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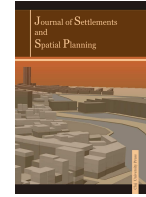
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The Inefficiencies of Energy Efficiency: Reviewing the Strategic Role of Energy Efficiency and its Effectiveness in Alleviating Climate Change

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ABSTRACT

Our present economy is high-energy and demand-intensive, demand met through the use of high energy yield fossil fuels. Energy efficiency and renewable energy sources are proposed as the solution and named the 'twin pillars' of sustainable energy policy. Increasing energy efficiencies are expected to reduce energy demand and fossil fuel use and allow renewables to close the 'replacement gap'. However, the simple fact is that fossil fuel use is still rising to meet increasing global demand and even when demand is stabilised, the substantial energy efficiencies achieved are not delivering the expected reductions in energy demand. The net effect is that efficiencies are gained and renewable energy use is increasing, even though the replacement of fossils is not an immediately plausible possibility. This points to the under-theorised problems in the 'efficiency and replacement' formula. We argue the need to pay closer attention to the 'systemicity' of the problem and to the technical and practical systems involved in energy demand. There are a number of detailed reasons why the 'efficiency and replacement' equation has become problematic ('globality', energy yield, 'rebound' and 'momentum' effects) and we include a short review of these and relate them to our 'systemicity' argument. We argue there is a need for better thinking, but also for a new primary instrument to drastically reduce energy demand and fossil fuel use. Attention should be urgently shifted from gains in energy efficiency to substantial year-over-year reductions in demand.

1. INTRODUCTION

Energy is a ubiquitous factor in contemporary life. Like clean water, it appears cheap and plentiful and for many people living in prosperous western societies it is simply there at hand and available on demand. Indeed, it has been engineered into modern life in a way that encourages making it part of the background (assumptions) rather than the foreground (consciousness) level in everyday life. We take it for granted in the same way we do not question the floor we walk on. At the same time, our current rates of fossil fuel use to meet energy demand are unsustainable. We

need to eliminate carbon emissions in a timely way to keep the global temperature rise within the 2°C limit we have set (or even 1.5°C as stated in the Paris agreement of UNFCCC in December 2015), thus making energy demand reduction a priority.

National and supranational bodies around the world have climate change alleviation as a major priority. EU energy policy aims to radically reduce fossil fuel use. This aim is represented in the immediate future by the EU 20-20-20 targets: a 20% reduction in carbon dioxide emissions and 20% of energy from renewables by 2020. The primary strategy in relation to these targets is to achieve energy efficiency. Research

and implementation funds are being spent on meeting these targets through establishing energy efficiency policy and practices at national and local levels and implementing them in an effective way.

Europe and other developed regions have seen energy demand stabilised since the 1970s. The stabilisation in demand does not however reflect the substantial efficiencies gained. The problem is compounded by the fact that we have such limited time to achieve energy demand and carbon emission reductions. It is further compounded by the global dimension of energy and climate questions – globally carbon emissions continue rising steeply – and by other factors we describe here as the ‘paradoxes’ of energy efficiency.

In spite of the effort and forty years of Earth Summit conferences, the path towards sustainable development remains unclear and the aim of sustainability may be receding rather than being brought closer. We aim here to review the difficulties and paradoxes of energy efficiency as an instrument to contain and reduce demand. We find that the link between energy efficiency and demand is an unreliable basis for a strategy for radical demand reduction.

We will begin by outlining some of the systemic aspects of energy demand and efficiency and outlining major system changes in a brief historical overview before turning to some of the more detailed limitations and paradoxes of energy efficiency. These include framing issues – this is a global issue and we need to take a global perspective on energy in general – as well as technical issues of energy yields and energy returns on investment (EROIs) of fossil fuels and their replacements. They also include economic ‘rebound’ effects, as greater efficiency equates with greater productivity and ‘sociotechnical momentum’ effects as we are forced to consider the material and social aspects of change.

We conclude that there is no stable or direct relationship between energy efficiencies and energy demand and that energy efficiency is not any silver bullet for tackling climate change. We need to consider better the systemic aspects of the problem and the problem may need to be approached more directly, as a simple imperative of reducing demand. It may require new instruments, beyond energy efficiency, and certainly beyond the market, and such instruments must be found and implemented.

