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The uniqueness of the energy security, justice, and governance problem ☆

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ABSTRACT

This article argues that among all policy fields exhibiting externalities of a global scale, energy stands out on four dimensions: vertical complexity, horizontal complexity, higher entailed costs, and stronger path dependency. These structural attributes are at odds with contemporary key challenges of energy security, energy justice, and low carbon energy transition. With regard to the latter, energy governance challenges occur related to unclear levels of authority and weak resilience. This has implications for energy scholarship, specifically relating to the political economy of energy transitions, discussions about common pool resources, systems analysis, and other neighboring disciplines.

1. Introduction

The world faces a daunting number of interconnected social, environmental, and political problems, from emerging infectious diseases and the proliferation of weapons of mass destruction to a widening gap between rich and poor and rising levels of corruption. Yet while all of these issues deserve attention, energy is more than a sector, policy, or field; it is instead a cross cutting issue area that envelops a distinct set of governance challenges. As E.F. Schumacher put it, energy is "not just another commodity, but the precondition of all commodities, a basic factor equal with air, water, and earth" (Schumacher and Kirk, 1977, pp. 1–2). In a nutshell: energy is the lifeblood of the economy and human existence, in that, energy is deeply embedded in other sectoral and policy contexts. It is something that one group of governance scholars recently called a "mega-issue" (Lesage et al., 2010). But energy is even more. As we shall argue in this article, energy is, among all policy fields exhibiting externalities of a global scale, by far the most complex, path dependent, and embedded one.

This creates a particular practical and scholastic problem. As it is now widely recognized, energy stands at the core of key challenges the world is facing—energy access, energy security, and a low carbon systemic energy transition. These pressing challenges require policy answers. Here, it is clearly not individual structural attributes that energy exhibits which are a problem as such. But the very fact that they coincidently characterize a cross cutting policy area that needs to deliver on a variety of simultaneous goals makes energy stand out, both with regard to scholastic inquiry and governance challenges, i.e. the way power and policy is managed.[1] In other words, it is the confluence of structural attributes characterizing current energy systems and the urgency of energy challenges that makes energy distinct.

This article maps out the four key "dimensions of difference", in comparison to other policy fields requiring global governance. It asks what these differences in structural attributes imply for governance against the backdrop of the three major challenges of energy security, energy injustice, and a low carbon systemic energy transition, and draws conclusions on where to focus for further research. It begins by briefly defining energy and energy services before identifying four dimensions of difference: vertical complexity, horizontal complexity, higher entailed costs, and stronger path dependency. The next section of the paper identifies three energy challenges that put pressure on energy systems. Based on this, two distinct energy governance challenges related to fragmentation and unclear levels of authority and weak resilience are analyzed. The proceeding section translates what these governance challenges mean for scholarship, specifically relating to the political economy of energy transitions, discussions about common pool resources, systems analysis, and other neighboring disciplines.

2. Four dimensions of difference

Before we get started, some key terms deserve elaboration. For scientists and engineers, the term "primary energy" means the energy "embodied" in natural resources, such as coal, crude oil,

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[1] For a discussion of various definitions of governance see Rhodes (1996).

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natural gas, uranium, and even sunlight, wind, geothermal heat, or falling water, which may be mined, stored, harnessed, or collected but not yet converted into other forms of energy. Sometimes analysts use the term "end-use energy," to refer to the energy content of primary energy supplied to the consumer at the point of end-use, such as kerosene, gasoline, or electricity, delivered to homes and factories. The phrases "useful energy," "useful energy demands," and "energy services" are what we are most interested with in this study, and refer to what "end-use energy" is transformed into: heat for a stove or mechanical energy for air circulation. "Energy services" are often measured in units of heat, or work, or temperature, but these are in essence surrogates for measures of satisfaction experienced when human beings consume or experience them. Energy services can thus be regarded as the benefits that energy carriers produce for human well-being (Modi et al., 2005; Sovacool, 2011b).

So for this article, by "energy" we refer to the socio-technical system in place to convert energy fuels and carriers into services—thus not just technology or hardware such as power plants and pipelines, but also other elements of the "fuel cycle" such as coal mines and oil wells in addition to the institutions and agencies such as electric utilities or transnational corporations that manage the system. We propose that energy is different from a governance perspective due to four fundamental structural features: vertical complexity, horizontal complexity, cost, and path dependency. This section explores each in detail.

2.1. Stronger vertical complexity

Energy production and use involves multiple technological systems that cut across vertical scales within a country. A prime case would be a coal system that involves the coal mine and railway as well as the power plant and transmission and distribution network, or a wind farm, which requires the production of aluminum, copper, concrete, and fiberglass "upstream" to make the turbines and other components as well as switching stations and interconnection to the electricity network "downstream" from the turbines themselves. A few easily identifiable systems implicated in energy production and use are electricity supply, extractive industries, transport, buildings, water, and agriculture. These examples reveal that unlike other sectors, energy is really a nest or mesh of other global systems layered on top of each other.

