Governing Global Energy: Systems, Transitions, Complexity

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Governing Global Energy: Systems, Transitions, Complexity

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Research Article

Abstract

Global energy systems face multiple interconnected challenges which need to be addressed urgently and simultaneously, thus requiring unprecedented energy transitions. This article addresses the implications of such transitions for global energy governance. It departs from the reductionist approach where governance institutions and mechanisms are analysed in isolation from each other. Instead, the authors consider governance systems as complex and historically rooted 'arenas' coevolving with the energy issues they address. We argue that effective global energy governance requires striking a tenuous balance between the determination and efficiency needed to drive energy transitions with the flexibility and innovation necessary to deal with complexity and uncertainty. The article reviews three distinct and relatively autonomous global energy governance arenas: energy security, energy access and climate change. It argues that governance in each of these arenas can be enhanced through strengthening its linkages with the other two arenas. While widely shared and supported global energy goals are necessary and desirable, there is no case for a 'global energy government' as a single institution or regime. The current complexity of global energy governance is thus an opportunity to establish a polycentric governance system with various parts fostering complementary approaches necessary for addressing the highly interlinked energy challenges.

Policy Implications

- The three global energy challenges – providing access to modern forms of energy to all people, ensuring energy security for every nation and minimising the effects of energy systems on the climate should be resolved urgently and simultaneously. This requires an unprecedented transformation of national energy systems guided by internationally shared energy goals focused on these challenges.
- On the one hand, global energy governance aimed at addressing these challenges should command long-term commitment, determination, focus and resources with a high level of integration of energy policies across scales of governance, supply and demand sides of energy systems, and energy technologies.
- On the other hand, the complexity of energy challenges calls for wide involvement of different actors as well as flexibility, innovation, openness and diversity. Nations, energy industries and communities will need to find unique solutions that work for them. No panaceas, either technological or institutional, are likely to succeed.
- This combination of determination and flexibility required from global energy governance cannot be achieved within a single agency or regime but rather requires a polycentric governance system. The seeds of such a system already exist in three global energy governance arenas focused on energy security, energy access and climate change. A successful reform will need to transform these arenas by providing stronger interlinkages while preserving the unique and important characteristics of each of them.

Energy has always been at the centre of human economies and societies (Smil, 1994). More recently the role of energy in achieving development goals, and affecting environmental sustainability, has been recognised (AGECC, 2010; UNDP et al., 2004). Yet, at present the global energy system has come to face multiple critical challenges which, taken together, are unprecedented. These include rapidly rising energy demand in face of increasing geographic concentration of the remaining deposits of conventional fuels; the need to mitigate the impact of energy systems on the climate; and the lack of access to modern forms of energy for billions of people (AGECC, 2010; Goldemberg et al., 1987; IEA, 2009b; IPCC, 2007; UNDP et al. 2000, 2004). Energy systems should reliably meet the ever growing demands of societies that are increasingly sensitive to even the slightest disruptions, with minimal health and environmental impacts and risks of accidents or nuclear weapons proliferation.

All of these challenges are massive, urgent, global and systemic. Their sheer magnitude is daunting. Common estimates of energy investment needs range between $1 and $2 trillion per year for the next several decades, or about twice the current US annual GDP (IEA, 2009b). But meeting energy challenges is not only about the size of investment. It is also about an unprecedented systemic transformation from a 'high carbon' to a 'low carbon' energy system. According to the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas (GHG) emissions would need to peak in the next decade (IPCC, 2007), in order to limit the global temperature increase to 2.0–2.4°C. Given that over three-quarters of our energy supply comes from fossil fuels accounting for about 70 per cent of all GHG emissions (IPCC, 2007), existing energy systems will need to be urgently overhauled. Such transformation will affect how the world produces, transmits and consumes energy and will penetrate all societal levels, from individual households to the global economy. It may be similar to profound historic 'energy transitions' such as when coal replaced wood and biomass, or electricity was rapidly introduced in many countries.

This potential energy transition occurs against the backdrop of the increasing interdependence of energy systems and the spread of energy externalities beyond national borders. At the same time the capacity of nation states to control and design 'their' energy systems is eroding. Fewer and fewer states can continue to rely on their own energy resources. Furthermore, many nations lack the capacity to mobilise the necessary capital and expertise to acquire and deploy the technological solutions that are likely to accompany an energy transition such as carbon capture and storage, nuclear energy, smart grids and renewable energy facilities. In this respect energy shares core characteristics with other sectors, notably increasing systemic interdependencies, externalities spilling beyond national borders and a decreasing regulatory capacity of individual states. Contemporary literature has linked these characteristics to the need for governance beyond the state, often referred to as 'global governance' (Held and McGrew, 2002, 2007; Koenig-Archibugi and Zürn, 2005; Rosenau, 1995; Rosenau and Czempiel, 1992). Yet, while there are comprehensive studies of global governance aspects of public health (Cooper et al., 2007; Dodgson et al., 2002; Fidler, 2007), development (Kaul, 2003; Kaul et al., 1999; Thomas, 2000) and climate change and the environment (Biermann et al., 2010; Speth and Haas, 2006), studies have been notably less comprehensive in the field of energy. In fact, the most visible strand of contemporary scholarly literature on global energy issues does not even discuss current energy challenges in terms of global governance. Instead, it is firmly anchored in classical realist assumptions about international relations and security. Debates in this strand of literature selectively focus on 'energy security', suggesting a strong link between the supply of fossil fuels, energy reserves and 'geopolitics'. Objects of analysis are a looming 'scramble over resources', China 'going to Africa' or Russia's alleged 'energy weapon' and 'energy imperialism', or 'energy battles' in a particular region, suggesting that the world is locked in a battle over resources and presuming that energy is a means of state power and foreign policy (Bahgat, 2003; Barnes and Jaffe, 2006; Klare, 2008; Orban, 2008; Smith, 2006; Stulberg, 2008; Zweig and Jianhai, 2005). In this strand of thought, states remain units of analysis whose interaction is portrayed in terms of a series of zero-sum games, ignoring markets and other multilayered institutional arrangements.