2. QUESTIONS ABOUT ENERGY EFFICIENCY

According to U.S. Energy Secretary Steven Chu “energy efficiency isn't just low hanging fruit; it's fruit lying on the ground” [1]. The assumption is that energy efficiencies are the first and obvious way to reduce demand and allow renewable energy to eventually fill demand. Energy efficiency is promoted as the first and

sometimes, with replacement with renewables, the only thing we should be doing to address climate change. It is also argued that increasing energy efficiency stimulates economic growth, though the low energy yields of replacements suggests rather more expensive and less productive energy.

Today we are facing the urgent imperative to reduce our dependence on energy sourced from cheap fossil fuel and replace fossil fuels with sustainable energy sources. At the same time, however, fossil fuels are still responsible for well over 80% of demand and fossil fuel use continues rising and is projected to further rise at least until 2040 [2], by which time we are likely to be over the 2° C climate change ‘limit’ [3]. Renewable energies are also rising but at a much slower rate. The problem, as illustrated in figure 1, is to get these two rising curves to meet, and to do it soon enough to avoid a 2° C global temperature rise.

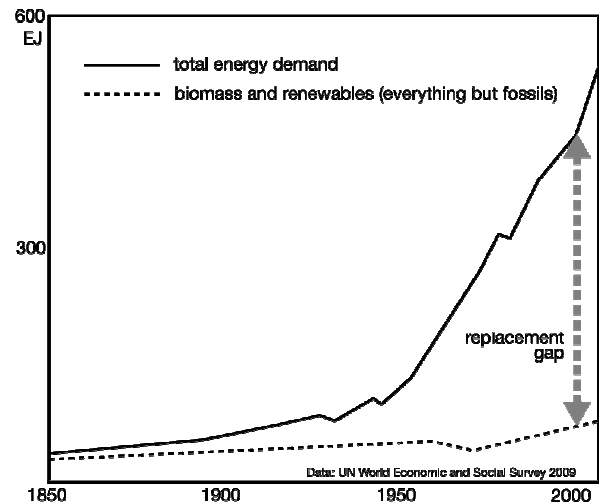


Fig. 1. Energy demand from 1850 to 2009. Source: Data from Nakicenovic, 2009¹.

The energy efficiency + replacement of fossil fuels = sustainability strategy [4] is widely accepted and increasingly acted upon. Energy efficiencies have been achieved sometimes at spectacular rates, but the hope for reduction in the demand for fossil fuels is not materialising at rates we would expect. In addition, while there is significant public concern and direct action regarding the promotion and implementation of renewable alternatives, this is not at the scale required to curtail fossil fuel use and the release of more carbon emissions into our atmosphere². The link between energy use and economic growth is often cited as a reason that further demand reduction is not an option

¹ Nakicenovic, Nebojsa (2009). Supportive policies for developing countries: a paradigm shift. Background paper prepared for World Economic and Social Survey 2009.

² Some countries like Iceland and Sweden are close to the carbon-free target but these countries are blessed with exceptional natural potentials (geothermal and hydroelectric), whilst Sweden makes up the difference with the nuclear one.

[5] and may explain the tendency of governments to prioritise the economy over the environment.

What efficiencies have not done up till now is turn the graph of energy demand downwards. In order to understand what the efficacy of energy efficiency is we first need to understand the reasons for these sometimes paradoxical situations. The graph suggests also that the plausibility of the achieving the aim within a relevant time frame can be questioned. The aggregate of Intended Nationally Determined Contributions (INDCs) by 146 countries collated by the UNFCCC will not keep global temperatures within the 2° C limit in their current form. They conclude that carbon emissions will continue to grow, though they also see hopeful signs for progress [3]. But the fact is that today well over 80% of energy worldwide is derived from oil, natural gas, and coal [2]. This means that the biggest practical problem remains the sheer capacity that has to be filled by alternatives [6]. Vaclav Smil (2003) also emphasises the magnitude of the task: “*the shift to non-fossil energies is an order of magnitude larger task than was the transition from phytomass to fossil fuel, and its qualitative peculiarities will also make it more, rather than less, demanding*” [7].

3. TOWARDS A SYSTEMIC GRASP OF ENERGY EFFICIENCY

Part of the problem lies in the way energy efficiency and demand are grasped, that is, understood and defined, as well as acted upon in pursuing and stimulating improvements. Energy efficiency in a social context is linked to our technologies and practices, and our dependency on energy resources related to socially valued results.

