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Is there a 1970s syndrome? Analyzing structural breaks in the metabolism of industrial economies

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Abstract

In this paper we focus on long-term socio-ecological transitions from the agrarian to the industrial metabolic regime. Statistical analysis is used to identify structural breaks in the development of energy use in the second half of the 20[th] century. A stabilization of per capita energy and resource use in most high-income countries was reached in the early 1970ies, after a period of accelerated growth of resource use since the end of World War II. Most empirical turns in trend coincide with the oil price crises of 1973 and 1979. This stabilization could offer lessons for a future sustainability transition.

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1. Introduction

The dominant narrative on the course and causes of the industrial revolution and modern economic growth is based on a few powerful concepts which continue to influence individual thinking, discourses and policy on the relationships between energy, society and nature. These ideas are “[...] that economic growth rests on the perpetual increase of fossil energy consumption; that environmental and social costs are neglibible; that natural resources need to be put under private property regimes in order to become productive” [1]. From such a view the industrial revolution and economic growth are seen as a continous

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process of liberation, from natural as well as from moral limits and that technological and institutional ingenuity are the key drivers [1]. This is why human agency expressed in technological innovations is seen as the key factor to distinguish between phases of the process.

Counter these mainstream perspectives of 'progress and liberation' are approaches [1], among others, in environmental history [2,3], the emerging field of long-term socio-ecological research [4] and social metabolism [5]. These systematically link long-term changes in natural and social systems, stressing the unequal distribution of social and environmental costs and benefits and thereby yield a very different perspective also on current global social, environmental and economic change ([6] and the entire special issue in *Global Environmental Change*). At the heart of this alternative approach stands a rejection of "development and economic growth" as an incremental continuous process in favor of a perspective on radical changes in society-nature interactions in history conceptualized as systems transitions. Nature itself plays a more active role: through its processes of conversion and storage of energy it offers particular opportunities and the human utilization of these opportunities marks the decisive historical shifts.

In the next section, we shortly discuss the theory on socio-ecolgical transitions, introduce our methodological perspective and then take a glance at the full course of the transition process into the industrial regime, from pre-development through take-off, acceleration and finally, into stabilization. This requires very long time series, and we can do this only for those four countries for which we can build on such data: the UK, the US, Japan and Austria. In the section thereafter, we will concentrate only on the second part of the transition process: acceleration and stabilisation, and use ten high income industrial countries as cases for a statistical analysis.

2. The socio-ecological perspective on transitions

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 socio-metabolic systems [7], interacting with biophysical systems in the natural environment. Society itself is seen as a structural coupling of a communication system [7] 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 [5], 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. In the tradition of Sieferle [2], we call historically evolving distinct patterns of society-nature interaction "socio-metabolic regimes" [†], which are rooted in the energy system a society depends upon, that is the sources and dominant conversion technologies of energy [5].

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 1 for the agrarian and the industrial regime).

[†]This is a very different use of the term regime than, for example, in the Dutch transitions management theory (see [8] for a detailed discussion).

Table 1: Typical metabolic profiles of agrarian and industrial socio-metabolic regimes (see methods section for the definition of the indicators used in this table). [9]

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

During the socio-ecological transition between the agrarian and the industrial regime per capita domestic energy consumption (DEC) and domestic material consumption (DMC) increase by a factor of 3 – 5. The importance of biomass as energy source decreases from a share of over 95% in DEC to around 10 - 30%, when fossil fuels become dominant. Compared to biomass, fossil fuels offer highly favorable features, one of the most most important being their high energy density, both in terms of energy content per unit of mass and energy supply density per unit of area [10]. Absolute biomass consumption, though, does not decrease, as it is strongly linked to population size in the form of food demand [11], 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% [9,12]. Growth in agrarian regimes is mainly population driven, with the consequence that it generally leads to a decline in energy and material use per capita. Industrial growth in contrast is based on both population growth and a surge in per capita use of natural resources [9,12]. A more sustainable future industrial sociometabolic regime – say a sustainable or a low carbon society – cannot possibly continue along this energetic and biophysical growth path and will require a next transition towards substantially less materials and energy use [13].

In this contribution, we will make an effort to analyse the course of the transition into, and possibly also out of the industrial socio-metabolic regime. The typical model of alternating phases in transition processes is the so called S-curve model, where a pre-development is followed by a take-off into the transition, which rapidly accelerates and eventually stabilises again (Figure 1).