A more recent and still emerging strand of literature on 'global energy governance' attempts to fill this gap. It starts from the assumption that governance in global energy needs to be understood as a patchwork of institutions, organisations and regimes, coexisting on various levels of analysis and involving both state and nonstate actors, and hybrids such as networks or public–private partnerships (e.g. Florini and Sovacool, 2009; Goldthau and Witte, 2009, 2010). This approach, however, is somewhat reductionist in both the interpretation of governance as a collection of relatively autonomous institutions or organisations (such as the International Energy Agency (IEA), OPEC or development banks) and in the interpretation of energy challenges as a set of relatively well defined, static and unconnected problems for which known solutions exist. In case the set of existing institutions does not match the set of prevalent problems, 'gaps' are noted which can presumably be remedied by introducing new or by redesigning existing institutions. The current patchwork of governance arrangements is mostly also regarded as chaotic, incoherent, fragmented, incomplete, illogical or inefficient. Accepting Christoph Frei's claim that 'a global public good would require the intervention of a global institution' (Frei, 2007), studies tend to put a strong focus on assessing the potential of various existing organisations such as the G8 (Kirton, 2006; Lesage et al., 2009) or IEA (Colgan, 2009; Van de Graaf and Lesage, 2009) to reform global energy governance or put forward new ones, such as Victor and Yueh's, 'Energy Stability Board' (2010). As a consequence, the core question of effective global energy governance is frequently formulated as '*who* governs or should govern energy?' (Carin and Mehlenbacher, 2010; Florini and Sovacool, 2009). Yet the more fundamental question of '*what* should be governed in energy, and *how*?' has barely been addressed.

The aim of this article is to start laying the conceptual framework to bridge this gap. In search for the 'what' and 'how' in global energy governance, this article

centres on the notions of systems, complexity and transitions. We argue that the magnitude, urgency and interconnectedness of contemporary global energy challenges have profound implications for the form of effective global energy governance. Based on this, we outline an intellectual and policy agenda for a greater understanding of the implications of this complexity for contemporary global energy challenges. Section 1 describes the magnitude of global energy challenges and the profound energy transitions that are required to deal with them. It also argues that dealing with these challenges will require wrestling with the uncertainty, openness and path dependency inherent in the energy system as a complex system.

Section 2 presents the implications of energy systems complexity for global energy governance. We draw from a rich body of literature on 'governing for complexity', ranging from more theoretical studies (Duit and Galaz, 2008; Meadowcroft, 2009) to more practical research in the fields of ecosystem and resource management (Berkes, 2006; Cash et al., 2006; Folke et al., 2005; Olsson et al., 2004; Pahl-Wostl, 2009) and 'transition management' (Geels, 2002; Kern and Smith, 2008; Loorbach, 2007; Rotmans and Loorbach, 2009; Voss et al., 2009). This literature argues that governing complex systems and governing transitions requires striking a tenuous balance between exploitation, determination and efficiency on the one hand and exploration, flexibility and diversity on the other.

In section 3 we use this taxonomy to map the global energy governance landscape, not as a sum of static and largely autonomous institutions, but as dynamic arenas coevolving with energy systems and challenges. We argue that the current global energy governance landscape is dominated by three largely autonomous governance arenas with different strengths and weaknesses. The energy security arena is one with limited actor and industry participation but a strong focus on efficiency and exploitation of the existing strengths of the system. The climate change arena is a largely explorative space with a large inclusion of diverse actors but currently unclear effectiveness in implementing known solutions or making tangible progress towards decarbonising the energy system. The energy access arena is similar in its exploratory character, focused on facilitating flows of financial and technical assistance which in many cases are not able to support effective exploitation of known solutions and technologies.

We conclude by outlining an intellectual and a policy agenda for increasing effectiveness of global energy governance. We argue that the seeds of polycentric energy governance exist in the current arenas, but in order to address energy challenges effectively, these arenas need to become more strongly interlinked and eventually converge to focus on commonly shared global energy goals.

1. Global energy challenges and transitions

Complexity of contemporary energy systems and challenges is an essential property to be considered in global energy governance. Put simply, complexity is a characteristic of a system that makes it difficult or impossible to understand, predict and influence its behaviour. Literature from natural and social sciences typically refers to several key features of complex systems as summarised in Box 1. Energy systems share most of these characteristics. They comprise a multitude of interconnected elements; they openly interact with natural, social and technological systems; they are strongly path dependent; and, at the same time, they are capable of undergoing rapid and largely unpredictable changes. Our argument, however, goes beyond this intuitive and relatively obvious observation. It is that the contemporary energy challenges and the transformations required to address them are increasing and altering the character of this complexity, with profound implications for global energy governance.

Findings of compelling and comprehensive studies, notably the World Energy Assessment (Reddy et al., 1997; UNDP, UNDESA and WEC, 2000, 2004), early findings of the Global Energy Assessment (GEA) (IIASA, 2010) as well as recent studies on energy transformation scenarios (e.g. IEA, 2009a), provide strong evidence supporting this statement. These scenarios portray profound transformations of energy systems, often called 'sustainable energy transitions', which are needed to support the climate change goals while preserving the economic and technological viability of energy systems.[1] Existing scenarios show that successful sustainable energy transitions require the necessary combinations of resources, technologies and practices to be

Box 1. Characteristics of a complex system

Interconnectedness: Complex systems contain large numbers of interacting elements with their collective relations producing feedback loops and intricate networks.
Unpredictability: Hindsight in the past behaviour of a complex system does not lead to reliable foresight of its future behaviour.
Nonlinearity: Minor changes can produce disproportionately major consequences.
Path dependence: A system has a history affecting its present and future. Its evolution is often irreversible.
Openness: The boundaries of complex systems are often not clearly defined; they exist in a flux constantly interacting with the surrounding environment.
Adaptability and resilience: Complex systems can adapt to external circumstances and preserve their patterns even under external pressures and shocks.

