sustainability

Article

Latecomers to the Fossil Energy Transition, Frontrunners for Change? The Relevance of the Energy 'Underdogs' for Sustainability Transformations

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Abstract: The global energy system subsumes both extreme wealth (and waste) and extreme poverty. A minority of the global population is consuming the majority of the fossil fuel-based energy and causing global warming. While the mature industrialized economies maintain their high levels of energy consumption, the emerging economies are rapidly expanding their fossil energy systems, emulating traditional patterns of industrialization. We take a global, socio-metabolic perspective on the energy transition phases—take-off, maturation, and completion—of 142 countries between 1971 and 2015. Even within our global fossil energy system, the transition to fossil energy is still ongoing; many countries are in the process of replacing renewable energy with fossil energy. However, due to globally limited supplies and sinks, continuing the fossil energy transition is not an indefinite option. Rather than a "Big Push" for renewable energy within pockets of the fossil energy system, a sustainability transformation is required that would change far more than patterns of energy supply and use. Where this far-reaching change requires pushing back against the fossil energy system, the energy underdogs—the latecomers to the fossil energy transition—just might come out on top.

Keywords: energy supply; international inequality; renewable energy; fossil energy system

1. The Fossil Energy Transition

> " ... the capital city became the victim of repeated visitations of a thick, yellow, sulphurous vapour that plunged the streets into darkness, choked the lungs, and turned day into night." [1]

> " ... as the sun rose, still the fog didn't disappear, and the visibility was even less then. Everyone around has an uneasiness in their throat due to this kind of smog. Our next step is to keep ourselves inside and step outside only when it is important." [2]

Anthropogenic climate change may not have been on the mind of 19th century Londoners, but the local impacts of fossil fuel combustion certainly were. Today, the deadly smog for which London was renowned hangs over New Delhi (described above) or Beijing [3]. We know that—due to the physical limits to supply—our fossil energy systems have an expiration date [4–6] until which they will have detrimental environmental impacts [7,8]. However, none of this has deterred high and growing reliance on fossil fuels—such as oil, coal, and natural gas—for societies' energy supply [9]. The development of capital-intensive infrastructures and the power-infused institutions of the fossil energy system [10,11] have ushered in “the age of oil” [12] with its “fossil economies” [13].

Under intensified globalization and a rigorous international division of labor, it is no contradiction that this global system subsumes both extreme wealth (and waste) and extreme poverty when it comes to energy. At the turn of the century, 15% of the world population in the Global North used approximately the same amount of energy as the 85% of the population living in the Global South [14]. In 2013, one-tenth of the population caused more than half of the global greenhouse gas emissions [15]. While the mature industrialized economies maintain their high levels of energy consumption, the emerging economies are rapidly expanding their fossil energy systems, emulating traditional patterns of industrialization [16]. Technologies for (renewable) energy are now available that did not exist when the industrialized countries embarked on their energy transitions. But these are not enough of a springboard to leapfrog the colossal fossil energy system [17]. Alternative energy technologies themselves require a boost over the critical barriers posed by the infrastructures and institutions of the fossil energy system [18,19] and the inertia of the fossil energy transition [20]. To enable an alternative energy system, the built infrastructures—predetermining energy demand for decades to come [21]—and the vested, institutionalized interests of powerful political and economic actors [12,13,22] of the fossil energy system would have to be abandoned [10].

Instead, the fossil energy system is solidified by investments and subsidies, and the politics that favor these transactions. Trillions of dollars are globally being earmarked for energy infrastructures in Europe and the United States of America, as well as in countries with much lower energy access [23]. Development banks and private sector companies identify investment opportunities wherever the fossil energy transition has not yet been completed [24,25], and even economies diversifying domestic energy supply favor the fossil energy system in their investment choices. Chinese banks, for example, have surpassed the World Bank in their investments into the infrastructures of coal-fired power plants [26]. High subsidies for fossil energy supply and consumption and the tit-for-tat between mines and power plants maintain a cheap energy source [11,27], despite the associated social and environmental ‘costs’, and often make it difficult for renewable energy to compete. Despite the unsustainability of the fossil energy system, it is increasingly being bartered politically, in fully industrialized [28] as well as emerging economies [29].

1.1. Renewable Energy in the Pockets of the Fossil Energy System

Compared to the urgency with which a fundamental change to the energy system is now required [7,30,31], the formidable fossil energy system has had a long time to develop. The take-off phase of historical fossil energy transitions alone lasted 58 years on average, and was not systematically shorter for the countries that began their transition later. Only the very early development of fossil infrastructures in the United Kingdom and the Netherlands took longer and provided all other countries with a bit of a piggy-back ride on their innovations [32]. The transition to a fossil energy system is pursued not as a goal in itself, but was and is the by-product of political and economic development enabled by technological innovation and motivated by opportunities to make a profit [33]. In contrast, a transition away from fossil fuels and toward renewable energy would in itself constitute a goal, allowing for big challenges such as climate change and energy security to be met [34,35]. So far, this difference has not materialized as the rapid adoption of renewable energy that might have been hoped for [36]. In the mature industrialized economies, it has taken strong, continuous political and economic support alongside country-specific cultural attitudes and/or resource endowment to allow for renewable energy to develop in pockets of the fossil energy system. By 2015, the German effort to change the tide with an *Energiewende* [37] had amounted to 12% renewable energy in the total primary energy supply (TPES). Higher shares were achieved by countries boasting a unique combination of resource endowment and political will (Sweden: 42%, Iceland: 88%). However, none of these countries have renewable energy systems. What they do have are renewable energy projects within a fossil energy system. The state-owned Swedish power company *Vattenfall* owns and operates almost 100 hydroelectric plants in Sweden, but hydropower only accounts for 30% of the "Waterfall's" electricity generation [38], in which coal and gas play an important role. Iceland has the world's highest electricity generation per capita, which is almost exclusively from geothermal and hydro power plants [39], and mostly used in aluminum smelters [40]. After buildings, the bulk of aluminum is globally engaged in transportation [41], such as in automobiles and airplanes, for example, guzzling fossil fuel.