A common way of understanding energy efficiency is: if the same results are produced with less input of energy resources, the practice is more energy efficient. Practices are performed with the help of certain tools and technologies (cars for transportation, light bulbs for lightning or isolation material in houses) and energy efficiency is often measured by the energy efficiency of these technologies. In everyday terms, it means getting the most out of the units of energy you buy, so that energy (and money) is saved. Increasing energy efficiency is then presumed to save energy, reduce overall energy use as well as pollution, emission and other non-wanted effects in its production and consumption.

This instrumental, ahistorical and narrow technological view has been questioned [8], [9]. Starting with such a view, energy efficiency may be misconceived and ineffective in energy policy for transition to a sustainable society. Whether we understand the energy system as a simple tool (i.e. light bulbs) or a complex eco-inclusive assemblage (whole

systems producing light) can have significant consequences for policy and for the direction of transition and innovation.

A systemic understanding and approach to energy is required. Assessment of potentials and improvements requires that we look at the performance of specific energy systems in context [10] and in relation to systemic factors. A change that improves energy efficiency in the method we use in certain practices may have complex effects in a broader context. What happens to the practices that are made more energy efficient? What happens to other practices? What happens to the community context of the practices? How does the context respond back on the efficiency enhanced practices? How do practices dynamically interact when some practice is made more energy efficient?

Practices are also performed, managed and steered by different actors and groups, thus initiation, change and results of energy efficiency measures depend on their particular interests, values and motivation, and their perspectives used in analysing energy efficiency. Economists may understand the problem in terms of inefficient market processes implying the need for a ‘freer’ market backed by enabling institutions and norms. Technical people will tend to look at technical efficiency, while innovators may look at innovation efficiencies in the effort to transition to a more eco-smart organisation [11]. It should be clear that efficiency is seen here as a factor which leads directly to a reduction in energy demand.

To begin looking at the systemic aspects of this complex array of problems we need to consider how boundaries are drawn, and how they include and exclude factors, not least nature, people and the sociotechnical systems constraining and affecting efficiency of the use of energy. A real challenge is, for example, the comparative inefficiency of the emerging more sustainable energy practices, such as electric vehicles or solar panels, in their infrastructural and practice context and in comparison to existing, already streamlined and institutionalised practices. The first may be less efficient at converting energy sources to energy, whilst the relative ‘inefficiencies’ of the second may only appear at the outer boundary conditions, at the level of global climate change and emissions. We need to be careful, as well, where the problem boundaries are drawn at political and social levels. Climate change respects no political borders and global social inequality, which is one of the reasons for modernisation and development along with the associated consumption of fossil fuels in developing lands.

Secondly, we should consider how we understand the complex economic effects of energy efficiency and saving (see section 5c). Saving energy

cannot simply be assumed to directly translate into reduction of energy demand. It also implies a greater productivity of energy that may expand the possible uses of energy and lead to the exactly opposite result. In section 3, we argue that there is evidence of energy being the systemic driver in the economy-energy couple. Historically, new energies have been precursors to new economies as hunter-gather economies have been overtaken by agricultural, industrial and global economies. It is clear nevertheless that this relationship between energy and economy is not a simple one and that economy seems to 'decouple' from the relationship as sometimes spectacular energy efficiencies are achieved. The relationship however has to be seen in the context of a 'regime', which means that energy and economy interpenetrate in complex patterns of material and practice that have been constructed historically and on the ground.

Thirdly, we should consider the 'regime' nature of the problem – the complex overlapping and integrated nature of whole regimes of energy production, distribution and consumption in their historically constituted forms. From a tool and technological perspective it is often implicitly assumed that it is possible to pick and choose from a *Smörgåsbord* of existing best available practices in operation worldwide. This instrumental view on energy efficiency implies a naive view of the systemics of energy production and use, which include technical as well as practice dimensions. Change involves therefore not just the introduction of new energies but also the addition and integration of new technical arrangements into social contexts and for social purpose.

Fourthly, we need to understand impediments and costs of change and innovation. Change requires new practices and new technical arrangements, all of which require energy as well as money to build. We tend to overlook the massive construction programme involved in every energy transition in order to integrate social, economic and cultural with material and technological aspects. The last energy transition (discussed in section 3) involved the adaptation of global technological systems (automation, computerisation, communications and logistics) but also new national and urban systems that have transformed cities and regions. The motorcar and new housing patterns and standards have dominated here and have been the object of huge development programmes, first, after Second World War, in the West and more lately in the global East. Figure 1 shows at least partly the energy costs involved.