Source: Summarised by the authors from Snowden and Boone, 2007; Axelrod and Cohen, 2001.

mobilised, developed and deployed in a long-term sequence of highly coordinated activities. Change should occur both rapidly and in a longer time frame. For example, in order to achieve widely accepted climate targets the world energy system should become carbon neutral by 2080 while the GHG emissions would need to peak within the next decade. Such a dramatic and sustained transformation would require the unprecedented ability to coordinate between immediate and long-term goals.

Moreover, there is a consensus among energy experts that the major energy challenges need to be addressed simultaneously, not in a sequence (IIASA, 2010). This reflects both the urgency of challenges as well as the interconnections between the challenges and potential solutions.

Most of the proposed technological solutions to energy challenges come in highly integrated packages and will lead to systemic changes in energy production, transformation and consumption. On the energy supply side, energy transition means massive introduction of renewables, potential expansion of nuclear energy and deployment of carbon capture and storage (CCS). With respect to energy infrastructure, 'super smart grids' may be needed both to manage local loads intelligently and to transmit electric power over very large distances, possibly between countries and continents. Infrastructure for liquid natural gas (LNG) and possibly biofuels or hydrogen transportation will also be an integral part of this transition. On the energy end-use side, low-energy buildings and new industrial technologies will be needed to allow the use of much less energy for the same comfort or per unit of production. Access to electricity will need to be provided to some 1.5 billion people and access to clean fuels and improved appliances to some 3 billion people, many of them living in remote locations and under extremely challenging circumstances. It is not likely that a single technology or fuel will dominate the future energy system to the extent that fossil fuels dominate our energy systems today, forming relatively autonomous enclaves that can be operated with little reference to other energy technologies. It is more likely that in the future multiple coexisting energy technologies will need to be tightly linked in sophisticated networks and thus governed jointly.

Coordinating these solutions will need to occur in the context of increasing interdependence between national energy systems. Such interdependence is already a prominent concern of an increasing number of countries. Over 3 billion people live in over 80 countries that import more than 75 per cent of the oil they consume and this number is posed to increase dramatically in the next few decades. Some 600 million people, primarily in Europe and East Asia, are in a similar position with respect to natural gas. Contrary to common belief, switching to non-fossil types of energy will not necessarily reduce interdependencies. For example, capacities to enrich uranium, manufacture nuclear reactors and process spent fuel is limited to just a few countries. It is not uncommon for large-scale hydroelectric facilities to be located on shared rivers, utilise internationally shared dams or export most of the produced electricity to a neighbouring country. Likewise, some of the more ambitious renewable energy projects envision large-scale trade in electricity (Trieb and Muller-Steinhagen, 2007). Thus, whether it is the replacement of imported fuels by domestic ones, substitution of fossil fuels with renewables, introduction of decentralised renewable energy systems or measures to increase energy efficiency, coordination between achieving different challenges would need to occur in the context of increasing interdependence of national energy systems. In summary, most energy transition scenarios project interdependence of national energy systems far into the future although the nature of this interdependence is likely to change as energy and technological flows shift.

In addition to the interconnections *within* and *between* energy systems, the links between energy and non-energy sectors such as industry, transport, land use, agriculture, water management, urbanisation and many others will likely multiply under energy transitions. In some cases, the boundaries of the energy systems themselves may even be redefined, for example when non-energy industries, farms or municipalities turn from energy consumers into energy producers as they have done in many places in Scandinavia. Probably most importantly in this context, changes in energy and climate systems may mutually impact each other. For example, the changing seasonal availability of water affects hydro power potential in southern Europe, California and other regions and recent droughts have hindered the operation of nuclear and thermal power plants in several countries. Melting permafrost increases the vulnerability of oil and gas production in Russia while rising summer temperatures increase the demand for energy used for cooling in warmer climates. As a result, climate change could potentially lock energy and climate systems in a new feedback loop.

Thus, the connections between energy challenges, national energy systems, energy technologies, sectors and scales of operation of energy systems as well as the interface between energy and non-energy sectors are likely to strengthen and shift during energy transitions. Many of these shifts are unpredictable. This is just one feature of a larger aspect of energy transition: its inherent uncertainty. Energy transitions are associated with increasing uncertainties because they require looking far into the future and accounting for many different factors, changing configurations and unpredictable developments such as new technologies. None of the

above-mentioned scenarios are able reliably to project the combination of fuels and technologies that will most likely define the energy systems of the future. The extreme cases of uncertainties are 'nonlinearities' in energy systems, that is, abrupt changes whose occurrence cannot be modelled. Nonlinearities may occur due to game-changing technologies, may mark tipping points in the climate system or become visible as cascading blackouts in interconnected electricity systems.

The final two properties of complexity relevant to energy transitions are path dependence and resilience. Path dependence severely constrains the options and choices regarding the future of energy systems based on the choices already made. This property may lead to 'path lock-in' where premature choices predetermine suboptimal evolution of the system as in the case of the QWERTY keyboard and nuclear energy technologies in some countries. Path dependence is exacerbated by powerful actors that have a vested interest in maintaining the status quo such as oil-producing countries that continually block and obstruct climate change negotiations. Resilience is the ability of energy systems to preserve their function under changing external circumstances. Energy security strategies of consumer nations, for instance, often aim to increase resilience through diversification of suppliers, transportation routes or through keeping emergency stocks. Energy security strategies of exporting nations may also centre on diversified export routes, and rely on keeping spare capacities in the system or on organising market power to adjust supply downwards to stabilise prices. Both resilience and path dependence are likely to play more prominent roles under energy transitions where path dependence and system inertia may be particularly detrimental to desired changes and resilience may prove a useful property under large-scale modifications.