Countries in which traditional biomass (mainly fuelwood) plays an important role in energy supply have high renewable shares at very low levels of total energy supply per capita; these include Ethiopia (93% renewable in 2015), Tanzania (84%), and Ghana (43%) [40]. The high share of fuelwood limits the possible total energy supply [42] and access to energy is low, especially in sparsely populated rural areas [43–45]. Decentralized electricity generation from renewable sources has been championed as a safe, sustainable, and even cost-effective way to address energy poverty [29,46–48]. However, within the global fossil energy system, renewable energy has had to fall in line with existing power grids and energy use patterns and established institutions and interests [49–52].

1.2. A "Big Push"—But Where?

In 2017, the US–American Energy Information Administration released its International Energy Outlook. One of the major sights on its horizon was how growing Chinese energy consumption would dominate increases in global energy consumption [53]. For many, it was and is a terrifying trifecta: An energy-"hungry" China [54] on the prowl [55], peak oil [5,31], and anthropogenic climate change [8]. The projections according to which population—as an important driver of energy demand—would grow in (energy poor) countries not members of the Organisation for Economic Co-operation and Development [53], conjured a question with unthinkable consequences: billions of people aspiring to US–American levels of energy consumption?

The narrative of the "Big Push"—large-scale, foreign-financed investment to grow countries out of their "poverty trap"—had been making a convenient comeback [56] and was brought into play against energy hunger: Could a "'Big Push' [...] to scale up renewable energy in the developing world" prevent countries "get[ing] locked into cheaper, dirtier fossil fuels, [with] no chance of meeting global CO2 reduction targets"? The article from which this question stems [57] is illustrated by an image of a modern-day Sisyphus (cf. Figure 1) in a business suit pushing a boulder up a steep incline. In the world of Greek mythology, that boulder would never reach the top of the hill, but would present our businessman with an afterlife of work and frustration—punishment for having bested the gods. And in the modern-day world? Can a "Big Push" transform our energy system?

Figure 1. "With mighty labour" Sisyphus rolls a millstone up a hill. As soon as he reaches the top, the stone rolls back down, providing him with the opportunity "to keep imployed his afflicted soul" [58].

Energy transitions—from the passive use of solar energy by hunters and gatherers to the active harnessing of that solar energy in agrarian society and the use of fossil fuels in the industrial society—involve fundamental societal transformations of how people live and work, the communities they form, societal values and norms, power relations and hierarchies, and societies' relation to nature [59]. As part of a sustainability transformation, transitions to renewable energy systems will entail equally fundamental societal change, including how much energy we use and for what and how we live and work and organize our societies. Limited to an existence in pockets of the fossil energy system, a "Big Push" for renewable energy might well be a Sisyphusian endeavor.

Push as we may, there is no "quick fix" [60] to the inherent unsustainability of our global resource use patterns. In order to produce knowledge for sustainability transformations, science must address the underlying causes, not only the symptoms, of unsustainability [61]. What we have to offer is a socio-metabolic reading of *currently ongoing energy transitions* with the motivation that better understanding the symptoms of unsustainable development may help in the identification of possibilities for intervention [62]. It seems imperative to have a better idea of what we are up against before we push for change. While it may be clear that the energy system will have to fundamentally change in a sustainability transformation, it is essential to be pushing for change in the right direction. The boulder we're pushing shouldn't roll back to crush those at the bottom of the hill and everyone along the way; renewable energy development shouldn't solidify the fossil energy system.

In that sense, we have our eye not on the transition to renewable energy, but rather on the *transition to fossil energy*. For the period between 1971 and 2015, we examine energy supply patterns for three major country groupings: (1) those countries for which the take-off period of their fossil energy transition falls within this period; (2) those accelerating their transition and maturing their fossil energy systems; and (3) those that have completed this transition. These three groups are in themselves highly heterogeneous, and it is not our aim to provide a definitive analysis of the energy transitions at the national level, much less the subnational, level. The socio-metabolic perspective that we take allows us to show that while we may be eyeing renewable energy, the currently ongoing transition is one to fossil fuels. This seems important in determining where we need to push (back). We focus on the latecomers to the fossil energy transition, referring to them as the 'underdogs' to indicate that in the uphill struggle for a sustainable transformation of not only the energy system, our support lies with the people of these countries. It appears to us that in the deliberation of sustainability transformations, the role of these countries—with their extremely low per capita energy supply—is crucial but often overlooked.

2. Materials and Methods

For our socio-metabolic analysis of energy transitions, we required quantitative data on the amount and composition of primary energy supply per country. We were able to include 142 countries in our sample, achieving good representation of the world population for all of the years between 1971 and 2015 (see Section 2.2). We grouped these countries according to quantitative data on energy supply [40] and on the corresponding phase of their energy transition (see Section 2.1).

2.1. Energy Transition Phases

Following Rotmans et al. [63], we assume that the energy transition, similar to other societal transitions, has four phases of development: (1) predevelopment; (2) take-off; (3) acceleration, and (4) stabilization. The take-off period for the transition to fossil fuels (and later also other modern energy sources, including nuclear) tends to occur at levels of domestic modern energy use between 0.47–7.71 Gigajoules per capita (GJ/cap). This range was identified in the analysis of a large country sample (representing approximately two-thirds of the global population) in a long time series (beginning as early as the 15th and as late as the 18th century) [32]. During the following phase of acceleration of modern energy use and maturation of the energy transition, domestic energy consumption increased up to 50 GJ/cap. In the 20th century, the fossil energy transition in the industrialized economies was largely completed, and modern energy consumption was stabilized. The fossil energy system is global [12,13], but this does not mean that all of countries have concluded their energy transition. In particular, we identified the countries that are latecomers to the transition to fossil fuels, i.e., those for which the take-off period has not yet been concluded by 1970. In this grouping, we included all of the countries with fossil TPES below 8 GJ/cap in 1971. Other countries are still maturing their energy transition, with energy supply above 8 GJ/cap (but below 50 GJ/cap). In this grouping, we included all of the countries in which the fossil TPES grew continuously from above 8 GJ/cap. This acceleration phase applies to many of the successor states of the Soviet Union which had high energy supply from fossil fuels (above 50 GJ/cap) in 1991—indicating a completed energy transition—but then experienced a collapse of their energy systems, and have been accelerating again since and subsequently re-building these energy systems. Countries appearing to be at the precipice between take-off and acceleration with energy supply clearly above 8 GJ/cap but not (yet) continuously growing were classified as maturing energy transition if an energy supply above 8 GJ/cap dominated the time period between 1970 and 2015. Those countries were considered as having completed their fossil energy transition that had fossil TPES above 50 GJ/cap. Table 1 provides an overview of the three country groupings.