Lastly, innovation systemics are linked to all these factors. Innovation requires creativity and experimentation. It involves ideas and research, feeding into and incorporating business relevant knowledge of energy solutions, venture capital, entrepreneurs and workable business models. Innovative and sustainable

development will be a collaborative achievement of a broad range of actors across sectors [12], [13], [14]. Research indicates that, in order to be successful, sustainability transition in communities will require engagement and collaboration between public, private and civic actors and groups, guided by common, long term visions and goals where policy development itself may take the shape of a contested process of social innovation [15], [16]. This expands the dynamics but also creates constraints for realising energy efficient solutions.

Furthermore, the 'momentums' (section 5d) of socio-material infrastructures (e.g. technologies of energy production or transport systems) are difficult to change. In an EU project on Planning for Energy Efficient Cities a small experiment was made with an electrified, pedalled tribike, modern rickshaw. The technology is quite simple and well tried out in Asian context, so why should not it also work in western, industrialized countries? From a purely technical point of view, such a modern rickshaw is energy efficient and could potentially satisfy a significant share of the needs for short-range transportation. But it would require not only incentivised consumers but a radical reshaping of suburban housing patterns and cultural-material lifestyles.

Tribikes go against the grain of the socio-technical momentum, while Tesla electric cars seem more in line but imply significantly higher energy consumption. Simply put, it probably requires another society as infrastructure for realising certain efficiency potentials [11].

One of the socially 'valued results' we seek from energy efficiency is sustainability but this can be seen to be 'extra-systemic', secondary to the direct intention embedded in the techniques and practice. Sustainability is an 'externality' in relation to the more systemic results which are the immediate effects or benefits we derive from those practices (a meal or a hot shower or transport to work for example). Systems are already intentional, focused on the direct results of practice, and give results which seem pre-behavioural, even pre-conscious. We can extend Heidegger's analysis of a skilled practitioner here to explain. The carpenter uses his hammer to hammer the nails. A secondary effect of this may be the noise and he may use a more advanced hammer to reduce noise. But the activity of the carpenter is carpentry not noise reduction, his attention and purpose is on the nail and the timber and not on the hammer or its noise. His intention remains to hammer the nails and only secondarily to make less noise. The person driving home from work has an intention to get home and only secondarily to save the planet. In fact, the business of life is all technologically mediated and she has to take care of these things before she may even have the leisure to devote to thinking of the planet. It is in this way of being integrated with

activity and intention that technology and infrastructure become taken for granted and even invisible.

Heidegger (1977) also questioned the dominant technical orientation to nature as one of ordering and calculating nature, whose energy and its efficiency' expresses. Technology has become *Ge-stell* (a framing), revealing Nature as *Bestand* (a resource), ready to hand, to be demanded and exploited. "The revealing that rules in modern technology is a challenging, which puts to nature the unreasonable demand that it supply energy that can be extracted and stored as such" [17].

The character of more 'reasonable' technology is still disputed, whether as alternative, eco or people-focused technology [18], [19], or as refinement of modernist approaches to technology to be the basis of ecomodernisation paths. Most probably it will be a combination of alternative and mainstream technology as well as social innovation emerging from a "war of innovation" [20] and contested processes of policy innovation [21] and political struggles. It has core implications for how energy efficiency models and measures are to be designed.

4. THE HISTORY OF ENERGY DEMAND AND EFFICIENCIES

The systemic aspects of energy demand and efficiency are seen most clearly from a historical perspective. Far from being a new strategy to respond to today's crisis of energy demand, energy efficiency gains are a systemic aspect of the historical record of energy production and use. Smil (2010) uses the example of combustion for heating, which started at about 5% efficiency for an open wood fire and has moved to above 95% for modern conversion of natural gas to heat [22]. Efficiencies have been gained rapidly and continuously over the industrial era. It is clear that both technologies and efficiencies are advancing in this process, that gains in efficiency are part of the total process and that these have been no cause for the reduction of energy demand – in fact it seems the opposite is true.