In summary, addressing energy challenges would require massive and urgent transformations of energy systems. Such transitions will affect all scales and components of energy systems and are likely to unfold over long time periods. The transitions will result in multiplying and shifting connections between national energy systems, technologies, sectors and scales of operation as well as between energy and non-energy sectors. Uncertainty and nonlinearity in energy systems may increase while path dependence and resilience may become more prominent under energy transitions. The next section discusses the implications of these factors for global energy governance by gleaning lessons from governing complexity and transitions in other fields.

2. Governance for transitions and complexity

The challenges and related transitions that energy systems face pose a serious dilemma for governance. Ideally, as our discussion has revealed, successful governance for energy transition should mobilise unprecedented resources, overcome tremendous inertia and ensure coordination across timescales, national energy systems and energy sectors as well as effectively interface with non-energy arenas. This requires highly effective and forceful interventions embedded in strong institutions or governance mechanisms. At the same time, due to uncertainty and complexity, governance solutions will need to be not only efficient and pervasive but also foster innovation, flexibility and adaptability to deal with uncertainties and nonlinearity by leaving space for diverse actors and industries. This section seeks to address this dilemma by building on to experience of managing national energy transitions (Heiskanen et al., 2009; Kern and Smith, 2008; Loorbach, 2010; Loorbach et al., 2007; Verbong and Geels, 2007); governing socio-ecological systems and common-pool resources (Cash et al., 2006; Dietz et al., 2003; Duit and Galaz, 2008; Folke et al., 2005; Ostrom et al., 2007; Pahl-Wostl, 2009; Young, 2002); and governing development (Folke et al., 2002; Imperial, 1999; Mcginnis, 1999).

As this literature suggests, the first principle is that governing for complexity should be capable of coordination across sectors and scales or levels (Cash et al., 2006; Young, 2002). Coordination between different actors has always been part of energy governance, for example through long-term contracts or energy markets. Yet, under profound energy transitions, the connections between elements of energy systems will change. As a consequence, the coordination mechanisms will need to be strengthened and likely reconfigured to match the new circumstances.

Such coordination should, second, achieve a balance between centralised and decentralised forms (Imperial, 1999). Traditional 'centralised' arrangements ensure coordination through vertical top-down linkages where centralised leadership and power drives decisions. Kooiman (2003) suggests that this hierarchical arrangement is the best way to deal with uncertainty since it is most nimble in managing nonlinear surprises. The advantage of this governance arrangement is that it can allow accurate transmission of information and intentions, efficient division of functions and responsibilities, and effectiveness in overcoming system inertia. However, while vertically directed change is appealing, this arrangement is not always feasible or even desirable. For one thing, a hierarchical institutional arrangement can only account for a limited number of connections and linkages between energy subsystems and scales. Thus, relying too heavily on these hierarchical arrangements may exclude important connections, particularly since many of these connections are unknown or dynamically changing. Additionally, 'strong' governance arrangements are likely to be rigid and static and are

inevitably limited by the knowledge and capacity at the top of the hierarchy. Thus they are often based on an oversimplified picture of the respective system. Under profound energy transformations, the moment will come when this oversimplification will no longer be valid when previously insignificant connections will start to matter and vice versa, and thus governance institutions will start constraining rather than supporting change. Asymmetric top-down decision making can also limit the formulation of solutions because it can lead to the suppression of information of knowledge of actors on lower levels.

To respond to these difficulties, a stream of governance literature suggests a set of principles to 'govern for complexity' that is based on softer forms of coordination. In such governance, coordination is assured through softer mechanisms such as flows of knowledge and information, horizontal and vertical interaction across scales and sectors, and trust-building mechanisms. The flow of knowledge and capacity helps facilitate adaptive governance structures (Cash et al., 2006; Folke et al., 2005) which are crucial for dealing with system uncertainty as well as gradual and abrupt change (Dietz et al., 2003; Folke et al., 2005). Since information tends to pool and be understood differently by different actors operating at different scales (Cash et al., 2006), maintaining open flows of knowledge is crucial for keeping different options open and allowing for system flexibility (Folke et al., 2002). For the global energy system, this means that the governance structures must facilitate open flows of information in order to be flexible and ready to change to respond to both slow and rapid changes. Thus the availability and steady flow of information within the energy system helps foster flexible mechanisms that can respond to changing and evolving conditions. Another example of a softer mechanism is multistakeholder involvement in long-term goal formulation and planning (Loorbach and Rotmans, 2006). The focus on the long term can facilitate the free flow of innovative ideas since it creates distance for actors from their current concerns and interests (De Kerkhof and Wieczorek, 2005) while the articulation of goals and visions with various actors can help direct capacity and knowledge of various interests and actors in an agreed-upon positive direction. Applied to global energy governance, this translates to the need for mechanisms and platforms to foster flows of information and technology.

These two necessary forms of coordination are an aspect of a more general balance between 'exploration' and 'exploitation' essential for governance for complexity (Duit and Galaz, 2008). 'Exploitation' refers to governance mechanisms, which support goal achievement through 'hard' coordination. It increases the stability, coherence, focus and efficiency of a system. 'Exploration' refers to flexibility, diversity, experimentation and innovation. It ensures that a system can deal with uncertainty and nonlinearity and is essential under a global energy transition where it is impossible to know which technology, institutional arrangement or actor will be critical to the success. For example, non-mainstream actors are likely often to be the source of innovations (Loorbach, 2010) and are necessary for balancing the inertia and path dependency supported by mainstream actors. Thus, fragmentation and redundancy are not obstacles in successful governance for complexity, but rather necessary preconditions for it.

