental Innovation and SocietalTransitions, 1:152-159.

Fischer-Kowalski M., Haberl, H. 2007. Socioecological transitions and global change: Trajectories of Social Metabolism and Land Use, Edward Elgar, Cheltenham, UK; Northhampton, USA.

Fischer-Kowalski M., Krausmann, F. Giljum, S. Lutter,S.. Mayer,A. Bringezu,S. Moriguchi,Y. Schütz, H. Schandl, H., Weisz,H. 2011. Methodology and indicators of economy wide material flow accounting. State of the art and reliablity across sources. Journal of Industrial Ecology, 15:855-876.

Fischer-Kowalski, M., Krausmann, F., Pallua, I. 2014. A sociometabolic reading of the Anthropocene: Modes of subsistence, population size and human impact on Earth. Anthropocene Review. 1(1). DOI: 10.1177/2053019613518033

Fischer-Kowalski M. ,. Rotmans, J. 2009. Conceptualizing, Observing and Influencing Social-Ecological Transitions. Ecology and Society, 14:1-3. [online] URL: http://www.ecologyandsociety.org/vol4/iss2/art3.

Fouquet R., 2010. The slow search for solutions: lessons from historical energy transitions by sector and service. Energy Policy, 38:6586-6596.

Gales, B. 2012. Energy use in the Netherlands (1800-2003). Personal communication, 2012-09-03.

Gales, B., Kander, A., Malanima, P., Rubio, M.d.M., 2007. North versus South: Energy transition and energy intensity in Europe over 200 years. European Review of Economic History, 11 (02), 219-253.

GEA 2012. Global Energy Assessment - Toward a Sustainable Future. Cambridge, UK and Laxenburg, Austria: Cambridge University Press and the International Institute for Applied Systems Analysis.

Geller H. S., Harrington, P., Rosenfeld, A. H., Tanishima, S., Unander,F. 2006. Policies for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy, 34:556-573.

Gerding, M.A.W., 2010. Canals and Energy. The relationship betweeen canals and the extraction of peat in the Netherlands 1500-1950. Peatlands International, 2/2010, 32-37.

German Advisory Council on Global Change (WBGU), 2011. World in Transition. A Social Contract for Sustainability.Berlin.

Gierlinger S. Krausmann, F. 2012. The physical economy of the United States of America: Extraction, trade and consumption of materials from 1870 to 2005. Journal of Industrial Ecology, 16:365-377.

Goldstone, J.A., 1980. Theories of Revolution: The Third Generation. World Politics, 32 (3), 425-453.

Gouldner, A. W. 1979. The Future of Intellectuals and the Rise of the New Class. New York: Seabury Press.

Grübler A., 1998. Technology and Global Change, Cambridge University Press, Cambridge.

Gruebler, A., 2004. Transitions in Energy Use. In: Anonymous (Eds.), Encyclopedia of Energy. Elsevier, Amsterdam, pp. 163-177.

Grübler A., 2012. Energy transitions research: Insights and cautionary tales. Energy Policy, 50:8-16.

Haberl H., 2001. The Energetic Metabolism of Societies, Part I: Accounting Concepts. Journal of Industrial Ecology, 5:11-33.

Haberl H., Fischer-Kowalski, M., Krausmann, F., Weisz, H., Winiwarter V., 2004. Progress Towards Sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. Land Use Policy, 21:199-213.

Issawi C., 1978. The 1973 Oil Crisis and after. Journal of Post Keynesian Economics, 1:3-26.

Kander A., 2002. Economic growth, energy consumption and CO2 emissions in Sweden 1800-2000, Lund University, Lund.

Krausmann F., K.-H. Erb, S. Gingrich, H. Haberl, A. Bondeau, V. Gaube, C. Lauk, C. Plutzar, and T. Searchinger, 2013. Global human appropriation of net primary production doubled in the 20th century. Proceedings of the National Academy of Sciences of the United States of America, 110:10324-10329.

Krausmann F., Fischer-Kowalski, M., Schandl, H., Eisenmenger, N. 2008. The global socio-metabolic transition: past and present metabolic profiles and their future trajectories. Journal of Industrial Ecology, 12:637-656.