Solar energy, converted to biomass by way of photosynthesis, drove hunter-gather (uncontrolled solar energy use) and then agricultural (controlled solar energy use) socio-ecological regimes. Biomass accounted for 95% of society's demand of primary energy and a land-based, decentralised energy system underpinned socio-economic development. A critical transition occurred with fossil fuels, which powered the industrial revolution by breaking the link between energy and land [23].

Figure 1 illustrates the history of the rise of energy demand from the middle of the 19th century.

Coal passed biomass as the leading source of energy globally just before the beginning of the 20th century. Around mid 20th century oil came into prominence and grew in importance [24]. The most significant change is the radical acceleration of the growth of demand after the 1940s. Demand here is simply defined in gross EJ.

The reasons for this are significant. The Second World War was itself a significant consumer of energy. In addition, Britain and the USA built their reconstruction programmes on the logistical capacities they had developed during the war. Other countries were enabled or obliged under the Marshall Plan to restore their production capacities as quickly as possible and begin reconstruction.

The change was characterised by massive urban and social development, accompanied, in spite of a relative decline of energy consumption in the industrial sector, by a rapid increase in energy consumption. Besides construction, a growth in household and transportation sectors accounted for this [23]. Cities expanded on a huge scale, but also motorcars, central heating, washing machines and refrigerators became affordable and were consumed by all classes in the West. The spread of the consumer society in Europe led by 1970 to a doubling of energy consumption per-capita as well as of waste and emissions [24]. Since then, development in terms of urban construction, industrialisation and the growth of the consumption sector have continued, in Asia in particular, pushing the energy demand curve steadily higher.

We can define different regimes (in the forms of what McNeill (2000) called 'technological clusters') [25] and within these clusters high innovation and efficiency gains tended to be concentrated at the beginnings of clusters and relative gains harder to achieve as time went on. But, getting new energy systems on line is formidably difficult due to the social and infrastructural organisational realignments required and the costs and time this takes.

Coal and then oil defined two rather different 'technological clusters' with different characteristics of resource distribution, transportation and potentials for exploitation. Coal-based technologies were replaced by oil-based technologies, particularly in transportation, but also in the communications technologies and industries that complemented them [24].

Older clusters transformed. Coal did not disappear but retained importance, particularly for the generation of electricity whereas biomass use has more than doubled and accounts today for the bulk of non-fossil fuel energy sources.

Clustering of technologies and the drop-off of innovation and efficiency potentials as time goes on appear to be quite straightforward systemic effects. We will explain how energy efficiency relates to energy

productivity in section 5.3 and this productivity factor (and the profits implied) could partly explain the appearance of new clusters over time. This triggers questions about the particular systemics of renewable energy sources (low energy yield) given the tendency of energy yields to increase historically. New renewable alternatives remain marginal today, and practically transition is focussed on simple replacement of fossil-sourced with renewable energy rather than proposing ? a full technological cluster or regime change.

Is there to be a new cluster of 'green' technologies and associated practice changes? We question whether the same sorts of rapid advances in innovation and economic effects of resource exploitation will be forthcoming with energy sources of much reduced energy yield and energy return on investment. We will return to these points later.

But the most important tendency remains the rapid and sustained increase of global energy demand overwhelmingly sustained by fossil fuels. Not only has the increase in demand been sustained by fossil fuels but fossil fuels have consistently increased their share of the total.

5. PARADOXES OF ENERGY EFFICIENCY

It is necessary to clarify the efficacy of energy efficiency mainly because there may be an excess of faith and an overreliance on energy efficiency as a policy measure intended to mitigate climate change. We will set out in the remainder of this paper a more detailed review of some of the limitations and paradoxes of energy efficiency.

Firstly, there is a problem of the framing of energy efficiency and demand reduction policies. We are told we would be able to reduce energy demand by 73% through efficiency savings alone [26]. But sustainability and climate change are secondary effects of some very basic social and economic things humans do and these basic things are deeply embedded in multiscale and interacting sociotechnical systems (technical and practice). They are also global issues and our perspective on the problem needs to be global.

Secondly, replacing fossil fuels may paradoxically itself entail high outlays of energy. Fossil fuels may themselves play a substantial role in producing energy from renewables and getting the energy to point of use.

Thirdly, 'rebound' refers to another paradox of energy efficiency and replacement – the increase in energy use as a consequence of the more efficient use of energy.

Fourthly, there is a coherence factor – a 'sociotechnical momentum' to the systems involved and these will have to go through an extremely challenging (and expensive in energy and money terms) reconstructive process for the effective change to happen.