The requirements for exploitation and exploration taken together present a challenge not only for the governance of a particular sector but for the entire governance structure (Duit and Galaz, 2008). Balancing exploitation and exploration is unlikely to be achieved by a simple agency or mechanism. There are no panaceas to energy governance challenges and it would be naive to believe that a governance system arising from a complex system could or even *should* be simple. Thus, the lens of complexity is useful not only for analysing energy systems but also for examining global energy governance arrangements as evolving complex systems with their own histories, fluid boundaries, dynamic connections, intricate networks and feedback loops, uncertainties and nonlinearities. Consequently, and recognising such complexity, Duit and Galaz (2008) argue that the form of governance for complexity should fit the features of the system that is governed, particularly the rate and predictability of change in the system. Mismatches between the two can develop as a result of their divergent evolution. For example, if a governance mechanism or institution emerges to ensure stability and continuity during a time of crisis and disruption, it may hinder innovation within the energy system at a later time. Achieving the balance between exploitation and exploration will likely mean that effective governance structures incorporate diverse institutions and mechanisms arranged in 'nested', 'multilevel' and 'polycentric' systems of governance (Dietz et al., 2003; Duit and Galaz, 2008; Folke et al., 2005; Mcginnis, 1999; Ostrom, 1996). Such arrangements can prevent catastrophic failures from overreliance on either state-run or market mechanisms (Dietz et al., 2003) and can facilitate system robustness by allowing different levels of governance to foster different system properties (Folke et al., 2005), in particular striking a balance between system 'exploration' or risk innovation on the one hand and 'exploitation' or efficiency and refinement of existing structures on the other (Duit and Galaz, 2008) and by taking advantage of both disequilibria and equilibria states (Loorbach, 2010).

The next section reviews existing global governance arrangements in light of these findings.

3. Assessing global energy governance arenas

Based on and reflecting upon the discussion of complex systems governance, this section assesses the current global governance arrangements in relation to the energy challenges and transitions that they need to address. We identify and analyse three governance arenas that emerged in three very different historic settings and catered to distinct policy agendas: the security of energy supply concerns triggered by the oil shocks of the 1970s; access to energy in the context of the international development agenda articulated in the 1980s; and the climate change closely related to environmental sustainability concerns that became prominent in the 1990s.

Reflecting the view of global energy governance as a complex path-dependent system, we analyse governance arenas defined by their histories, underlying paradigms and networks of actors rather than focusing solely on individual institutions (Table 1). Further, we focus on the scope of global governance arrangements, namely their intentions to coordinate across energy sectors, spatial scales and time horizons. Next, we draw conclusions on the dominating mode of governance, seeking in particular to distinguish between exploration and exploitation. Finally, we test for the potential mismatch between the historically shaped governance arrangements and the present state and challenges of energy systems.

Global governance for energy security

The first and most dominant energy governance arena focuses on security of energy supply or 'energy security'. It was historically shaped in response to the oil crises in the 1970s. The combination of a less fungible oil market dominated by national oil companies in exporting countries, most of them in the Third World, and a consumer front consisting of the rich industrialised nations, rendered energy a matter of national security concern for consumer nations, and part of foreign policy for exporting nations. As a consequence, this governance arena is dominated by nation states and their alliances (some of which trace back to the cold war). Most prominent of these alliances are the Organization of Oil Exporting Countries (OPEC) uniting major oil exporters, and the International Energy Agency (IEA) closely affiliated to the Organisation for Economic Cooperation and Development (OECD), organising consumer interests. In addition, the Group of Seven (now G8) was established in the 1970s, uniting the world's seven then largest western economies in a loose forum with the initial aim to harmonise energy and macroeconomic policies. More recently established platforms such as the International Energy Forum (IEF), Latin America's OLADE or the Shanghai Cooperation Organisation (SCO) are also active in this governance arena. Moreover, a plethora of bilateral and multilateral agreements between nation states complement the aforementioned institutions in regulating access to resources and energy infrastructure. Global governance for energy security also occasionally interfaces with economic cooperation and development, trade regimes, nuclear nonproliferation, anticorruption and good governance in energy exporting countries.

The primary aim of this governance arena has been oil market stability. This principle is found both in the IEA's and OPEC's founding charters (OPEC, 1960; Scott, 1995). Consequently, it focuses almost exclusively on energy, mostly oil, supply. As a result, the patterns of governance have evolved to match the peculiar characteristics of the oil sector. The key mechanisms in this governance arena persist in the very form in which they have been established. They include binding agreements on output control, that is, quotas (OPEC), and on strategic petroleum stocks (IEA), both of which are designed to ensure a reliable supply of oil in the market and smooth price developments. Oil data gathering and centralised dissemination complement these mechanisms.

Thus 'exploitation' clearly dominates over 'exploration' in governance for energy security, which shows a remarkable rigidity of its paradigms, patterns of governance and even the main actors in spite of the significant changes in the world since the oil crises of the 1970s that originally triggered the energy security agenda. These rigid mechanisms, and the narrow scope, short-term orientation and noninclusiveness have fostered efficiency and have been reasonably successful in reducing the risk of supply disruptions and price volatility.