Given the ubiquity of electricity to our modern lifestyles, electricity supply is perhaps one of the most obvious large-scale socio-technical systems involved in converting energy fuels into services. In the United States, for example, the electricity sector is so big that it consists of almost 20,000 power plants, half a million miles of high-voltage transmission lines, 1300 coal mines, 410 underground natural gas storage fields, and 125 nuclear waste storage facilities, in addition to hundreds of millions of transformers, distribution points, electric motors, and electric appliances. It is the most capital intensive sector of economic activity for the country and represents about 10% of sunk investment.

Particular forms of electricity supply, such as nuclear power, differ further still by necessitating their own collection of facilities unique to the fuel cycle, such as uranium mines, uranium mills, enrichment facilities, fuel cladding facilities, temporary waste sites, permanent waste repositories, research laboratories, and research reactors. Electricity supply, however, is only one such massive system involved in the provision of energy services. The extractive industries and mining sector overlap with parts of the electricity sector, providing raw fuels such as crude oil, unprocessed natural gas, and unwashed coal through a series of hundreds of thousands of mines, onshore wells, and offshore drilling platforms, to say nothing of the material needs – copper, rare earth elements, alumina, and others – needed to manufacture power plants, cars, transmission lines, and other electronic devices. The transport system must deliver more than 20 million barrels of oil per day to the United States alone, or 55% of the world's 87.8 million barrels of oil per day globally, backed by more than one thousand refineries and almost one million gasoline stations, to the world's roughly one *billion* automobiles, which drive on 11.1 million miles of paved roads (EIA, 2010; US Bureau of Transportation Statistics, 2011). These roads require USD 200 million of maintenance per day, and constitute a paved area equal to all arable land in Ohio, India, and Pennsylvania. The transport system also creates seven billion pounds of un-recycled scrap and waste each year (Hawken, 2010). Yet another cross cutting subsystem is that of buildings, housing, and real estate, the location where most energy services are "consumed." Construction, for example, represents 10–15% of the GDP of most countries and buildings consumed up to 40% of global energy use in 2009 (EIA, 2010; UNEP, 2009).

In the agricultural sector, humanity has changed its land use and dietary patterns and attuned our crops to be dependent on fossil-fuel based fertilizers, borrowing their energy to produce and transport food. The industrial food system depends on the same sources of fossil fuels as those of the electricity and transport sector, meaning farmers around the world have become more energy intensive. The land-use implications are massive: about half of global useable land is now in pastoral or intensive agriculture (Brown and Sovacool, 2011).

Finally, in the water sector, thermoelectric power plants – those relying on coal, oil, natural gas, and biomass/waste, or the use of uranium in nuclear reactors – use water in two ways. They withdraw water from rivers, lakes, and streams to cool equipment before returning it to its source, and they consume it through evaporative loss. The average power plant uses about twenty-five gallons (95 l) of water for every kilowatt-hour (kWh) generated. Given that the world consumed about 17,000 terawatt-hours (TWh) of electricity in 2007, power plants ostensibly used 425 trillion gallons (1.61 quadrillion liters) of water that year (Sovacool, 2010). This means that, on average, thermoelectric generators use more water than the agricultural and horticultural industries combined (though if we were just talking about consumption of water, the agricultural sector consumes more).

2.2. More pronounced horizontal complexity

Energy is not just vertically complex, it is also horizontally complex because it involves many states and actors across geographic scales. Put another way, energy is what Elinor Ostrom would call "polycentric" (Ostrom, 2010). Consider three scales: the macro or global (encompassing transnational and supranational engagement), the micro or local (encompassing activities at the the household level), and the meso (encompassing mid-level influence to energy systems and specific technologies).

At the macro and global level, modern economies rely heavily on oil, natural gas, coal, and uranium, which are often imported. The resulting pattern of extensive international trade in energy sources – particularly oil – engenders major security concerns whenever supplies are concentrated or production capacities constrained. The world's known oil reserves are concentrated in a handful of largely volatile countries – notably in the Middle East, Russia, Nigeria, and Venezuela – whose governments have been known to yield to the temptation to use their control of this vital resource for political ends. Moreover, meeting the growing global demand for energy will require massive investments of trillions of dollars, with significant challenges relating to anachronistic regulations, trade constraints, and intellectual property rights.

At the scale of individuals and households, without modern energy carriers, women and children are typically forced to spend significant amounts of time searching for firewood, and then burning wood and charcoal indoors to heat their home or prepare meals. The women and children collecting this fuel suffer frequent falls, bone fractures, eye problems, headaches, anemia, internal body disorders, and miscarriages from carrying loads often equal to their body weights.

At the meso scale, fossil fuels are prone to depletion, nuclear power is expensive, and hydroelectric dams can disrupt ecosystems and damage livelihoods. Looking at current reserve to production ratios for proven fossil fuel reserves and identified uranium resources, with a zero increase in production the world has 137 years of coal left, 60 years of natural gas, 43 years of petroleum, and 85 years of uranium (Brown and Sovacool, 2011). Given the projected growing consumption levels, at least in fossil fuels, depletion is likely to happen much sooner. One unique governance challenge to nuclear power is the connection between reactors and weapons of mass destruction, and the average construction time for all 376 nuclear power plants built from 1976 to 2007 was greater than 7 years and some have loomed on for more than 20 years. Hydroelectric dams can drastically disrupt the movement of species and change upstream and downstream habitats, and require the forcible relocation of tens of thousands of people.