5.1. The global dimension

Due to our increasing influence on the planet it is proposed that we live not only in a new epoch called the Anthropocene [27], but also in an Anthroposphere, a humanly-made world [28]. Our relationship with nature has changed, and some argue the only way 'back' to nature is through our technology [29]. For them technology is not a force for 'alienation', but it neither is simply the hardware of our human world, technology is a highly integrated set of spaces we have created for ourselves in order to live at a global scale in global cities and societies and a global economy. The meaning of technology today is to act and participate (directly and indirectly) in the world at regional and planetary scales. It is difficult to see how we can stop this process now [30] or deny it to those who still do not participate fully in its benefits [31].

The predicament is compounded by the fact that our global economic system is founded on a model of growth so that to maintain it, it has to grow. It is compounded further, and is given an ethical dimension, by the fact that the development of those parts of the world catching up to Western levels of prosperity demands growth rates that can exceed 10%. The linkage of energy consumption with growth is not fixed but is persistent and energy consumption at these levels threatens the biosphere. Mathis Wackernagel (1996) and his colleagues have shown that if we all were to achieve the standard of living enjoyed by the 'developed world' today, we would need four Earths to sustain our resource consumption [32].

The distributional aspects are also clear at the global level: while the per capita availability of productive land has decreased from 5 to 1.7 hectares since 1900, the per capita footprint in 'developed' countries is now 4 to 6 hectares [32]. The limits relating to growth are as clear: seen globally, over the past 30 years, carbon intensity per dollar of economic activity has fallen by a third. At the same time, however, carbon emissions increased by 40% as the economy scaled up. Scaling up has always overtaken increasing efficiencies over our industrial period. If it continues to do so we would have to continue producing efficiencies to levels which are not credible [33].

Another point is that economic theory is unable to accommodate geography or to recognise the geographical displacement of ecological effects [34]. Industrial era globalisation spatialises exploitation by way of a flow of resources to the industrial north. The Western developed nations in the post-industrial era have exported the industrial use of fossil fuels to the developing world. Whereas policy and aims are typically framed at national and supranational levels, it is clear that the questions cannot ultimately be contained at these levels. We need to account for bringing the rest of the world up to a standard of living that could be called

equitable, and this, even at optimum efficiency, would entail increases of energy use that would more than cancel efficiency gains.

5.2. Energy yields and returns on investment

There are technical aspects to efficiency and replacement which are crucial. 'Energy yields' (Joules per unit mass of energy source) and energy return on investment (EROI) (how much energy is left over at point of use after correcting for the energy required to generate the energy at point of extraction and transport it to point of use) [35] are important parts of the calculation because even if the energy yield starts high, there is a loss of EROI from the point of extraction to the point of use. The energy yields of fossil fuels per kilogram or volume are higher than those of biomass and it is this factor that has opened up transportation in particular in the industrial era and released us from our bondage to the land. For any energy regime to be viable it must obtain substantially more energy than it needs to invest to obtain that energy [36]. There will be a minimum EROI below which it takes more energy to make energy than we get out and some 'alternatives' end up being energy consumers! Most biofuels for example must be 'subsidised' by fossil fuels to be useful. Thus any energy system is constrained by a 'law of minimum EROI'.

Smil (2008) points out that "*recent costs of many renewable techniques have been actually increasing ... because [they] depend on large inputs of more costly fossil energies*" [37]. In addition, current models of national and global economies are set up so they depend on the high energy yields and EROI of fossil fuels. Infrastructure and transportation are dependent on the energy yields and densities of oil and support the mobility flows of the global industrial system. The mobility of production materials, components and consumer goods is behind the consumables that eventually end up in our shops. The products hide not just their energy processes but also global distributional and ethical aspects their processes of production are complicit in.

When the energy yields and energy returns on investment of alternatives and renewables are lower than those of fossil fuels, producing the energy and getting it to the point of use may not represent a net energy gain. Fossil fuels are then likely to play a role in producing energy from renewables and getting the energy to the point of use so that the replacement factor in the energy efficiency strategy equation is cancelled and renewables end up producing carbon emissions. The classic example is food, which of course was a primary energy source but today requires substantial energy input – about 15% of total energy [22] – to produce and deliver. Again, to put some perspective on

the problem, a future primary energy source needs to be renewable of course and without negative environmental or geopolitical effects. But it needs to also be capable of generating a substantial proportion of all energy used as well as having a net energy yield of 10:1 or more [6]. Anything less and we would be left in the paradoxical situation of needing fossil fuels just to generate the energy!