Table 1. Between 1970 and 2015, most people lived in countries that either were latecomers to the fossil energy transition or were in the process of maturing that transition, based on their fossil total primary energy supply (TPES). Very high fossil energy consumption following the completion of the energy transition was experienced by only one-fifth of the global population.

Group	Description	N	Population 2015
Late energy transition, *energy underdogs*	Take-off phase of per capita fossil TPES (0.4–8.0 GJ/cap) within 1970–2015 time range	39	3.1 billion people 42% (of world) 44% (of sample)
Maturing energy transition	Transition from above 8.0 to below or equal 50 GJ/cap fossil TPES between 1970–2015	44	2.5 billion people 34% (of world) 35% (of sample)
Completed energy transition	Above 50 GJ/cap fossil TPES during entire 1970–2015 period	59	1.5 billion people 21% (of world) 21% (of sample)

In order to identify the latecomers to the fossil energy transition, it was necessary to define this grouping according to whether the countries were below 8 GJ/cap fossil TPES at *any point* during the period. For the other two country groupings, we included five countries (Algeria, Bosnia and Herzegovina, China, Iraq, and Mongolia) that did not reach 50 GJ/cap until the 2000s in the maturing energy transition and five countries (Cyprus, Greece, Hong Kong, Republic of Korea, and Libya) that reached above 50 GJ/cap during the 1970s in the completed energy transition. With the exception of China, the individual or collective re-assignment of these countries to the respective other possible grouping would not have a significant impact on our results. Which grouping China belongs to significantly affects the per capita results. Since China did not supply more than 50 GJ/cap of TPES from fossil sources until 2005, and 88 GJ/cap in 2015 (compared to 147 GJ/cap in the completed energy transition grouping without China), we considered the maturing period to clearly dominate our period of investigation. This affects the interpretability of our results.

We present and discuss the very heterogeneous energy transition groupings as wholes throughout the article. To make the lack of homogeneity more transparent for our focus on the energy underdogs, we also provide information on ranges of variables within the group. Although the energy underdogs share the trait of still being in the early transition phase to a fossil energy system in the period between 1970 and 2015, their transitions are by no means synchronized.

2.2. Data

Data on national TPES from fossil (coal, oil, natural gas), renewable, and other (mainly nuclear) sources were extracted from the International Energy Agency's World Indicators [40]. These data were available in time series for a sample of 142 countries, accounting for more than 90% of the world population at all points in time between 1970 and 2015 (and until 2050 in the United Nations' low variant population growth projection [64]).

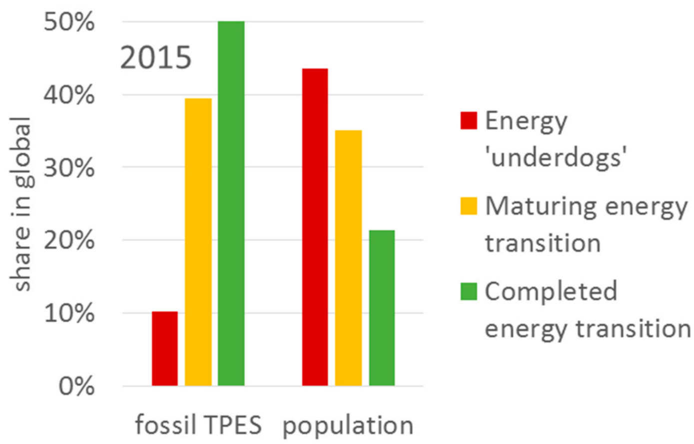
Throughout the article, we refer to the shares of the three country groupings in the total sample as global shares, and ask the reader to bear in mind that—because approximately 10% of the global population is missing from our sample—true global shares would be slightly lower than the sample shares that we discuss (Table 1).

3. Fossil Energy: A Global System that Cannot Be Universal

An energy transition to lower energy use increasingly met from renewable sources must form part of a sustainability transformation. And yet, the fossil energy system is solidified rather than challenged through the combination of sustained high levels of fossil energy supply in the mature industrialized economies, the rapid growth of fossil fuel use in the maturation of the energy transition, and decreasing shares of renewable energy in the transition latecomers.

3.1. Low Energy Supply in Fast-Growing Underdogs

More than 3 billion people—44% of the world's population—live in countries with a late take-off phase of the fossil energy transition and only 10% of global fossil energy supply. Half as many (1.5 billion) live in countries with a complete transition to fossil fuels supplying five times as much primary fossil energy (Figure 2). Per person, fossil TPES in the energy underdogs amounts to one-tenth of that in the countries with a completed energy transition. These international disparities challenge us to identify barriers to more equitable resource distribution: if energy supply in the countries with a completed energy transition could be reduced to half its current level, supply in the energy underdogs could be increased by a factor of 3.5 without increasing global supply, all else remaining equal.