2.3. Higher entailed costs

In addition to – and partially correlating with – its generic complexity, energy entails higher costs than other sectors. These costs arise on three fronts: a strong link between growth and energy use; the high capital intensity of energy infrastructure; and related externalities stemming from energy production, consumption, and use.

First, economic growth is inextricably linked to energy consumption. Industrializing economies tend be characterized by an over-proportional energy use compared to their GDP before exhibiting flattening energy consumption patterns once the economy matures (Carter, 1985; Darmstadter et al., 1977; Schipper, 1987). The stellar rise of Asian economies as new global power centers therefore, and as discussed in more detail below, comes with a significant additional demand. These demand increments come with costs. As the IEA estimates, some USD 33 trillion will need to be spent between now and 2035 in energy-supply infrastructure to meet projected global energy demand (IEA, 2010b, p. 93). In that, capital needs roughly equate 2.5 times the entire 2009 US GDP—an unprecedented investment volume compared to other sectors. Most of the capital will need to go into the power sector, which will absorb around half of it. Further, a significant part of the national energy mix will remain fossil. Countries are therefore likely to spend more on imports. As the IEA projects, global spending on oil and gas imports more than doubles between 2010 (USD 1.2 trillion) and 2035 (USD 2.6 trillion; IEA, 2010b, p. 77). No other imported good or service reaches similar volumes for a given economy. Finally, governments are tempted to shield their population against price fluctuations in dominant (fossil) fuels or keep energy prices low to buy domestic political support. As a consequence, more than half of the world's nations subsidize energy in one way or the other (Dansie et al., 2010, p. 475). Energy subsidies easily become major cost items to national budgets. Tehran, for instance, spends an annual estimated USD 66 billion or 20% of the country's GDP in energy subsidies, mostly oil, to keep prices low and people happy. India, an importing country, subsidizes fossil energy consumption by USD 21 billion (IEA, 2010b, p. 580) or some USD 16 per person every year. As Dansie et al. (2010, p. 482) argue, this is a considerable figure given that close to 500 million Indians subsist on under USD 1.25 a day. Few sectors are characterized by equally significant subsidies.

Second, energy infrastructure is highly capital intensive and tends to come with long lead times. On average, it takes some 5 years from first discovery to production for giant oil fields, and up to 10 years for reservoirs in technically demanding areas such as deep sea water; uranium mines need an average lead time of 8 years (Brown and Sovacool, 2011; Höök et al., 2009). Crucial gas projects such as the development of the Russian Shtokman natural gas field in the Barents Sea, a demanding region due to climate and geology, are estimated to take 5–8 years from first capital investment to full production (Thomas, 2006, cited in EIA, 2009). Building coal fired power plants requires 5 years on average, whereas new nuclear ones take 7–12 years on average. Modernizing the US power grid is widely regarded to be a task of 30–40 years, a function of its sheer size. For these investments to happen, a strong and reliable regulatory environment is the key, as are clear expectations on energy prices. The lack thereof, in turn, may trigger uncertainty among investors, which translates into a lack of investment whose effects will be both massive in scale and felt only 10 years later. In fact, following the economic and financial crisis in 2008, but also caused by high price volatility, capital spending on energy projects has been massively cut. That year, some 20 large-scale upstream oil and gas projects have been put on hold or canceled, and investment in renewables fell even over-proportionately (IEA, 2009).

Finally, energy is "different" with regard to the costs that indirectly flank contemporary systems of energy production, consumption, and use. Classifying as externalities, these costs have been widely discussed in the context of reducing greenhouse gas emissions and fighting climate change (Stern, 2005). Various studies attempt to estimate the additional costs of switching towards a low carbon energy system. Yet, the probably most telling quality of these costs is their exponential nature in the case of non-action. As the IEA suggests, between 2008 and 2020 carbon intensity already needs to fall at twice the rate of 1990–2008, and in case this will not happen—four times faster in 2020–2035. Comparing related costs to achieve that goal the agency argues that the burden has risen by a total of USD 1 trillion within 1 year only, notably due to the failure of Copenhagen (IEA, 2010b, pp. 380, 404). Adding to this, and though much harder to quantify, costs stemming from energy production and consumption comprise negative social impacts (see below) or eroding biodiversity, in addition to other forms of environmental damage (Brown and Sovacool, 2011).

2.4. Stronger path dependency and inertia

The final dimension in which energy stands out compared to other policy fields requiring global governance is path dependency and inertia. A comparably stronger "stickiness" arises along two main fronts: a "lock in" effect characterizing complex and large scale socio-technical systems; and a stronger mutual feedback loop between individual energy choices and the system's organizational principles and characteristics.