5.3. Rebound

It appears that increases in energy efficiency do not translate directly into reductions in energy demand. What history tells us is that efficiency gains are a regular systemic aspect of technological innovation, that there have been spectacular advances in energy efficiency over the industrial era but that none of them have led to declines of total energy consumption [22]. Others have suggested that there is an economic dimension to this in that energy efficiency increases the productivity of energy which may lead to increases in energy consumption consequent on economic growth.

The Jevons' Paradox, named after the English economist William Stanley Jevons, refers to how the demand for and rate of consumption of a resource rises with technologically driven increases in the efficiency with which that resource is used. He observed in 1865, that technological advances that increased the efficiency of coal use led to more coal being used in more industries [38]. In other words, energy efficiency can be equated with energy productivity. Lower energy costs mean more energy can be used relative to other production inputs, and more goods can be produced cheaper and for more profit. Then more uses can be found for the cheaper goods and these goods may stimulate new ways of consuming energy. These 'rebound effects' mostly manifest as increases in the production of energy and raw materials, and more consumer goods – in the economic profit and growth therefore that may be extracted from production efficiencies. Energy efficiency may therefore increase economic productivity and growth but may not be a way to reduce energy consumption and carbon emissions.

Energy rebound effects are indirect and difficult to see if one looks only at direct energy end use at the household or business level. Two-thirds of energy is in fact consumed indirectly, not in the use of but in the production of goods and services. So, while we may save money on energy not used due to efficiencies that money tends to be spent on more goods and services that require big energy inputs to produce. This in turn means more consumption and pushes economic growth but continues polluting.

At household level, energy consumption has been more or less static in the developed parts of the

world since the early 1970s. In that period household appliances have become more than 50% more efficient. However, the size of houses has grown, meaning more heating and cooling load, but also there are many more appliances, some of which consume energy even when not in use [39].

New efficient technologies may be important for improving quality of life and economic welfare, especially in less developed regions, but they may not be the answer to climate change [40]. In a study of the effects on energy consumption due to new more efficient solid-state lighting technologies [41] the authors conclude that the cost of lighting over the last three centuries as a proportion of GDP has been surprisingly constant and that this will probably not change. While it is assumed that more efficient light bulbs will reduce energy consumption and carbon emissions, there also exist new potentials for growth in the consumption of light from more efficient and lower cost lighting technologies. New uses can be found for light and new areas of the world could become better lit. The result may be increased qualities of life and productivities in those places, so that what it may not mean is a reduction gross energy demand or in carbon emissions. *“The consequence is not a simple ‘engineering’ decrease in energy consumption with consumption of light fixed, but rather an increase in human productivity and quality of life due to an increase in consumption of light”* [41].

Discounting rebound effects can lead to profound miscalculations of the effects of energy efficiency. Cullen et al (2011) see us reducing energy demand by 73% through efficiency savings alone [22]. The ‘450 scenario’ of the International Energy Agency sees improved energy efficiency being responsible for 71% of emission reductions to 2020, and 48% to 2035 [42]. Estimates like these are derived from calculations of the efficiency opportunities available in different sectors which are then added up to give us total demand and emissions reductions. This fails to account for indirect consequences of efficiencies. Such calculations underpin the climate strategies of McKinsey and Co, the IEA, and the IPCC for whom the economic implications are surely not lost.

5.4. Socio-technical momentum

Thomas Hughes, the historian of technology proposed the idea of technological or sociotechnical momentum. For Hughes as well technology is a set of highly integrated spaces – he called these integrated spaces large technical systems (LTS). Momentum is a property of LTS that suggests its mass, its complexity in terms of numbers of components, its dynamic properties in terms of movement or growth, its sociality and integration with social organisation, and its purposefulness or goal-directedness [43].

We have previously argued [44] along these lines that technology “is an ongoing and unfinished process through which people, society” and things “weave ... the meaningful conditions of everyday life” [45]. Technology is also though, in its origins, about what we make and this points to mankind’s nature as fabricators of its own world. Technology – the components of the LTS – are organised in integrated and coherent socio-technical ensembles so that technology’s essence is its integration as socio-technical and material-cultural infrastructures. These are immersive environments in which interdependencies of ends and means are established as practice. As with Hughes’ LTS, technology here exists not apart from but as an integrative factor of society. It creates an immersive environment in which we know and do things in ways technology makes possible and natural.