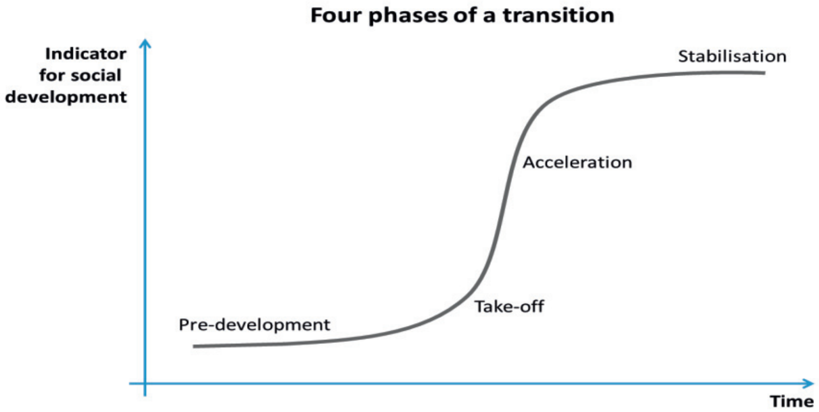

Figure 1: The typical phases of a transition [14]

From such a perspective 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. These distinctions are extremely sensitive to the observer's choice of scale. Gradual processes may well be nested into the larger dynamics. Nevertheless, the idea of a system gradually behaving ever more sustainably (as suggested in theories of ecological modernization sometimes) does not comply with the notion of transition as used here – we need to look for structural breaks in the trends of long-term developments to capture these four phases. The scale we choose in this analysis is therefore very large: we look at national economies as units of analysis, and at a time scale of decades and centuries.

2.1. The material and energy flows accounting framework (MEFA)

The data used for this work is derived from material- and energy flow accounting (MEFA, [15]). MEFA allows for the calculation of 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 that is, the primary energy sources for the provision of human work and draught power ([16]). 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 [16].

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 [17] and [15]. We use four long term DMC series available from the literature (USA 1870-2005 [18] , Japan 1879-2005 [19], UK 1870-2005 and Austria 1960-2010 based on [20]). 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., [21]; [22]; [23]) which have been updated and extended (e.g. for lacking biomass components) to calculate DEC [24], with biomass data from [25].

2.2. The long course of the socio-metabolic industrial transition

The transition into the industrial regime can take several centuries, or it may happen much faster; still fairly similar patterns of pre-development, take-off, acceleration and eventually stabilization can be identified. We demonstrate this for the OECD economies UK, USA, Austria and Japan (Figure 2).

The prime example for the transition from the agrarian to the industrial regime is of course the United Kingdom, which lasted about 350 years (Figure 2) and [2,12]. Already in the 17th century the use of coal began to spread, gradually substituting for dwindling wood supplies and allowing for textile manufacturing in growing urban centres. Much later, with the diffusion of the iron - steam engine - railroad complex [26], we can see a second take-off of industrialization in the more common sense of the word and a first acceleration phase from the mid-19th century onward. This early phase takes a fairly similar course for all three indicators of energy and materials use and GDP (per capita and year, Figure 2). A next acceleration began after World War II (WWII), through the expansion of the oil – steel - auto cluster, together with electricity [26]. This also marked the beginning of mass production and consumption and can be looked upon as "the" acceleration phase of the industrial transition, which has also been termed "1950s syndrome" [27], characterized by rapid biophysical and economic growth. But in the 1970s this seems to have ended and a per capita stabilization at high levels set in.

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 2). 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) 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 [18].

In Austria the transition took off in the second half of the 19th century (Figure 2 and [12]). 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 the beginnings of mass consumption led to an exponential increase of materials and energy use. As in the other industrial economies, resource use stabilized in the 1970s, while economic growth continued (Figure 2).

The Japanse transition is highly interesting because of its rapidity and because Japan is one of the few cases where absolute decoupling of economic growth from materials use has been observed [19]. 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 2). 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 1970s (Figure 2).