The phenomenon of path dependence has been part of the social sciences discourse for long; yet, it has gained increasing attention in economics and the study of complex systems only by the late 1980s (Arthur, 1989). At the core of the concept stands the idea that outcomes are sensitive to initial conditions. The latter are viewed to prescribe a socio-technological path exhibiting major inefficiencies compared to alternative solutions, yet hard to leave without major costs. Often, only minor historical events prove to be causal for establishing path dependency, leading to a self-perpetuating process. Once a technology or design has been chosen, positive feedback loops among the various elements of a socio-technical system lead to a situation of "lock-in" in which the selected technological solution remains dominant by at the same time creating strong resistance against introducing new technologies.[2] Path dependency of such kind has been investigated and proven for various sectors and phenomena, such as video recorder formats (Liebowitz and Margolis, 1995), computer keyboards (David, 1985), or economic reforms (North, 1990). Energy systems are no exception. Power systems, for instance, exhibit strong path dependencies due to the large investments made into grids and plants, perpetuating a mostly fossil fuel based system of electricity production and consumption. On similar accounts, some observers point to a "carbon lock-in" of industrial economies arising from a long term systemic interaction and positive feedback loops between fossil fuel-based energy and transportation systems and the societal and economic actors creating and using them (Unruh, 2000).

As a general rule, inertia increases with the degree of complexity of the socio-technological system. On the positive side, more complex hence more developed and mature systems tend to be very efficient, as their constituting elements have been well synchronized over time. On the negative side, alternative or new technological options, even if coming with higher performance or lower costs, remain "locked out", notably due to vested interests (Markusson and Haszeldine, 2009). New technologies may succeed only if they can "add on" to the incumbent system, i.e. if they are compatible with the system's dominating features. By definition, this prevents radical change.

In energy systems, path dependency and inertia are dominant features. The world's key energy system – electricity generation, powering the socio-economic life of 4.8 billion people – is built to exploit economies of scale in order to provide for (cheap) energy for large geographic entities. It is also designed to use the optimal price-to-energy-content fuel and hence powered by fossils, not the least because coal and also natural gas enjoy a competitive edge since related greenhouse gas emissions are not priced in effectively. As a consequence, power generation and distribution has come to be heavily centralized, characterized by huge converters (power plants) and end consumers largely dependent on both the network and the converters. On top of that, institutional legacies protect status quo. Formal institutional setups in tax regimes or sector regulation are complemented with informal institutions such as the expectation people bring to the organization of human energy and create tremendous inertia.

Adding to the system's inertia there is a second – though related – aspect reinforcing path dependence in energy. Put simply, individual costs related to individual choices tend to be higher in energy than in other field. While individual choices certainly do matter in, say, global health, choices are relatively easy to make and bear little individual costs. People can get a flu shot against H1N1 or not, they can decide to use airports or means of transports less prone to spreading epidemic diseases, etc. In energy, and though often indirect in nature, individual choices come with comparably longer time horizons. Choices range between such fundamental issues as building a house fueled by fossils or by renewables, or between adopting a suburban community and life style or an urban one. User infrastructure is an essential part of energy systems, determining the money and the organizational pattern "locked in" an individual choice. As a corollary, initial individual choices entail comparably higher costs once it comes to changing patterns (e.g. sell high carbon house and buy low carbon one), reverting directions taken (e.g. re-organize human life and economic activity towards urban areas and concentrate population in order to reduce carbon intensity), or simply switching habits. As a consequence, the very fact that human life and socio-economic activity is deeply embedded in and dependent on energy input reinforces the mutual feedback loop between individual choices and the energy system's characteristics.

3. Key energy challenges

As argued above, energy systems face serious challenges. These occur along the fronts of energy security, energy justice, and low carbon energy transition. Since most of their aspects are well documented, we in the following only briefly sketch these challenges in order to then conclude on why they clash with dominant structural attributes of energy systems.

3.1. Energy security

Energy security, defined as the way of equitably providing available, affordable, reliable, efficient, environmentally benign, proactively governed, and socially acceptable energy services to end-users, is gaining ever more prominence on contemporary policy agendas. Energy security has supply-side and demand-side components.

One, and reflected mainly in public debates, is the changing landscape of global energy production and consumption. According to the "New Policies" scenario[3] of the International Energy Agency (IEA), the rich countries' energy watchdog, global primary energy demand will be 36% higher in 2035 than in 2008. Oil consumption is expected to rise by 18% and reach some 99 million barrels per day (mbd) in 2035, compared to less than 84 mbd today (IEA, 2010b, p. 77). Gas consumption will be up by 44% and stand at 4.5 tcm in 2035, up from 3.1 trillion cubic meters in 2008 (IEA, 2010b, p. 179). Almost the entire increment will come from non-OECD countries while energy demand in the OECD world is instead expected to plateau. Newly emerging, energy hungry Asian economies not only come with rising purchasing power, but also test models that rely on a more pronounced state backing, notably in upstream. An almost proverbial "Chinese shopping spree" in Africa and elsewhere has therefore become subject of extensive scholarly investigation and policy debate (Alden et al., 2007; Andrews-Speed et al., 2002; International Crisis Group, 2008; Taylor, 2007). Energy security challenges therefore arise on several fronts: a (liberal) market model under stress, being at least complemented if not replaced entirely by alternative models based on strong state intervention (Goldthau, forthcoming); supply security, i.e. the availability of energy resources for incumbent (OECD) consumers in a world characterized by rapidly emerging new ones; and those new (and mostly Asian) consumers claiming their fair share in available energy resources to fuel their growth and economic catch up process, thereby bringing back mercantilist approaches towards resource access.