Energy transition underdogs
3.1 billion people
48.6 EJ fossil TPES
15.8 GJ_{FF}/cap
Maturing energy transition
2.5 billion people
188.0 EJ fossil TPES
76.2 GJ_{FF}/cap
Completed energy transition
1.5 billion people
239.8 EJ fossil TPES
159.3 GJ_{FF}/cap

Figure 2. In 2015, the energy underdogs had the lowest share in global total primary energy supply (TPES) from fossil fuels and the highest share in population, while the 21% of the global population that was living in countries that had completed their fossil energy transition accounted for 50% of global fossil TPES. Source of data: International Energy Agency [40].

International inequality in energy supply persists despite gradual reductions since the 1970s of per capita fossil fuel supply in the countries with a completed energy transition and an increasing per capita supply in the underdogs (Figure 3). At only 3.8 GJ/cap in 1971, fossil TPES in the energy underdogs was at a very low level (compared to 14.9 GJ/cap for the maturing and 170.9 GJ/cap for the completed energy transition). At an average of 2.2% per year, population in the energy underdogs grew more strongly than in either of the other two country groupings (1.4% and 1.3% per year). Growth in fossil TPES (averaging 5.5% per year), however, was comparable to that in the countries with a maturing energy transition (5.2%). Only in those countries that had already completed their energy transition did population growth surpass growth in fossil TPES on average, causing a slight decline in the per capita values.

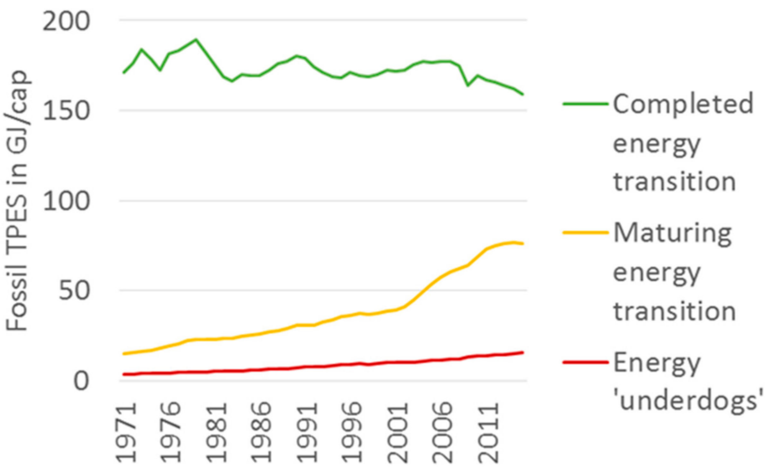


Figure 3. Between 1971 and 2015, fossil total primary energy supply (TPES) in Gigajoules per capita (GJ/cap) stagnated at a very high level in the countries that had completed their energy transition by 1970. The countries in the maturation phase of the energy transition were characterized by high fossil TPES and low population growth, causing per capita values to increase strongly. While fossil TPES growth was even slightly higher in the energy underdogs, their higher population growth and very low initial values did not translate this into the same high per capita gains. Source of data: International Energy Agency [40].

Fossil energy supply beyond 20 GJ/cap is not systematically related to improved access to electricity, but rather to higher levels of consumption [65]. While even well below 20 GJ/cap, countries may provide high levels of access to electricity (in 2015: Tajikistan at 7 GJ/cap, Paraguay at 12 GJ/cap, and Pakistan at 13 GJ/cap, for example), rates of access below 50% are common among the energy underdogs (in Angola at 10 GJ/cap and the Republic of the Congo at 13 GJ/cap, for example). Especially in rural areas and at the fringes of urban areas, unreliable or a lack of access to electricity represents energy poverty with its many implications for the education, health, nutrition, and safety of the population [44,45]. This is not to say that increased energy supply would automatically translate into better energy access and associated improvements for the population. In countries that are integrated into the global economy as suppliers of cheap raw materials and/or labor, the opposite may be true, with gains in energy supply representing increased industrial production for export.

3.2. From Renewable to Fossil Energy and Back? Composition of Energy Supply

Not only the level of fossil energy supply, but also the role it plays in overall energy supply is telling in terms of energy transition phases. Despite the considerable development of renewable energy sources and the increased use of nuclear energy, the energy system in the countries that have completed their transition to the fossil energy system remains dominated by fossil fuels (83% of TPES in 2015; Figure 4). The energy underdogs were characterized by high shares of renewable and low shares of fossil energy in their (comparatively very low) total primary energy supply, especially at the beginning of the period under investigation here. By 2015, the composition and per capita level of energy supply in the underdogs were comparable to the 1971 values for the countries maturing their energy transition.

Can we expect the energy underdogs to do in the next 50 years what the maturing transition countries did in the last half century? Given the biophysical constraints on supply and sinks, this appears increasingly unlikely. As those countries with a maturing energy transition add claims to fossil resources for which demand is already high from the countries with a completed transition, reserves are depleted, and anthropogenic climate change is exacerbated. Between 1971 and 2015, the maturation phase of the energy transition consisted of increasing the energy supply by 64 GJ/cap. The contribution of fossil energy to this growth was almost 15 times as high as the contribution of renewable energy. The completion of the energy transition has—thus far—been characterized by very high levels of energy supply that keep up with low population growth mainly through increased fossil energy use with small contributions from renewable and nuclear energy. Individual countries that strongly decreased the share of fossil energy in their supply were generally able to do so based on a combination of renewable and nuclear energy sources (e.g., France, Switzerland, and Sweden). Only three countries (Iceland, New Zealand, and Norway), representing 0.7% of the population in the grouping with a completed energy transition, currently feature very high levels of renewable energy. Not only is this a small pocket of the world, it is also a pocket of the global fossil energy system. All three countries use hydro and/or geothermal power to generate electricity. Iceland and New Zealand rely on extensive fossil energy systems elsewhere (of which Norway is an example) as sources of their imports of petroleum and natural gas [39]. Neither the economic trajectories nor the resource endowment of these countries can be generalized, not even amongst the high-income industrialized economies. For the majority of the countries in our sample, representing over 90% of the global population in 2015, high shares of renewable energy and high levels of energy supply are incompatible. There is no blueprint for the underdogs to follow.