However, these very strengths of efficiency, determination, focus and commitment make this arena less equipped to address more systemic changes in the global fossil fuel market and the energy sector in general. For example, the lack of inclusiveness means that consumer heavyweights such as China and India are not at the table, which may eventually render the IEA's emergency response mechanisms ineffective. Likewise, OPEC still fails to recruit important independent oil producers such as Russia or newcomers such as Brazil. Furthermore, this governance arena has by and large remained a 'state-only' affair and has failed to incorporate multisector and multi-actor involvement.[2] The goals within this arena have also remained relatively rigid and in general lack exploratory aspects such as the inclusion of different sectors and scales.

Global governance for energy access

The second energy governance arena focuses on the provision of energy in the developing world and has been strongly linked to the global development

movement. It emerged in the 1960s and has dynamically evolved over the last several decades. This arena is primarily dominated by the international development community and includes international development organisations, international and regional development banks, aid agencies of industrialised countries and large international NGOs. In general national governments of developed countries do not actively participate in this arena except through their international aid agencies. While some regional energy organisations have listed energy access as part of their mission, it is usually far less prominent than energy security.

Initially the development agenda focused on energy by supporting national energy infrastructure such as hydroelectric dams. More recently the focus expanded to more decentralised interventions framed as providing access to modern forms of energy such as electricity (both centralised and decentralised), modern cooking fuels and appliances (such as improved cooking stoves). Thus, this governance arena spans most energy technologies as well as all sectors including supply, infrastructure and the demand side of energy systems. It also interacts with other poverty alleviation and environmental sustainability efforts such as reducing the use of traditional fuels and the associated pollution and deforestation.

In general, from a systems perspective this governance arena can be characterised as highly explorative, non-hierarchical, inclusive and diverse. Its primary focus is in organising the flows of international finance (state loans, financial aid, micro credits) and technical assistance to support energy access initiatives. There is significant horizontal cooperation between various actors which goes in parallel with these efforts.

While this fosters an adaptive, inclusive and diverse arena, it leads to low levels of commitment and coordination, weak long-term coherence and questionable efficiency. Indeed, there are no internationally accepted energy goals or commitments in this arena, and most actors such as international development banks and international NGOs are not even accountable to the population of the countries they 'serve'. While energy access is clearly part of the poverty alleviation agenda, it remains so only at the margins. In fact the Millenium Development Goals (MDGs) do not even mention energy access even though experts agree that it is fundamental to achieving most of them (AGECC, 2010; Haines et al., 2007).

This may be one of the reasons why the number of people without access to modern energy in the world continues to grow in stark contrast with advances in such areas of international development as public health and primary education. Where success in providing access has been achieved – most notably in rapidly growing economies such as China and Vietnam – it has often been based on highly centralised state-led interventions rather than on international aid and loose cooperation of diverse actors. This suggests that in general the access arena is overly 'explorative' and fails to capitalise on and deploy efficiently the solutions that do exist. Moreover, the historic belief that international assistance can catalyse modernisation of infrastructure has been empirically denied in the 'bottom billion' countries (Collier, 2007). Thus, in order to solve energy access problems, a stronger commitment and more efficient execution will be necessary.

Global governance for energy-related aspects of climate change

The third energy governance arena – focused on reducing the negative impacts of energy systems on the climate – emerged within the environmental sustainability movement in the early 1990s. Concerns about climate change became internationally prominent in the context of the Rio Earth Summit in 1992. The United Nations Framework Convention on Climate Change (UNFCCC) adopted at the summit was the most visible expression of these concerns. The climate change arena was led by the post-cold war belief that concerted global action on climate change and other 'sustainable development' challenges is indeed feasible.

The climate change arena 'inherited' multiple actors from broader global governance for environmental sustainability including nation states, intergovernmental organisations and NGOs. The IPCC, a peculiar state-sponsored academic network, plays a prominent role. The arena also includes some recently founded industry–state–NGO partnerships promoting clean technologies, such as IRENA which was founded in 2009 and REEP which was founded in 2002. Even so, this arena is dominated by environmental rather than energy-related actors. For example, the national UNFCCC focal points are connected to the ministries of environment, not energy. The climate change governance arena is not primarily focused on energy. In addition to aiming to reduce greenhouse gas emissions, of which energy systems provide some 60 per cent, it is also concerned with forestry and land use as well as adaptation to climate change, particularly in poor and vulnerable countries and regions. Nevertheless, it is the arena with the clearest and most ambitious goal of systemic energy transitions or 'decarbonisation' and the longest perspective (up to 2050 and possibly beyond) with inclusion of supply, distribution and end use. Thus, although formally the climate change arena is focused only on GHG emissions, it in fact affects virtually all energy technologies and sectors.

The climate change arena is characterised by institutional and structural diversity. The governance instru-

ments range from legally binding agreements such as the Kyoto Protocol, nonbinding declarations (such as the final document at the COP Copenhagen meeting) backed up by flows of technical and financial assistance as well as formal knowledge and information dissemination (e.g. via the IPCC or WorldWatch) and capacity building (especially pursued by NGOs, UNEP and development agencies). Equally strong are 'horizontal' and 'bottom-up' flows of information and feedback mechanisms across all levels of actors and instruments. Mechanisms in the climate change arena also comprise investment and trade (via the Clean Development Mechanism (CDM) and Joint Implementation (JI) from the Kyoto Mechanism and industry initiatives).

In spite of these elaborate flows of knowledge and capacity, in terms of influencing energy systems the effectiveness of this arena has so far been negligible. One immediate explanation may lie in the already mentioned distance between the mainstream energy concerns (energy security and energy access), their actors (be they OPEC, the IEA or national energy ministries) and the climate change agenda. The historic belief of the architects of the climate change arena that a voluntary global agreement imposing limits on GHG emissions may save the climate is proving to be dramatically wrong. For one thing, it seems that key states will not agree to such limits and even if there were widespread agreement, the necessary transitions would not be induced by limits alone: they must also be accompanied by effective and committed interventions and deployment of existing and known solutions (Pacala and Socolow, 2004). In all, the climate change arena seems to be stuck in the exploration and experimentation mode and fails to integrate effective and efficient deployment of known technologies.