Though less discussed, a second energy security challenge is equally pressing: rapidly aging infrastructure. According to IEA projections, the total global capacity of retiring power plants amounts to 2000 gigawatts (GW) until 2035. Two thirds of this loss occurs in coal, oil, and gas fired power plants, and most of that in OECD countries (IEA, 2010b, p. 227). Nuclear capacity loss might even be higher than projected, due to recent decisions in many countries to put a moratorium on atomic energy, topped by a total phase out in Germany. This capacity needs to be replaced—not by yet another generation of fossil fueled power

[2] For a discussion on change in socio-technological systems see Geels and Kemp (2007).

[3] The New Policies scenario provides for energy demand and supply projections based on government pledges, assuming they would be put in practice and implemented. See IEA (2010b, p. 3).

plants; rather, and in light of looming climate change, it is "green", i.e. low carbon capacity that is needed. This is a daunting challenge: in terms of figures, replacing retiring power capacity would equal some 450 Fukushima plants.

3.2. Energy justice

On the demand-side, the global energy system is incredibly unjust, leaving billions of people without access to electricity or dependent on highly polluting traditional fuels for cooking and heating. Energy access was recently brought to the forefront of energy policy mainly by the rises of newly emerging economies in developing Asia. Using the most recent data from the International Energy Agency, United Nations Development Program, and United Nations Industrial Development Organization, in 2009 1.4 billion people lacked access to electricity, 85% of them in rural areas, and 1.2 billion will likely remain off-grid by 2030. The number of people relying on traditional biomass will rise from 2.7 billion today to 2.8 billion by 2030. The health consequences are monumental, and of epidemic proportions. Household air pollution from the inefficient use of biomass combusted in indoor stoves causes about 1.5 million premature deaths per year. As the authors of one recent study ruefully noted, "there are more people dying from smoke from biomass for cooking than from malaria or tuberculosis today. By 2030 over 4000 people will die prematurely every day from the effects of indoor smoke" (IEA, 2010a).

Low income households pay proportionally more for energy services, hindering their ability to accumulate the capital necessary to make investments to escape their poverty. Furthermore, the United Nations has warned that energy pollution has an often ignored class dimension: infant mortality rates are more than 5 times higher among the poor, the proportion of children below the age of five who are malnourished is 8 times higher, and maternal mortality rates are 14 times higher (UNDP, 1997). One study, looking at the impacts of recent increases in electricity and petrol prices in four developing Asian economies from 2002 to 2005, found that poorer households paid 171% more of their income for cooking fuels and 120% more for transportation, 67% more for electricity, and 33% more for fertilizers when compared to the expenditures on energy from middle- and upper-class households (UNESCAP, 2008). These numbers again also highlight the fact that the negative social impact of energy consumption and use varies from region to region as well as with regard to social strata.

Such serious energy disparity and even poverty intersects with other pressing problems, including gender equity, social justice, and environmental degradation. Without access to modern energy carriers, women and children are typically forced to a large part of their day searching for firewood, and then burning wood, dung, coal, and charcoal indoors to heat their home or prepare meals. Tragically, this presents many occupational hazards. For example, 10,000 fuel-wood carriers in Addis Ababa, Ethiopia, supply one third of the wood consumed by the city and they suffer frequent falls, bone fractures, eye problems, headaches, anemia, internal body disorders, and miscarriages from carrying loads often equal to their body weights. Fuel collection also places women in locations of physical or psychological violence. Hundreds of documented cases revealed Somalian women being raped while collecting fuel, and women in Sarajevo, Bosnia, risked sniper fire to collect biomass (Holdren and Smith, 2000; UNDP, 1997).

Indeed, even within highly industrialized countries, access to energy services is often unequal, and fuel poverty has always been a debated issue also in the OECD world. The poor must expend a larger proportion of their income on energy services despite using less energy than the rich. Using a metric known as a Gini coefficient or Lorenz curve, which assesses the degree of income concentration related to energy (varying between 0 for perfect equality and 1 for maximum inequality), Jacobsona et al. (2005) looked at the equity of energy use in El Salvador, Kenya, Norway, Thailand, and the United States. They found that no country was truly equitable in its energy use. The best country was Norway (where half of residential electricity was used by 38% of household customers with the highest incomes), followed by the United States (25%), El Salvador (15%), Thailand (13%), and Kenya (6%), where the percentages shown represent the highest income households using half of the residential electricity. Still, however, the shift away from low efficiency solid fuels to higher efficiency ones remains the key challenge (Pachauri and Jiang, 2008), particularly for high growth countries China and India. For them, access to clean and modern forms of energy is of utmost importance in order to foster economic development and increase welfare.