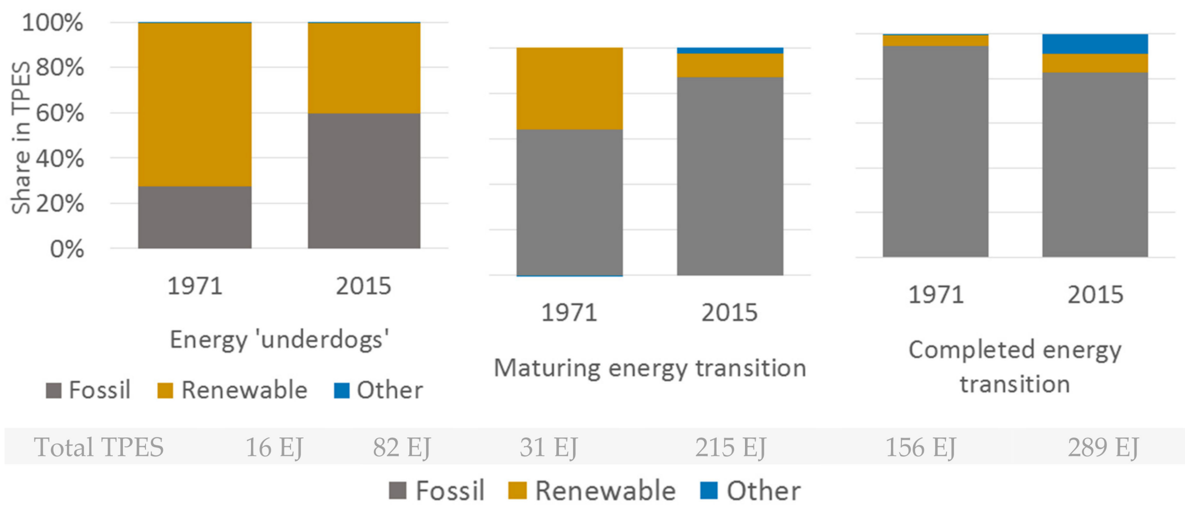


Figure 4. Between 1971 and 2015, the share of renewable sources in the total primary energy supply (TPES) increased only in the countries with a completed energy transition. Here, other energy sources (almost exclusively nuclear energy) have also become relevant. The energy underdogs are characterized by high shares of renewable energy, while the maturing energy transition was marked by renewable energy shares displaced by fossil fuels. In absolute terms, growth in renewable energy supply (in 10^{18} Joules or Exajoules EJ) was most substantial in the energy underdogs, while fossil energy supply increased most strongly during the energy transition maturation phase. Source of data: International Energy Agency [40].

Far be it from us to cite the inherently bad example of the fossil energy transition as pursued by the world's wealthy and wealthier countries as grounds on which the world's poorest countries must not pursue the same path. However, it does appear that the patterns of fossil energy use until today have strained and drained our global environment and its resources to the extent that the option of completing the fossil energy transition will not present itself to all countries [4–6].

3.3. What Would it Take? Thoughts on Completing or Abandoning the Fossil Energy Transition

If the underdogs' fossil energy supply were to continue growing by 3.3% per year as it has done on average since 1971, these countries would embark on the maturation period of their fossil energy transition by 2050, reaching an average of approximately 50 GJ/cap of fossil TPES. Even if the countries with a completed energy transition continue to gradually reduce their fossil TPES and the countries now in the transition maturation follow suit, two things would have happened by 2050:

(1) The energy underdogs would still be global underdogs, with half of the per capita fossil energy supply of the transition maturation countries, and one-third of the supply of the countries with a completed energy transition.
(2) Limited reserves and dire environmental consequences of the continued fossil energy transition would—if they had not precluded this development altogether—mean that this transition would occur under conditions of extreme competition in a hazardous, toxic environment.

If the phases of the fossil energy transition were to play out globally, fossil TPES would reach just below 700 EJ/a in 2050 (Figure 5), and would be twice as high as the 350 EJ that have been determined as not altogether eliminating the chances of curbing anthropogenic global warming to two degrees [7]. Our very rough, conservative estimation is based on the United Nations Department of Economic and Social Affairs [64] low variant population forecast until 2050, and would be even higher if we had assumed stronger population growth. What it would take, only in terms of fossil fuel supply, in order for countries to continue along the path of the fossil energy transition, will not realistically be given, or, if so, it will be given under highly adverse conditions.

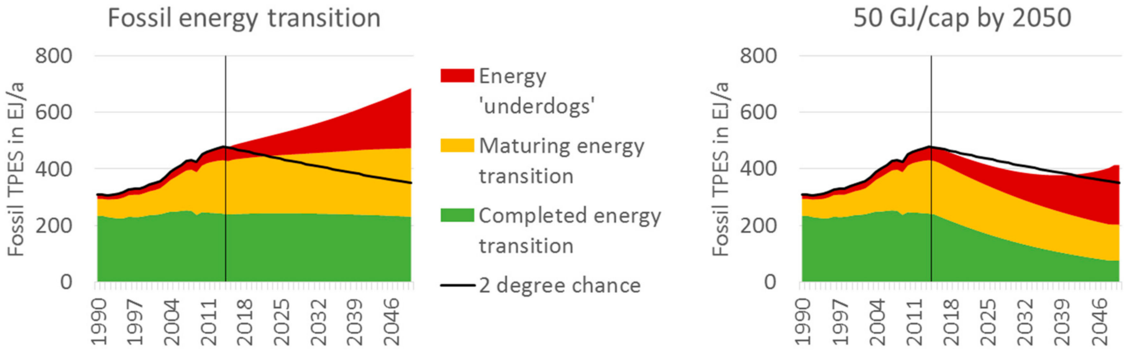


Figure 5. In order for the fossil energy transition to continue (left-hand side), almost 700 Exajoules (EJ) of fossil total primary energy supply (TPES) would be globally required by 2050, which is twice as much as would allow for the possibility of limiting global warming to two degrees [7]. The energy underdogs would barely reach the maturation phase of the transition by 2050. In order to supply an average of 50 Gigajoules (GJ) of fossil energy per person (right-hand side), regardless of the countries' transition phases, just over 400 EJ of fossil TPES would be globally required. All but the energy underdogs would have to drastically reduce their fossil fuel supply. Sources of underlying data: United Nations Department of Economic and Social Affairs [64] population forecast and International Energy Agency [40] World Indicators.