Krausmann, F., Fischer-Kowalski, M., 2013. Global socio-metabolic transitions. In: Singh, S.J., Haberl, H., Chertow, M., Mirtl, M., Schmid, M. (Eds.), Long Term Socio-Ecological Research. Studies in Society - Nature Interactions Across Spatial and Temporal Scales. Springer, Dordrecht,pp. 339-365.

Krausmann F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M. 2009. Growth in global materials use, GDP and population during the 20th century. Ecological Economics, 68:2696-2705.

Krausmann F., Gingrich, S. Nourbakhch-Sabet,R. 2011. The metabolic transition in Japan: A material flow account for the period 1878 to 2005. Journal of Industrial Ecology, 15:877-892.

Krausmann F., Schandl, H. Sieferle, R. P. 2008. Socio-ecological regime transitions in Austria and the United Kingdom. Ecological Economics, 65:187-201.

Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S., Schellnhuber, H.J., 2008. Tipping elements in the Earth's climate system. Proceedings of the National Academy of Sciences of the United States of America, 105 (6), 1786-1793.

Luhmann N., 1995. Social Systems, Stanford University Press, Stanford.

Lutz, W., W. Sanderson, S. Scherbov. 2001. The end of world population growth. Nature. 412: 543-545.

Maddison A., 2008. Historical Statistics for the World Economy: 1-2006 AD. http://www.ggdc.net/maddison/, online data base.

Mayer, D., 2010. Welten auf den Kopf gestellt: Revolutionen in der Globalgeschichte. In: Sieder, R., Langthaler, E. (Eds.), Globalgeschichte 1800-2000. Böhlau, Wien, pp. 525-550.

Meyers S., Schipper, L. 1992. World Energy Use in the 1970s and 1980s: Exploring the Changes. Annu. Rev. Energy. Environ., 17:463-505.

Mitchell, B.R., 2003. International Historical Statistics Europe 1750-2000. Palgrave Mcmillan, New York.

Möser, K., 2004. Prinzipielles zur Transportgeschichte. In: Sieferle, R.P. and Breuninger, H. (Eds.), Transportgeschichte im internationalen Vergleich. Breuninger Stiftung, Stuttgart, pp. 45-86.

Paige, G. M. 1975. Agrarian Revolution: Social Movements and Export Agriculture in the Underdeveloped World. New York: Free Press.

Pallua, I. 2013. Historische Energietransitionenim Ländervergleich. Energienutzung,Bevölkerung und Wirtschaftliche Entwicklung. Social Ecology Working Paper 148, IFF Social Ecology, Vienna

Pearson P. J. G., Fouquet, R. 2012. Past and prospective energy transitions: insights from history. Energy Policy, 50:1-7.

Pearson, L.J., Pearson, C.J., 2012. Societal Collapse or transformation, and resilience. Proceedings of the National Academy of Sciences, 109 (30), E2030-E2031.

Pfister C., 2010. The "1950s Syndrome" and the Transition from a Slow-Going to a Rapid Loss of Global Sustainability. In: F Uekoetter (Editor), The Turning Points of Environmental History. University of Pittsburgh Press, Pittsburgh, pp. 90-118.

PNAS. 2012. Critical Perspectives on Historical Collapse. Special Feature. Proceedings of the National Academy of Sciences of the United States of America , 109:3628-3681.

Podobnik, B., 2006b. Podobnik energy datasets. Retrieved from Knowledge Network for Energy Transitions. [http://www.netransitions.net/resources/view/165158/, edited by Cutler Cleveland 2011]. I

Polanyi K., 1944. The Great Transformation: The Political and Economic Origins of Our Time, Beacon Press, Boston.

Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: Transition management in public policy. Foresight, 3 (1), 15-31.

Rühl C., Appleby, G., Fennema, J., Naumov, A., Schaffer,M. 2012. Economic development and the demand for energy: A historical perspective on the next 20 years. Energy Policy, 50:109-116.