3.3. Low carbon transition

A final key challenge is energy transition. While principally describing a fundamental change in the quantity, quality, and structure of energy production and energy use (Gruebler, 2008), the term has now been normatively charged against the backdrop of climate change. Anthropogenic greenhouse gas (GHG) emissions are widely assumed to be the cause for a rise in temperature and its detrimental consequences, from rising sea levels to heavier droughts or loss of habitat. Despite growing efforts to curb them, energy related emissions are made responsible for about 70% of total GHG emissions in the years to come (IEA, 2010b, p. 389). In other words, energy production, consumption, and use need to be at the core of efforts to shift current emission patterns to more sustainable ones, i.e. a low carbon energy transition. In order to achieve the 450 ppm (ppm) goal, a CO_2 concentration at which, it is believed, climate change can be stabilized at still sustainable levels, it will not be enough to cut or replace carbon heavy technologies by "greener" ones. By contrast, energy systems need to be fundamentally overhauled. It is believed that "smart networks" are the key to such an overhaul. Such networks would make participants both producers and consumers of energy; enable a highly efficient use of available energy; communicate individual energy choices to all other participants, allowing them to respond timely and intelligently; and make variable energy sources compete against each other. This would require transforming centralized energy systems, characterized by bulky converters and energy flowing one-way from producer to consumer, into highly decentralized arrangements.

Low carbon energy transition is a huge challenge provided that it is based on a veritable shift towards renewable energy sources, i.e. not only on making existing fossil based systems "cleaner". Historically, mankind's energy use evolved from low quality and low content to high quality and high content energy fuels. This, and despite significant gains in energy efficiency and emissions reduction, has led to replacing biomass or wood by coal, eventually complemented by oil and gas. As Gruebler notes, evolution then came to a standstill since the mid-1970s, resulting in a strong reliance on carbon heavy fuels (Gruebler, 2004, p. 173). "Going back" to comparably low energy content and quality fuels such as biomass will prove difficult, as it would imply reverting historical developments.

4. Difficulty of effective global governance

Energy security, energy access, and energy transition each individually imply major policy challenges. It however is the confluence of the structural attributes characterizing current energy systems and the simultaneous urgency of energy challenges that put in question effective governance towards achieving crucial energy goals. Two issues stand out: unclear levels of interference and authority and weak resilience.

4.1. Unclear levels of interference and authority

Due to its horizontal and vertical complexity, energy systems are seamlessly integrated into social and economic structures. Energy actors comprise pretty much every human being (given their individual choices having repercussions on a global scale) and energy systems affect governments at all levels, from the local neighborhood council to the state legislature to the national parliament and intergovernmental organizations such as the United Nations, IEA, or OPEC. Energy systems also fuel, and deeply affect, every single private sector activity, and therefore banks, financial markets, futures traders, foreign exchange accounts, and debt in ways of deeper influence compared to that of health or trade only.

Because of this seamlessness, however, energy almost loses its coherence, making governance of it fragmented and inconsistent. National governments exert power and influence within regulatory frameworks clearly defined by geography, which limits the range and hence effectiveness of policy. Moreover, policies defined by national borders may create spillover effects for adjacent jurisdictions.[4] Intergovernmental organizations (IGOs), created and funded by national governments, which have secretariats that answer to some governing body, such as the International Energy Agency, play a dominant role, but so do summit processes that offer a sort of "halfway house" between formal IGOs and the normal practices of diplomacy between national governments. These summit processes typically have no charter, fixed membership, or secretariat, but offer a flexible way to address pressing multilateral problems. International nongovernmental organizations (INGOs), not confined to any particular country or summit process, which usually have boards and receive funding from a variety of actors, including foundations, governments, and the private sector, play a role as well. So do multilateral financial institutions, predominately the development banks, which provide economic and technical assistance to national governments and offer loans for energy projects. Regional organizations that involve two or more countries as members that attempt to tackle energy issues in a particular segment of the world complicate governance further. Lastly, hybrid entities including everything from transnational networks of advocacy to quasi-regulatory private bodies, global policy networks, and public–private partnerships that may weave some of the previous five types of governors together and may also include private sector entities exert their own influence on the energy governance landscape (Stone, 2008).

There is very little coordination between most of these actors. National governments, which logically would, at a minimum, have coherent strategies across the various bodies in which they are members, by and large lack anything approaching a coherent, long-term perspective addressing the full range of energy governance issues. This incoherence is reflected and amplified at the international level, where authority is fragmented and often altogether lacking (Newell, 2011; Cherp et al., 2011; Florini and Sovacool, 2009). The plethora of actors creates a global energy governance scene that appears frenetically busy—simply attending just the climate change meetings sponsored by all the relevant governors would constitute several full-time jobs.