For the energy underdogs to increase their fossil TPES to 50 GJ/cap by 2050 while all other countries reduce their energy supply to this level would take approximately 400 EJ of fossil TPES in

2050 (Figure 5), and generally fall within the overall consumption for a chance at the two-degree target. "50 by 50" is not a target for a more equitable and efficient fossil energy system. It is a generalized outcome that would require the transformation of the global energy system. At 50 GJ/cap, the emerging economies could not continue being the mines, the factories, and the sweatshops of wealthy industrial countries. At 50 GJ/cap, the wealthy industrial countries could not replace the fossil energy reductions with renewable energy. At 50 GJ/cap, the energy underdogs would never develop full-fledged fossil energy systems. If continuing the fossil energy transition is not an option, then alternatives must be sought out and rapidly pursued. The world over, these alternatives require pushing back against the fossil energy system. Maybe this is indeed the chance for the energy underdogs to come out on top, simply because they have less to dismantle and repurpose, less capital tied up in roads and buildings and factories and machines and gadgets that would largely become obsolete at 50 GJ/cap (or less) of fossil energy supply.

4. The Challenge for Change

"50 by 50" (Figure 5) would require transformative change to the global energy system, including the concerted international redistribution and reduction of fossil fuel-based energy. In the current trajectory of the energy transition, we do not find sufficient evidence for the global cooperation, prudence, and willingness to change that would have to precede such transformation.

If the change that might lead us to "50 by 50" is unrealistic, then sustaining the fossil energy transition is just as unrealistic, if not more so. It is already clear that in order to even have a chance of limiting global warming (to two degrees), the combustion of fossil energy carriers will have to be drastically limited, leaving most of the known reserves untouched [7] and accepting the demands of social movements to "leave the coal in the hole, the oil in the soil, and the tar sand in the land" [30,31]. However, the fossil energy transition depends on the unlimited availability of limited energy carriers, the combustion of which threatens the inhabitability of our planet, and the distribution of which is already and will increasingly be controlled violently.

A "Big Push" for renewables [57] that consists in harnessing wind and water to protect fossil capital from shortages in coal and gas or as an investment opportunity for fossil profits may be a more detrimental route up the hill than Sisyphus'. Renewable energy used to maintain the institutions on which the fossil energy system is built further solidifies the fossil energy transition, as exemplified by mega-projects based on large-scale investments and land deals that require access to massive electricity grids with their established issues of access, control, and power [12,49,50,52].

For the energy underdogs to—in the words of our quantitative analysis—succeed in transitioning from traditional to modern renewables at low but sufficient levels of supply and high levels of access would constitute not only transformational but revolutionary change. Abandoning the fossil energy transition is a direct challenge to existing political and economic institutions, both domestically and internationally. Energy supply would focus on households rather than the industry and military. A renewable energy system might not only enable but also necessitate leaving fossil fuels in the ground. The direct [66] and indirect [13,67] provision of energy via trade from the Global South to the Global North and from the *hinterland* to urban areas [68] would not be maintained. The oil supply crisis that almost all of the mature industrialized and emerging economies are facing [4] might be further exacerbated unless these countries, too, transform their energy systems.

It may not feel like we are on the precipice of established power relations toppling in such a transformation. However, why should an energy system failing in a spectacular way to provide "a good life for all within planetary boundaries" [36] even exist? Efforts to systematically reduce and prioritize energy use in order to strengthen decentralized energy systems based on renewable sources to meet people's needs are strategically vital in breaking the momentum of the fossil energy transition [11]. Where established institutions can be challenged to the extent that the fossil energy transition can be abandoned, the global energy underdogs may come out on top. However, the battle to this top—like any—is an uphill one.