We interpret this as meaning that we live in material-technical cultures in which technology is adjusted to and aligned with us and enables us – though not all of us equally, of course. Hughes’ LTS have taken a more environmental slant in this construction – environment intended to mean our personal and community environments, but also the public environments of cities, airports, shopping centres and so on. But all environments also mould the organisms that inhabit them. People are enabled in their environments; there is also purpose and goal-direction embedded in these alignments. On the one hand, we use environment to act and on the other hand working within them means that certain modes of action – the ones the environment already affords – are preferred. These modes of action thus become self-evident aspects of a ‘material-technical culture’.

The active impulse is not simply mental and human but is mediated through material and technology. But this impulse is also built into the socio-technical system as an environmental tendency. Some have argued *“we need to stop imagining that we will solve global warming through behaviour changes”* [29]. It is clear this environment has evolved to be the way it is through energy regimes and that at each transition massive new construction took place to fit the environment to purpose.

The environment we inhabit was built on the assumption of cheap and plentiful energy and the modes of actions it affords are in general high-energy actions. It may not be going too far to say that the purpose and goal the contemporary global city is directed to is consumption – and in particular the consumption of energy. This would suggest that the difficulty involved in the adaption of our cities today to different forms of travel and other behaviour is equivalent to shifting the momentum of an extremely large and very purposely moving body.

The present energy regime supports a complex of productive, consumptive and other

practices, and these practices are entangled with and dependent on the material technical apparatus of our environments – and energy in its present form is a necessary means to those practices. “*Our patterns of thought, behaviour, production, and consumption are adapted to our current circumstances — that is, to the current climate (and global biogeochemistry), to the twentieth century’s abundance of cheap energy and cheap fresh water, to rapid population growth, and to yet more rapid economic growth [and] these preferences and patterns are not easily adaptable should our circumstances change*” [25].

6. CONCLUSION

Energy efficiency will not be efficient and certainly not effective until also the character and structure of circularity of flows, the dynamics of use and demand, as well as socio-material ecosystem performances are included in the equation and relation. Moezzi (2000) is asking for design of definitions of energy efficiency “*that better reflect energy consumption or carbon emissions*” [46]. Winner (1982) argues that the focus on technical efficiency is an ideology in itself with moral force in a growth oriented world is assumed to be good both for business and society [47]. But as Rudin succinctly express it “*It’s not the lamp, it’s the switch...*” [52].

A systems approach can explicate values and assumptions in operation and in evolutionary scenarios. We will not elaborate on specific definitions here. Such definitions need to be based not only on appropriate models, models which reflect core features and valued outcomes of a sustainable society and the developments towards such society. Which guiding values and politics will define outcomes and performances?

Energy is an enigma, not clearly seen in our understanding of the world and not clearly marked or calibrated in our ways of doing things. But hunter-gatherers and early agriculturalists probably had no clearer view than we have of energy and the way it flowed through their systems. They articulated understanding in metaphor and myth; today we romanticise nature and its abundance and fetishise technology and industrial and economic growth. It is not farfetched to imagine that energy is the hidden source of, and ultimate limit to these mythical cornucopias of nature and technology [34].

Some have suggested that societies, economies and cultures are products of surplus energy in particular energy regimes. The structure of that demand itself, its substantive role in economy as we know it, and the role fossil fuels play in it, needs to be understood if we are to understand the practical difficulties of change.

We learn here we cannot equate energy efficiency with energy demand and that change

“necessarily involves swimming against a strong tide....” *This does not mean that energy demand cannot be reduced, but does imply that it may be more challenging than many analyses, policy documents and political statements suggest*” [42].

Some have stated the hard fact – a solution is a cap on energy demand and emissions at a level of about one fifth of what it is today [49]. A glance at our graph will show the logic of such a call. Such cap will have severe consequences for not just economies but also for equity (the poor will pay more for it than the rich) and for the logistical aspects of our global supply chains which are already under pressure due to falling profit margins [50], [51]. The dilemma is pressing, the need for action is urgent, but the space for action very limited. What is certain is that we have to find an alternative primary strategy to tackle climate change.

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