Therefore, compared to other policy fields exhibiting externalities of a global scale such as health, weapons proliferation, or even poverty induced migration, energy barely has clearly defined processes, rules for regulation, and interference. Instead, there are multiple "entry points" and "levels", reflecting the cross-cutting nature of energy. While governmental legislation can influence energy production, consumption, and use through taxes, subsidies, or regulation, it is hard to link these policies to other goals such as equity or economic development. Effective regulation and governance would therefore require "mainstreaming of energy", similar to other policy fields such as gender—a task that, given the high level of complexity discussed above, seems a daunting challenge even on a subnational or national level. From a global perspective, defining units and levels of interference may be even harder. In policy fields other than energy, global authorities have been established to take care of the "common good", notably in cases in which it was possible to limit their scope and tasks. If at the same time the benefits of cooperation were clearly defined, policy makers managed to overcome collective actions problems for certain global policy fields and created institutions. For health, the WHO was established; for proliferation the IAEA was put in place; and IOM takes care of migration (see, for instance, cases discussed in (Kaul et al., 2003; Held and Mcgrew, 2002). These organizations can effectively make nation states stick to their commitments or implement joint policies—not the least through their mandate to take action on behalf of the "global public good" if so required and a clear incentive of (most) member states to profit from joint actions.

In energy, such a global authority is clearly lacking. Organizations such as OPEC or the IEA represent clubs established around the interests of energy producers or consumers; emerging fora such as G20 are pre-occupied with reshaping global order during times of contested US dominance. An overarching institution "taking care" of energy is clearly not in sight. Due to the multifacet nature of energy, it would also need to take care of mainstreaming energy on a global level and interfere in other policy fields, notably development, finance, or security.

4.2. Weak resilience

Rooted in their strong path dependent nature, and combining with a high degree of complexity and interconnectedness, energy systems risk lacking the ability to quickly adapt to abrupt changes. This, in turn, implies that energy systems may fall short on an important quality: resilience. Put simply, resilience enables energy systems to preserve their function under changing external circumstances. As discussed, modern and hence complex energy systems tend to be efficiency driven, and to this end their constituting elements have been well synchronized over time. This synchronization, however, and its entailed inertia towards established functional modes, may prove detrimental in the case of external shocks. The system does not have any buffer to cope with unforeseen or non-linear phenomena, such as a sudden lack of an important input fuel—a key energy security concern. In addition, given the energy systems' prevalent and path dependent centralization, it may not be able to embrace in full the horizontal and vertical complexities discussed above, or the governance challenges that may arise from them. As argued elsewhere, systems organized in a centralized or hierarchical way can account for only a limited number of connections and linkages between energy subsystems and scales, thus being unable to respond to simultaneous challenges effectively.

In addition, centralized arrangements are likely to be rigid and static (Cherp et al., 2011). However, as discussed, decentralizing energy systems is largely viewed as being a key to achieving a low carbon future, empowering individuals to make smart energy choices by at the same time embedding end-users in an "intelligent" network of energy production, consumption, and use.

[4] A case in point is the recent German decision to phase out nuclear, which may impact on electricity markets of neighboring countries.

Switching from a centralized to a decentralized "mode" would require a fundamental change in the organizational model on the system runs. Yet, overcoming the path dependence of the prevalent organizational principle of energy systems (economies of scale) and their infrastructure (centralization) would not only entail high costs, notably infrastructure investment, but also require overcoming tremendous inertia, rooted in vested interests in businesses, in people's mindsets, and the organization of socio-economic entities. It would also endanger the reliable provision of energy at affordable costs since decentralizing would mean cracking up the system—which may make the latter more prone to failure, at least during the transition phase.

Finally, given the conservative bias in path dependent (energy) technology, add-ons tend to dominate debates on energy transition, not revolutionary change. A key example is Carbon Capture and Storage (CCS), being "added" to carbon heavy coal fired power plants, to make the latter less emitting. Another example would be combined cycle gas turbines (CCGTs)—marrying a gas turbine generator and a steam turbine that uses a higher portion of energy generated by the fuel. Still, it runs on fossils. In that respect, perceivable external shocks such as a looming low carbon energy transition will likely not be dealt with effectively through such arrangements.

5. Conclusion and scholastic implications

The four discussed structural attributes – stronger vertical and horizontal complexities and higher entailed costs as well as more pronounced path dependency and inertia – are at odds with the main challenges energy systems face. Due to unclear levels of interference and authority, and weak resilience, the current energy system is ill designed to cope with the triple challenges of energy security, energy justice, and low carbon energy transition. This creates crucial problems for effective energy governance.