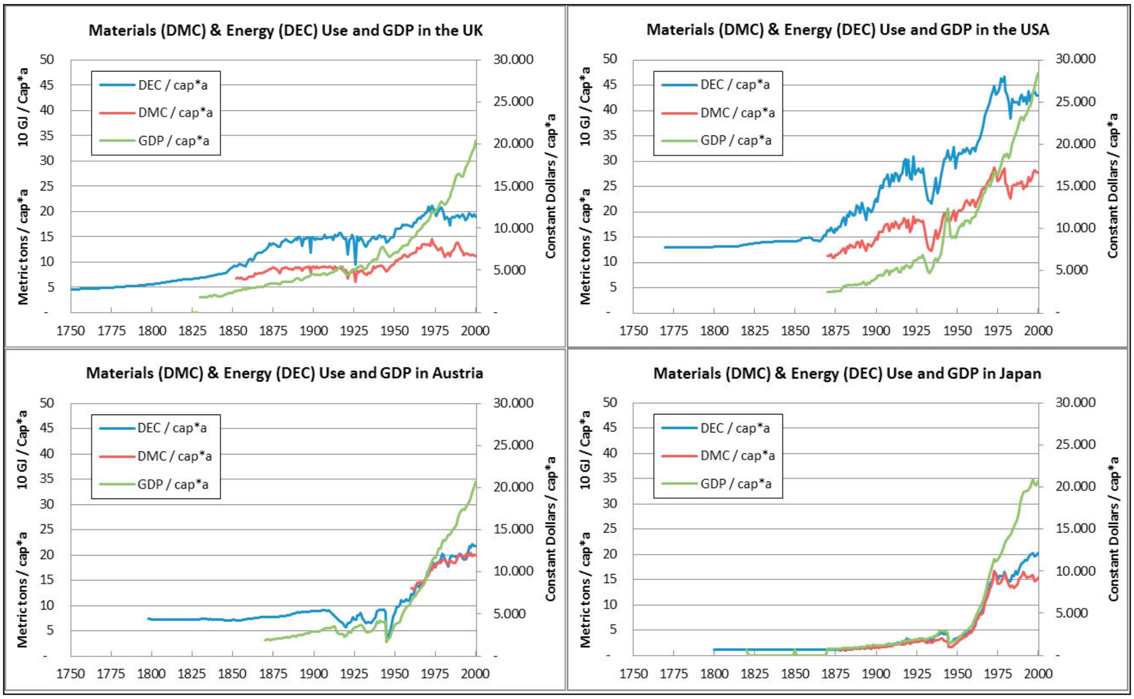

Figure 2: The socio-metabolic transition in the UK, USA, Austria and Japan, from 1750 – 2000 ([12,18,19,24] and [28] for GDP and population), Domestic energy consumption (DEC) in 10 GJ/cap/y, domestic material consumption (DMC) in t/cap/y and GDP in international constant 1990 Gheary Khamis Dollars. All indicators are per capita values; Rapid population growth translates into much steeper accelerations and increases of energy and materials use as well as GDP.

Interestingly not just for these four countries (Figure 2), 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 increase stabilize at a high level between the early 1970s and the late 1990s, after two and a half decades of fast growth [29,30].

2.3. The stabilization of the transition into the industrial regime in the 1970s: a statistical analysis

We attempt a first step towards clarification by identifying the timing when exactly these structural breaks occurred. For this purpose we use data for 10 major economies of the time (Austria, France, Germany, Italy, Japan, Netherlands, Sweden, United Kingdom, USA and the USSR – Table 2). For each country we adopt the following linear model:

$$DECpc_t = \alpha + \beta t + \varepsilon_t \tag{1}$$

where $DECpc_t$ stands for annual country's per capita domestic energy use at year t (Table 2); ε_t are errors; unknown parameters α and β are to be estimated. When estimating (1) by means of Ordinary Least Squares method (OLS), we found the values of the Durbin-Watson (DW) [31] statistics to be rather low. They usually fell below a lower critical value for the DW statistics respective to the number of data points (in econometric literature denoted by d_l) corresponding to the 1% significance level.

As this indicates significant positive autocorrelation of residuals, we carry out the necessary adjustments by introducing the first-order autocorrelation model for errors ε_t and supplementing it by the first-order moving average model; the combination of the two latter assumptions on errors gives $ARMA\,(1,1)$ model for errors. After re-estimation of model (1) given $\varepsilon_t \sim ARMA(1,1)$, updated values of the DW statistics indicate that autocorrelation of errors was successfully eliminated. Namely, they fall into the interval between d_u and $4 - d_u$ (respective to the number of data points and corresponding to the 1% significance level). The $ARMA\,(1,1)$ model of errors also improved the values of the coefficient of determination. Table 2 summarizes the outcome diagnostics which is convincing with respect to the model's validity. In a second step, we test the hypothesis of a structural break in the 1970s, assuming that it affects both model's parameters, the slope β and the intersection α. As pointed out by Hansen [32], structural breaks in complex socio-economic systems are unlikely to be immediate, but rather take several years to take effect. In terms of model (1) it can be interpreted so that during the structural break's period the model's parameters are changing gradually. Clearly, with certain accuracy this gradual change can be approximated by a step-wise constant function. In other words, one can assume an abrupt change in model's parameters with an unknown breaking point which allows for the application of the standard econometric methodology – the Chow test [33] - to explore structural changes. However, due to the fact that for the step-wise constant parameters a particular year of the break cannot be known a-priori, we carry out the Chow test sequentially assuming a break to occur in each year from 1960 until 1980. For each break year, the data series is partitioned into two sub-series. Null hypothesis is introduced by implying no break to occur in the considered year. Following [32], we track the F-statistic associated with each partition given null hypothesis against F-statistic critical values given significance levels