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References

1. Corton, C.L. *London Fog: The Biography*; Harvard University Press: Cambridge, MA, USA, 2015; ISBN 978-0-674-08835-1.
2. "I Feel Helpless": Delhi Residents on the Smog Crisis. Available online: https://www.theguardian.com/world/2017/nov/08/i-feel-helpless-delhi-residents-on-the-smog-crisis (accessed on 24 July 2018).
3. Health Effects Institute. *Health Effects Institute State of Global Air 2018*; Special Report; Health Effects Institute: Boston, MA, USA, 2018.
4. Dittmar, M. A Regional oil extraction and consumption model. Part II: Predicting the declines in regional oil consumption. *Biophys. Econ. Resour. Qual.* **2017**, *2*, 16. [CrossRef]
5. Meng, Q.Y.; Bentley, R.W. Global oil peaking: Responding to the case for 'abundant supplies of oil'. *Energy* **2008**, *33*, 1179–1184. [CrossRef]
6. Murphy, D.J. Fossil fuels: Peak oil is affecting the economy already. *Nature* **2012**, *483*, 541. [CrossRef] [PubMed]
7. McGlade, C.; Ekins, P. The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature* **2015**, *517*, 187–190. [CrossRef] [PubMed]
8. Stocker, T.F.; Qin, D.; Plattner, G.K.; Tignor, M.M.B.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. *Climate Chang. 2013, The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Intergovernmental Panel on Climate Change (IPCC); Cambridge University Press: Cambridge, UK; New York City, NY, USA, 2013.
9. Dale, M.; Krumdieck, S.; Bodger, P. Global energy modelling—A biophysical approach (GEMBA) part 1: An overview of biophysical economics. *Ecol. Econ.* **2012**, *73*, 152–157. [CrossRef]
10. Day, J.W.; D'Elia, C.F.; Wiegman, A.R.H.; Rutherford, J.S.; Hall, C.A.S.; Lane, R.R.; Dismukes, D.E. The energy pillars of society: Perverse interactions of human resource use, the economy, and environmental degradation. *Biophys. Econ. Resour. Qual.* **2018**, *3*, 2. [CrossRef]
11. Schmidt, T.S.; Matsuo, T.; Michaelowa, A. Renewable energy policy as an enabler of fossil fuel subsidy reform? Applying a socio-technical perspective to the cases of South Africa and Tunisia. *Glob. Environ. Chang.* **2017**, *45*, 99–110. [CrossRef]
12. Mitchell, T. *Carbon Democracy: Political Power in the Age of Oil*; Verso Books: London, UK; New York City, NY, USA, 2011; ISBN 1-84467-745-1.
13. Malm, A. *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming*; Verso Books: London, UK; New York City, NY, USA, 2016; ISBN 1-78478-130-4.
14. Haberl, H.; Fischer-Kowalski, M.; Krausmann, F.; Martinez-Alier, J.; Winiwarter, V. A socio-metabolic transition towards sustainability? Challenges for another great transformation. *Sustain. Dev.* **2011**, *19*, 1–14. [CrossRef]
15. Chancel, L.; Piketty, T. *Carbon and Inequality: From Kyoto to Paris Trends in the Global Inequality of Carbon Emissions (1998–2013) & Prospects for an Equitable Adaptation Fund*; Paris School of Economics: Paris, France, 2015.
16. Asif, M.; Muneer, T. Energy supply, its demand and security issues for developed and emerging economies. *Renew. Sustain. Energy Rev.* **2007**, *11*, 1388–1413. [CrossRef]
17. Van Benthem, A. *Has Energy Leapfrogging Occurred on a Large Scale?* Social Science Research Network: Rochester, NY, USA, 2010.
18. Unruh, G.C. Understanding carbon lock-in. *Energy Policy* **2000**, *28*, 817–830. [CrossRef]
19. Vergragt, P.J.; Markusson, N.; Karlsson, H. Carbon capture and storage, bio-energy with carbon capture and storage, and the escape from the fossil-fuel lock-in. *Glob. Environ. Chang.* **2011**, *21*, 282–292. [CrossRef]

20. Unruh, G.C.; Carrillo-Hermosilla, J. Globalizing carbon lock-in. *Energy Policy* **2006**, *34*, 1185–1197. [CrossRef]
21. Krausmann, F.; Wiedenhofer, D.; Lauk, C.; Haas, W.; Tanikawa, H.; Fishman, T.; Miatto, A.; Schandl, H.; Haberl, H. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 1880–1885. [CrossRef] [PubMed]
22. Mori, A. Socio-technical and political economy perspectives in the Chinese energy transition. *Energy Res. Soc. Sci.* **2018**, *35*, 28–36. [CrossRef]
23. Bridge, G.; Özkaynak, B.; Turhan, E. Energy infrastructure and the fate of the nation: Introduction to special issue. *Energy Res. Soc. Sci.* **2018**, *41*, 1–11. [CrossRef]
24. Naqvi, A. Energy Infrastructure: Seizing the Opportunity in Growth Markets | McKinsey & Company. Available online: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/energy-infrastructure-seizing-the-opportunity-in-growth-markets (accessed on 23 February 2018).
25. PwC. *Power in Indonesia: Investment and Taxation Guide 2017*; Pricewaterhouse Coopers: London, UK, 2017.
26. Gallagher, K.P. China's global energy finance: Poised to lead. *Energy Res. Soc. Sci.* **2018**, *35*, 15–16. [CrossRef]
27. Hvelplund, F.; Lund, H. Rebuilding without restructuring the energy system in east Germany. *Energy Policy* **1998**, *26*, 535–546. [CrossRef]
28. Trump, D.J. President Donald J. Trump's State of the Union Address. Available online: https://www.whitehouse.gov/briefings-statements/president-donald-j-trumps-state-union-address/ (accessed on 11 May 2018).
29. Sareen, S. Energy distribution trajectories in two Western Indian states: Comparative politics and sectoral dynamics. *Energy Res. Soc. Sci.* **2018**, *35*, 17–27. [CrossRef]
30. Bond, P. Social movements and corporate social responsibility in South Africa. *Dev. Chang.* **2008**, *39*, 1037–1052. [CrossRef]
31. Bridge, G. Geographies of peak oil: The other carbon problem. *Geoforum* **2010**, *41*, 523–530. [CrossRef]
32. Fischer-Kowalski, M.; Rovenskaya, E.; Krausmann, F.; Pallua, I.; McNeill, J.R. Energy transitions and social revolutions. *Technol. Forecast. Soc. Chang.* **2018**. under review.
33. Sovacool, B.K. How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* **2016**, *13*, 202–215. [CrossRef]
34. Kern, F.; Rogge, K.S. The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Res. Soc. Sci.* **2016**, *22*, 13–17. [CrossRef]
35. Sovacool, B.K.; Geels, F.W. Further reflections on the temporality of energy transitions: A response to critics. *Energy Res. Soc. Sci.* **2016**, *22*, 232–237. [CrossRef]
36. O'Neill, D.W.; Fanning, A.L.; Lamb, W.F.; Steinberger, J.K. A good life for all within planetary boundaries. *Nat. Sustain.* **2018**, *1*, 88–95. [CrossRef]
37. Beveridge, R.; Kern, K. The energiewende in Germany: Background, developments and future challenges. *Renew. Energy Law Policy Rev. RELP* **2013**, *4*, 3.
38. Vattenfall Hydro Power Operations. Available online: http://corporate.vattenfall.com/about-energy/renewable-energy-sources/hydro-power/hydro-power-at-vattenfall/ (accessed on 11 July 2018).
39. IEA Energy Atlas. Available online: http://energyatlas.iea.org/#!/tellmap/-1118783123/1 (accessed on 11 July 2018).
40. IEA World Indicators. Available online: http://dx.doi.org/10.1787/data-00514-en (accessed on 22 March 2018).
41. Liu, G.; Müller, D.B. Centennial evolution of aluminum in-use stocks on our aluminized planet. *Environ. Sci. Technol.* **2013**, *47*, 4882–4888. [CrossRef] [PubMed]
42. Sieferle, R.P. *The Subterranean Forest: Energy Systems and the Industrial Revolution*; The White Horse Press: Cambridge, MA, USA, 2001.
43. Davidson, O.; Mwakasonda, S.A. Electricity access for the poor: a study of South Africa and Zimbabwe. *Energy Sustain. Dev.* **2004**, *8*, 26–40. [CrossRef]
44. Doll, C.N.H.; Pachauri, S. Estimating rural populations without access to electricity in developing countries through night-time light satellite imagery. *Energy Policy* **2010**, *38*, 5661–5670. [CrossRef]
45. Tully, S. The human right to access electricity. *Electr. J.* **2006**, *19*, 30–39. [CrossRef]
46. Alstone, P.; Gershenson, D.; Kammen, D.M. Decentralized energy systems for clean electricity access. *Nat. Clim. Chang.* **2015**, *5*, 305–314. [CrossRef]