Schandl H., Schulz, N. B . 2002. Changes in United Kingdom´s natural relations in terms of society's metabolism and land use from 1850 to the present day. Ecological Economics, 41:203-221.

Schandl, H., Krausmann, F. 2007. The Great Transformation: A socio-metabolic reading of the industrialization of the United Kingdom. In: Fischer-Kowalski, M., Haberl, H. (Eds.) Socioecological transitions and global change: Trajectories of Social Metabolism and Land Use. Edward Elgar, Cheltenham, UK, Northampton, USA, pp. 83-115.

SCIENCE 2012. Human Conflict. Special Issue. Science, 336 (6083), 818-879.

Sieferle R. P., 2001. The Subterranean Forest. Energy Systems and the Industrial Revolution, The White Horse Press, Cambridge.

Singh, S.J., Krausmann, F., Gingrich, S., Haberl, H., Erb, K.-H., Lanz, P., Martinez-Alier, J., Temper, L., 2012. India's biophysical economy, 1961 – 2008. Sustainability in a national and global context. Ecological Economics, 76, 60-69.

Skocpol, T., 1979. States and Social Revolutions. A comparative analysis of France, Russia, and China. Cambridge University Press, Cambridge.

Smil, V., 2008. Energy in Nature and Society. General Energetics of Complex Systems. MIT Press, Cambridge, MA.

Smil, V. 2013. Reducing the Carbon and Sulfur Load of the Atmosphere. Assessing Global Decarbonization and Desulfurization and the Future of a Low-Carbon World. GAIA. 22(4): 255-262.

Spinney, L., 2012. History as Science. Advocates of 'cliodynamics' say that they can use scientific methods to illuminate the past. But historians are not so sure. Nature, 488 (2.Aug.), 24-28.

Statistik Austria, 2011. Materialflussrechnung. In: Statistik Austria (Editor).

Steinberger J. K., Krausmann, F., Eisenmenger, N. 2010. Global patterns of material use: a socioeconomic and geophysical analysis. Ecological Economics, 69:1148-1158.

Tainter J. A., 2007. The collapse of complex societies, Sixteenth printing edition. Cambridge University Press, Cambridge.

Tainter, J., Allen, T.F.H., Hoekstra, T.W. 2006. Energy transformations and post-normal science. Energy 31, 44-58.

Tapio P., Banister, D., Luukkanen, J., Vehmas, J., Willamo, R. 2007. Energy and transport in comparison: Immaterialisation, dematerialisation and decarbonisation in the EU15 between 1970 and 2000. Energy Policy, 35:433-451.

Tilly, C., 1978. From Mobilization to Revolution. Addison-Wesley, Reading, Mass.

Trimberger, K.E., 1978. Revolution from Above: Military Bureaucrats and Development in Japan, Turkey, Egypt and Peru. Transaction Books, New Brunswick, N.J.

UNEP, International Resource Panel, 2011. Decoupling Resource use and Environmental Impacts from Economic Growth. UNEP, Paris.

Unger, R., 1984. Energy Sources fort he Dutch Golden Age: Peat, Wind and Coal. Research in Economic History, 9, 221-253.

Verbong G., Geels, F. W., 2007. The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004). Energy Policy, 35:1025-1037.

Warde, P. 2007. Energy Consumption in England and Wales, 1560 -2000. Naples: Consiglio Nazionale delle Ricerche. Instituto di Studi sulle Societa del Mediterrano.

WBGU, German Advisory Council on Global Change, 2011. World in Transition. A Social Contract for Sustainability. Flagship Report. WBGU, Berlin.

Wrigley E. A., 1988. Continuity, Chance and Change. The Character of the Industrial Revolution in England, Cambridge University Press, Cambridge.

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Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs change. The financial crisis has exposed long-neglected deficiencies in the present growth path, most visibly in the areas of unemployment and public debt. At the same time, Europe has to cope with new challenges, ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundation for a new development strategy that will enable a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four-year research project within the 7th Framework Programme funded by the European Commission was launched in April 2012. The consortium brings together researchers from 33 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). The project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

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