Table 2: Time series properties, sample size, goodness-of-fit and autocorrelation test

	Time Series		Diagnostics	
	1945 – End	n	DW	R^2
UK	2000	56	1,7	0,88
USA	1996	52	2,0	0,93
Austria	2010	66	2,1	0,98
Japan	2006	61	2,0	0,99
France	1997	53	2,0	0,98
Germany	1997	53	2,9	0,98
Italy	1997	53	2,0	0,99
Netherlands	2003	59	1,9	0,97
Sweden	2000	56	1,8	0,97
USSR	1991	47	1,8	1,00

5% and 1%. In order to unify the representation of the results, for each partition we report the corresponding P-value, i.e., the probability of observing F-statistic as extreme as (or more extreme than) the one actually observed, provided the test statistic really were distributed as it would be under the null hypothesis. The P-value is then expressed of the probability of a structural break occuring, with a 99% confidence intervall choosen where the test rejects the null hypothesis of no structural break (Figure 3).

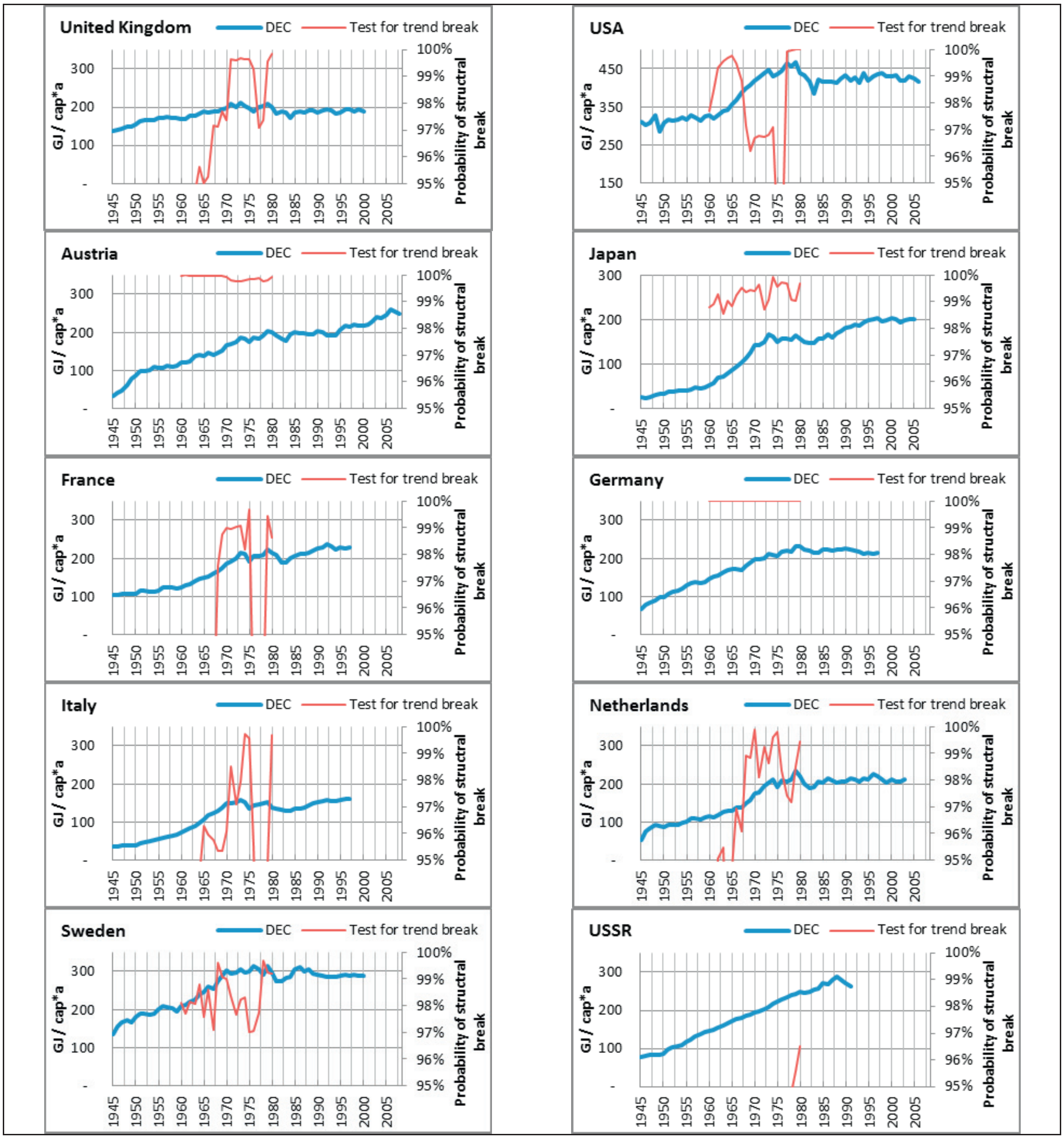

Figure 3: Testing for the timing of structural breaks between the acceleration and stabilization phases of the socio-metabolic transition. Time series for per capita domestic energy consumption (DEC) are presented with the same scaling of 0 – 350 GJ/cap*a, except the USA which is shown at 150-500 GJ/cap*a (showing the same range). Iterative chow tests were applied for each year from 1960-1980, with the red lines indicating the probability of a structural break on the secondary axis. Interpretation at the 99% level is preferred in oder to not over-estimate the number of breaks (see method section).

3. Discussion of results

For 9 out of the 10 countries investigated, the probability of a structural break in the time series is higher than 99% in at least one of the years of 1960 – 1980 (Figure 3). The major exception is the USSR: it shows nearly linear increases of per capita energy use until its collapse in 1991. The problem with this test, though, is its over-sensitivity: for Germany and Austria, for example, it identifies a significant structural break every year. In our case, we are only interested in those trend breaks from a steep increase (the acceleration) towards a stabilisation, which are also significant at the 99% confidence intervall. We then arrive at a cumulative frequency distribution across time as shown at the bottom of (Figure 4).