47. Chaurey, A.; Ranganathan, M.; Mohanty, P. Electricity access for geographically disadvantaged rural communities—Technology and policy insights. *Energy Policy* **2004**, *32*, 1693–1705. [CrossRef]
48. Nouni, M.R.; Mullick, S.C.; Kandpal, T.C. Providing electricity access to remote areas in India: An approach towards identifying potential areas for decentralized electricity supply. *Renew. Sustain. Energy Rev.* **2008**, *12*, 1187–1220. [CrossRef]
49. Del Bene, D.; Scheidel, A.; Temper, L. More dams, more violence? A global analysis on resistances and repression around conflictive dams through co-produced knowledge. *Sustain. Sci.* **2018**, *13*, 617–633. [CrossRef]
50. Howe, C.; Boyer, D. Aeolian extractivism and community wind in Southern Mexico. *Public Cult.* **2016**, *28*, 215–235. [CrossRef]
51. Scheidel, A.; Sorman, A.H. Energy transitions and the global land rush: Ultimate drivers and persistent consequences. *Glob. Environ. Chang.* **2012**, *22*, 588–595. [CrossRef]
52. Sovacool, B.K.; Bulan, L.C. They'll be dammed: the sustainability implications of the Sarawak Corridor of Renewable Energy (SCORE) in Malaysia. *Sustain. Sci.* **2013**, *8*, 121–133. [CrossRef]
53. EIA. *International Energy Outlook*; U.S. Energy Information Administration: Washington, DC, USA, 2017.
54. Kynge, J. *China Shakes the World: The Rise of a Hungry Nation*; Hachette UK: London, UK, 2010; ISBN 978-0-297-85693-1.
55. Zweig, D.; Jianhai, B. China's global hunt for energy. *Foreign Aff.* **2005**, *84*, 25–38. [CrossRef]
56. Easterly, W. Reliving the 1950s: the big push, poverty traps, and takeoffs in economic development. *J. Econ. Growth* **2006**, *11*, 289–318. [CrossRef]
57. AtKisson, A. The "Big Push" Transforming the World's Energy Systems. Available online: https://www.greenbiz.com/article/big-push-transforming-worlds-energy-systems (accessed on 15 March 2018).
58. Burton, R. *Choice Emblems, Divine and Moral, Antient and Modern, or, Delights for the Ingenious, in above Fifty Select Emblems, Curiously Ingraven upon Copper-Plates: With Fifty Pleasant Poems and Lots, by Way of Lottery, for Illustrating Each Emblem to Promote Instruction and Good Counsel by Diverting Recreation*, 6th ed.; Edmund Parker at Bible and Crown: London, UK, 1732.
59. Fischer-Kowalski, M.; Schaffartzik, A. Energy Availability and Energy Sources as Determinants of Societal Development in a Long-term Perspective. Available online: https://www.cambridge.org/core/journals/mrs-energy-and-sustainability/article/energy-availability-and-energy-sources-as-determinants-of-societal-development-in-a-longterm-perspective/095970C15255B4F19F034894B6107EDA (accessed on 26 July 2018).
60. Ehrenfeld, J.R. Searching for sustainability: No quick fix. *Reflections* **2004**, *5*, 1–13.
61. Abson, D.J.; Fischer, J.; Leventon, J.; Newig, J.; Schomerus, T.; Vilsmaier, U.; von Wehrden, H.; Abernethy, P.; Ives, C.D.; Jager, N.W.; Lang, D.J. Leverage points for sustainability transformation. *Ambio* **2017**, *46*, 30–39. [CrossRef] [PubMed]
62. Meadows, D. Leverage Points: Places to Intervene in a System. Available online: http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/ (accessed on 27 July 2018).
63. Rotmans, J.; Kemp, R.; van Asselt, M. More evolution than revolution: transition management in public policy. *Foresight* **2001**, *3*, 15–31. [CrossRef]
64. United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2017 Revision. Available online: https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html (accessed on 25 July 2018).
65. World Bank World DataBank. World Development Indicators. Available online: https://data.worldbank.org/products/wdi (accessed on 25 July 2018).
66. Schaffartzik, A.; Pichler, M. Extractive economies in material and political terms: Broadening the analytical scope. *Sustainability* **2017**, *9*, 1047. [CrossRef]

67. Peters, G.P.; Minx, J.C.; Weber, C.L.; Edenhofer, O. Growth in emission transfers via international trade from 1990 to 2008. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 8903–8908. [CrossRef] [PubMed]
68. Decker, E.H.; Elliott, S.; Smith, F.A.; Blake, D.R.; Rowland, F.S. Energy and material flow through the urban ecosystem. *Annu. Rev. Energy Environ.* **2000**, *25*, 685–740. [CrossRef]