This section provided a brief assessment of the three main energy governance arenas. Even though this overview is clearly incomplete (for example, it excludes governance arrangements dealing with nonproliferation of nuclear material or anticorruption in energy exporting countries) it clearly illustrates the dazzling complexity of contemporary energy governance arrangements. This should not be surprising as governance of complex systems is expected to exhibit the same properties. Yet, within this complexity one can clearly differentiate the three arenas with their distinct and occasionally overlapping groups of actors, organising principles, goals, scope and mechanisms of governance.

Each of these arenas has certain features necessary for governing complex energy transitions. The 'energy security' arena features commitment, focus, shared goals and strong enforcement mechanisms, all facilitating efficient 'exploitation' of complex systems. The 'energy access' and 'climate change' arenas on the other hand feature more 'exploration', learning and adaptability necessary for dealing with complexities and uncertainties and stimulating context-sensitive and innovative solutions. In addition, the climate change arena is unusually diverse and inclusive. However, the impressive repertoire of governance methods within each arena is increasingly inappropriate for the scale and nature of the relevant challenges. This is partially explained by the fact that the historic context in which each of the arenas emerged is rapidly changing, making their original organising principles less and less relevant.

The most fundamental problem is that there are surprisingly few links between the three governance arenas. They are virtually isolated from each other, each with its own distinct goals, actors and mechanisms. Due to the lack of interconnections, the existing global energy governance fails to address the major energy challenges in an integrated manner. These arenas also miss the opportunity to learn from each other and at times operate at cross-purposes. Table 1 summarises these findings. The concluding section contains some proposals for addressing these shortcomings.

Conclusions

The global energy systems face major interconnected challenges: providing access to modern forms of energy, ensuring energy security for all nations and safeguarding the earth's climate; these cannot be resolved by the efforts of nation states alone and thus evoke the need for global energy governance. This article examined the issues posed by the urgency and complexity of energy challenges to global governance. In contrast with other studies it did not ask 'who should govern energy?' but instead posed the more fundamental question of 'what should be governed to address energy challenges and how?'

The nature, scale and urgency of energy challenges require a massive transition in the way the world obtains, transforms and uses energy. Only under such a transition would we be able to resolve energy challenges effectively, simultaneously and in a timely manner. Such a transition would require unprecedented mobilisation of resources, effective coordination of change across energy sectors, spatial scales and time horizons as well as a dynamic interface with non-energy governance arenas. At the same time, the transition would inevitably 'wake up' the inherent complexity, uncertainty and path dependence of energy systems.

This means that the governance processes intended to affect energy transitions may benefit from the lessons and experience of governance of other complex issues. Such lessons – summarised in section 3 – point to the fact that effective governance of complex systems is characterised by its own complexity. The coordination between multiple and dynamically changing subsystems,

Table 1. The main global energy governance arenas

Criteria		Governance arenas: Energy security	Energy access	Climate change
Historical context	Historic origins	Oil crises of the 1970s	Development movement, 1960s–2000s	Environmental sustainability, 1990s–2000s
	Major actors and organisations	Major exporters and importers of energy (nation states) and their alliances, e.g. IEA, OPEC, IEF, OLADE, SCO	International development organisations and NGOs, multilateral partnerships, e.g. World Bank, UNDP	Nation states, IGOs, NGOs, e.g. UNFCCC, IPCC, UNEP, UNDP, GEF, WWF
	Main paradigm	Sovereign nation states acting in their self-interest establish arrangements guaranteeing mutual energy security	Development and modernisation needs to be catalysed by international assistance	Concerted international action motivated by shared global goals can deal with 'common bads' such as environmental pollution
	Central goals	Stable and secure global energy supply	Increase access to modern forms of energy	Reduce GHG emissions from energy systems
Scope	Sectors	Supply side, primarily oil	Supply side, virtually all technologies	Supply and demand side: energy systems with large emissions or reduction potential
	Scales	National	National and local	Global
	Time horizons	Primarily short term	Short and medium term	Medium and long term
Interface with non-energy arenas		Weakly related to trade, international relations and security	Strong link to poverty alleviation	Strong link to environmental sustainability
Governance mode, patterns and mechanisms		Commitment and efficiency. Binding agreements regulating access to resources and infrastructure as well as stocks and flows of fuels *Primary focus on exploitation*	Decentralisation. Loosely structured mechanisms regulating flows of financial and technical assistance. Capacity building and information exchange *Primary focus on exploration*	Diverse ranging from binding agreement to finance, technical assistance, production and dissemination of knowledge and facilitation of networks *Focus on exploration with emerging exploitation elements*
Fit with energy systems and challenges		Relatively effective in protecting short-term supply disruptions. Concerns about the ability to deal with more systemic changes including the rise of new centres of consumption and potential resource scarcity	Whereas some developing countries successfully modernise on their own, for many more 'catalysing assistance' is not enough to lift them out of the energy poverty trap	Shared global rhetoric is not sufficient to prompt forceful national action. Serious limitations on GHG emissions can only be enforced if economically viable energy alternatives to conventional fossil fuels are found

Source: Authors' own analysis.

spatial scales and timescales is ensured through maintaining a delicate balance between exploitation and exploration. Exploitation is usually associated with the choice, implementation and execution required to steer large-scale transitions; exploration, by contrast, requires the flexibility, diversity and innovation necessary to cope with uncertainty and change. Such a balance can be provided through a 'polycentric', 'nested', 'multiscale' patchwork of arrangements, each fostering different systemic properties. The research on governance for complexity offers no simple answers or 'panaceas', but instead points to the importance of a close yet dynamic fit between the complex systems being governed and their equally complex governance arrangements. The examination of global energy governance from this perspective – presented in section 3 – analysed governance processes and systems ('arenas'), rather than individual governance actors. It reviewed three major energy governance arenas focused on energy security, access to energy and climate change. These arenas are different in their historical origins, guiding principles, key actors, overall goals, scope, mechanisms and interfaces with non-energy systems. While the energy security arena is fairly narrow in its scope and exclusionary in terms of actors and sectors, historically it has been effective in achieving its goals through imposing binding rules. In contrast, the energy access and climate change arenas are more diverse and inclusive with respect to energy sectors, technologies and actors; however, they tend to emphasise exploration and inclusion at the expense of effective implementation.