Departing from these insights, further inquiry needs to focus on the political economy of energy transition, and the interaction between actors interests and institutional incentives. For example, the political economy of energy transition is a vastly understudied area. The current energy system relies on a firm belief that energy services primarily are private goods and supposed to have a market price, with energy infrastructure (plants, pipeline, electricity networks, refineries, etc.) by and large being privately owned. As a consequence, changing the status quo becomes subject to severe politico-economic issues of winners and losers. Resistance will come from vested interests, be it share holders valuing short term dividends over long term climate goals, managers having an incentive to squeeze more money out of written-off infrastructure, or individuals trying to outsource the costs for mitigation or adaptation to other parts of the society. Transition, moreover, comes with uncertainty on future costs or benefits, which – if standard models on human behavior are to be believed – are met by risk aversion and resistance. Further, transitions are susceptible to lead to socio-economic frictions and rupture; they imply profound economic adjustment processes; they require adaptation, technological innovation, and possibly leapfrogging; and they are susceptible to transform the cultural and social fundamentals of entire nations. In light of this, transiting from a high carbon to a low carbon model will centrally require identifying opportunities for winners while at the same time compensating losers. Managing successful energy transition will also involve finding a formula to share the burden, possibly linking adjustment costs to per capita GHG emissions, not the least to accommodate the interests of emerging consumer nations such as India or China. This crucially requires understanding what institutional setting is likely to exert incentives enabling involved actors achieving a new, stable societal and economic equilibrium—on a global basis. Starting points for research would lie in comparative assessments of transition processes that happened in other fields involving large scale systemic ruptures. Cases would involve the political economy of transition from plan to market, from dictatorship to democracy, or from industrial to postindustrial economies. Even historical analyses of energy transitions could be envisaged, whether from solids to liquids or further towards fuels delivered via dedicated networks (Gruebler, 2008; Schurr and Netschert, 1960; Smil, 2006, 2010).

Second, common pool resources deserve further inquiry. Particularly the costs related to energy production and use as well as individual and collective price tags coming with energy transition need more in-depth research on cooperation in social dilemmas and collective action problems. Climate change – a common pool resource problem of global scale – has recently become a subject of extensive studies. Less explored, however, are the conditions that result in the effective governance of low carbon energy transition. The need to "go low carbon", i.e. to rapidly decrease the carbon intensity of energy production and use, requires committing myriads of economic, societal, governmental, and civic actors without enforcement. A number of studies have argued that the presence of certain variables increases the likelihood of cooperation in social dilemmas and collective action problems (Dietz et al., 2003; Ostrom, 2009; Poteete et al., 2010; Sovacool, 2011a). These include the involvement of individuals who think in the long term and see resources as important for their own achievements; the availability of reliable information with minimal transaction costs related to its collection; open and frequent communication among stakeholders regarding costs and benefits; effective rule enforcement and provisions for forcing compliance (such as sanctions); and predictable and gradual changes to rules and enforcement when they occur. Conversely, major changes in group composition, inflexible and homogenous rules, rapid changes in technology, information failures between groups or generations, dependence on external sources for resources or aid, and unchecked opportunistic or rent seeking behavior seem to corrode effective governance and complicate cooperative efforts (Ostrom, 1990; Ostrom et al., 1999). Using this literature as a starting point, key aspects of low carbon energy transition could be framed as a common pool resources problem and investigated from that angle. Particular emphasis could be placed on the conditions that facilitate sharing responsibility among actors for current and future outcomes, that disseminate social norms that favor compliance and continual monitoring and that foster conditions of trust, reciprocity, and civic duty that can convince individuals and groups to emit lesser greenhouse gases and respond collectively to energy dilemmas. Since most of the available studies center on local contexts, a main challenge will consist in "elevating" concepts and models to a still highly contextualized but global level.

Third, system analysis holds promise for future research. From a governance perspective, it will be particularly important to better understand the conditions under which systems embrace the two competing goals of "exploitation" and "exploration". Put simply, the notion of exploitation refers to determination, essential to deliver on key targets such as reducing GHG emissions or lifting billions of people out of poverty; exploration, by contrast, points to an innovative element necessary to ensure that these targets are met without locking energy systems in suboptimal technologies or patterns. While systems characterized by the exploitative feature tend to be effective, they tend to show little resilience towards external shocks, putting in question their operational mode. Explorative systems, by contrast, tend to be adaptive and able to deal with uncertainty but have hard times delivering on defined goals. As argued elsewhere in more detail, the degree to which global energy systems are able to strike a balance between these two opposing goals will determine whether energy transition will be successful or not (Cherp et al., 2011). Studies centering on governance for complexity (Duit and Galaz, 2008; Meadowcroft, 2009), ecosystem, and resource management (Folke et al., 2005; Loorbach, 2010; Pahl-Wostl, 2009), or "transition management" (Geels, 2002; Kern and Smith, 2008; Loorbach, 2010) seem to be promising starting points.

Finally, selected normative aspects such as externalities or equity and justice provide for interesting starting points for reaching out to neighboring disciplines. Externalities characterize a number of policy fields, from health and disease management to proliferation, migration, or even fisheries and farms. Acknowledging their distinct challenges and logics, it may prove useful to investigate governance arrangements found in these sectors or policy fields from a best practice perspective, drawing lessons for the case of sectors characterized by global externalities in the absence of a global authority in more general terms (Rosenau, 1995). The equity aspect discussed above, moreover, entails strong connections points to disciplines that generally do not feature in energy research, namely gender studies but also IPE. As revealed, energy poverty and energy access have a strong gender dimension since affected parts of the population tend to be overwhelmingly female (Clancy et al., 2003; IEA, 2010a). Studies focusing on policies empowering women, gender mainstreaming, or the gender dimension of development are likely to offer important insights in that respect. In all, existing works and a vast scientific toolbox offer some promising routes to deal with the obvious energy governance problems arising from the structural attributes characterizing current energy systems.

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