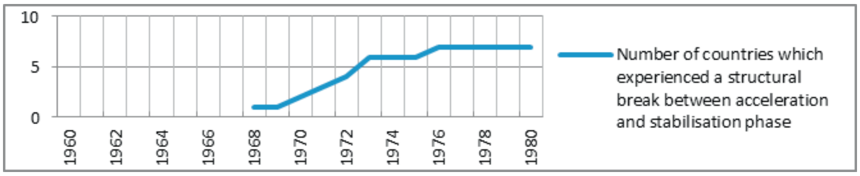

Figure 4: Cumulative number of countries which experienced a structural break in their domestic energy consumption (DEC). See method section for detailed description.

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 exterrnal signal to trigger the trend change in energy use, but an extended period of change.

But what happened in the 1970s, across so many countries around the world? An endogenous saturation of consumerism and lifestyles? The end of a long-term economic wave [34] ? A structural change in the workings of the economic growth engine [35]? Increasing and increasingly volatile oil prices during 1973 – 1980's changing firms decisions making which, supported by government subsidies, invested into energy efficiency [36]? Forced outsourcing of energy intensive production processes to developing countries? A destabilization of the prevalent model of progress triggered by the 1968 movements worldwide and underpinned by the newly discovered "Limits to Growth" [37]? These are all questions for ongoing research.

4. Conclusions

For the few countries where sufficiently long data series for ressource use are available we could demonstrate an S-shaped transition curve, across 150-300 years. What is even more surprising is that in high income industrial countries the 1970s marked the beginning of a stabilisation phase of energy and material consumption per capita, while economic growth continued. Our efforts to identify the exact timing of the turn from the previous trend towards ever higher per capital energy and materials consumption are not entirely conclusive yet, as we find turning points scattered in the 1970s. This could be an indication that is not very plausible to assume that one single cause – such as the first and/or second oil price shock – has triggered this lasting structural change, although we assume that the oil price shocks must have played an important role in inducing stronger efforts at increasing energy efficiency of businesses, the residential housing stock and transportation systems. 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"[13].

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