Global energy governance clearly exhibits elements of complexity. In current debates, this complexity is often characterised as a 'governance patchwork' and is criticised for its redundancy, fragmentation and lack of coordination. Many proposals for improving global energy governance therefore centre on consolidating its functions into a single institution. Yet the real problem of the existing global energy governance arrangements does not lie in its complexity. On the contrary, such complexity is a necessary precondition for eventual success. Unfortunately, this precondition is not sufficient; rather it needs to be accompanied by a close intricate fit between the governance system and the cluster of problems it tries to address. Yet, while energy systems and their respective governance mechanisms coevolved, the latter have been unable to 'keep up' with energy challenges as they themselves change. As a consequence, current global energy governance does not 'fit' the current challenges, nor is it fit to steer the imminent energy transition. In fact, it exhibits mismatches, both within the individual arenas and in relation to the energy system as a whole.

With respect to energy security, the current focus on short-term fossil fuel supply stability is both increasingly ineffective (as demonstrated by recent price volatility) and untenable in the face of persistent systemic challenges associated with rapid demand growth and increasing geographic concentration – if not outright physical scarcity – of petroleum resources. Moreover, stability, inherently preferred by energy security regimes, is at odds with the rapid and radical change expected of energy systems to meet sustainability objectives. Global governance for climate change has so far failed to affect meaningfully the agendas and strategies of key energy actors, be they national energy ministries of most emerging economies or the largest energy companies which still treat climate impacts as a marginal externality. Finally, the governance of energy access remains at the margin of both the energy sector and the poverty agenda and is not backed up by meaningful and credible commitments of key actors.

The second expression of the mismatch however lies in the very existence of three largely unconnected governance arenas in the face of the highly interconnected challenges. Even though the challenges cannot be addressed in isolation from each other, the majority of governance arrangements are designed to do just that. Arenas continuing to work independently will inevitably lead to failure in discovering synergies and thoughtfully dealing with trade-offs. It is clear that keeping the pace of fossil fuel production in line with growing demand, which is central for the energy security arena, is at tremendous odds with the climate change agenda. Similarly, imposing constraints on the use of coal as advocated by many in the climate arena negatively affects energy security in many countries. Eradicating energy poverty is often looked at with some suspicion from both climate and energy security quarters as it may both increase emissions and further deplete scarce resources.

The existing energy governance arenas need to be reformed to match current realities. Additionally, global energy governance needs to increase the links between the arenas. This is a tremendous opportunity to achieve synergy in moving towards the goals or, when it is not possible, to make careful trade-offs. In sum, our analysis leads to the following four policy recommendations.

First, the three global energy challenges (providing access to modern forms of energy to all people, ensuring energy security for every nation and minimising the effects of energy systems on the climate should be resolved urgently and simultaneously. This requires an unprecedented transformation of energy systems guided by internationally shared energy goals.

Second, global energy governance guided by such goals should command long-term commitment, determination, focus and resources for their achievement. There should be a high level of integration of energy policies across scales of governance, supply and demand sides of energy systems, and energy technologies.

At the same time the complexity of energy challenges would require the wide involvement of different actors and technologies as well as room for flexibility, innovation, openness and diversity. Nations, energy industries and communities will need to find self-tailored solutions as well as to make space for less powerful actors. No panaceas, either technological or institutional, are likely to succeed.

Fourth, the combination of determination and flexibility required from global energy governance cannot be achieved within a single agency or regime but rather requires a polycentric governance system. The seeds of such a system already exist in the three global energy governance arenas focused on energy security, energy access and climate change. Successful reform will need to transform these arenas by providing stronger interlinkages while preserving the unique and important characteristics of each of them.

Energy security seems to be the most feasible entry point for such a reform. The energy security agenda is both most powerful and most challenging because of its inherent focus on stability (rather than change) and the associated vested interests. Nevertheless, evidence from the nation state level indicates that this inertia can be overcome and powerful interests can be harnessed to support energy transitions. Brazil expanded ethanol production in the 1970s through concerted action across industry sectors, government agencies and societal groups, while Denmark fostered wind energy in the 1980s and the 1990s on the basis of persistent innovation centrally motivated by energy security but occurring within a decentralised energy governance system.

Providing details on the proposals put forward in this article will require extensive empirical research. We believe that such research will be most productive if it continues the tradition of studies on complex socioecological systems. The strength of the latter lies in rigorously examining existing governance arrangements in close connection with the empirical evidence on the details of systems they coevolve with and are designed to govern. In order to guide global and national energy policies, the approaches developed in such studies will need to be scaled up from their original focus on the local and regional level and reinterpreted in relation to the specific nature of energy systems, challenges and transitions.

Notes

1. The more ambitious GEA scenarios scheduled to be released at the end of 2010 span the period between 2010 and 2100 and present plausible pathways towards a climate-safe and economically prosperous future where everyone has access to modern forms of energy by 2030.
2. The recent establishment of the IEF may be a step in the direction of a more inclusive approach to energy security, as it now involves business representatives.

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