PLANET UNDER PRESSURE 2012 MARCH 26-29 LONDON

RIO+20 POLICY BRIEF #8

An energy vision for a planet under pressure

Transformation to sustainability: interconnected challenges and solutions

PHOTO: CREATIVE COMMONS / H. ADAMSKY

Worldwide, global energy systems face an array of challenges, from access for the poor to reliability and security. Meanwhile, the provision of energy creates local human and ecological health impacts as well as dangerous global climate change. Addressing these issues simultaneously will require a fundamental transformation of the energy system. Recent assessments show that such a transformation is achievable in technological and economic terms, but it will present formidable supply- and demand-side challenges as well as problems of governance, transparency and reliability across scales.

This policy brief presents a long-term vision for the energy system and describes the elements required for the transition towards this vision. To succeed, this transformation must integrate several key components, including a focus on high levels of energy efficiency and the scale up of investments in technology deployment as well as research, development and demonstration (RD&D).

Rio+20 Policy Briefs

One of nine policy briefs produced by the scientific community to inform the United Nations Conference on Sustainable Development (Rio+20). These briefs were commissioned by the international conference *Planet Under Pressure: New Knowledge Towards Solutions* (www.planetunderpressure2012.net).

GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme · IHDP · DIVERSITAS an international programme of biodiversity science · WCRP World Climate Research Programme · Earth System Science Partnership · ICSU International Council for Science

Summary of key points and policy recommendations

- To achieve the multiple objectives of the energy system transformation, the implementation of a large number of system changes must begin today.
- Integrated policies in support of transformation objectives can have important synergies.
- A long-term vision for the energy system is essential, given the critical importance of the system to society and the involved inertia that slow-down the required transformation.
- A successful transformation must scale up investments in deployment and RD&D and align these investments with the long-term vision. Scenario analysis shows that:
  - Energy efficiency is likely to play a key role. Transformation pathways typically achieve energy intensity improvement rates that are double the historical rate of change.
  - A broad portfolio of supply-side options, focusing on low-carbon energy from non-combustible renewables, bioenergy, carbon capture and storage (CCS) and nuclear energy must provide 60–80% of the world's primary energy by 2050. This requires the further development of storage, conversion and end-use technologies and infrastructures, such as smart and super grids and, in general, a rapid decarbonization of energy systems.
  - Universal access to electricity and clean cooking by 2030 should be the most urgent priority, but this will be difficult to achieve and will require global partnerships and concentrated efforts, especially in sub-Saharan Africa and parts of Asia.
  - In the transportation sector, electrification or the introduction of hydrogen vehicles could increase the flexibility of supply and improve the overall cost-effectiveness of the energy system transformation. The benefits of this transition will depend on the simultaneous decarbonization of the electricity and hydrogen supplies and the sustainability of the materials used to construct the vehicles.
  - In the building sector, achieving rapid improvement of thermal integrity through establishing standards for new constructions and retrofitting, along with improved appliances and innovative business models (such as energy service companies), holds the potential to reduce energy demand dramatically.
  - In the industry sector, energy demand may be reduced substantially by the widespread adoption of the best available technology, the retrofit of existing plants, optimization of material flows and enhanced recycling.

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THE ENERGY CHALLENGE

Throughout modern history, energy systems have been central to economic development and social progress. Energy systems, however, have also played a key role in humanity's negative impact on the global environment. Clearly, the further development of the energy system is of critical importance to achieving societies' economic, environmental and social sustainability objectives.

In this context, current energy systems face several major challenges that must be addressed urgently and comprehensively. First, to support economic development, energy systems need to be able to deal with the rapidly increasing global demand for energy services. Second, access to modern and clean forms of energy needs to be extended to the 40% of the global population who currently cook with solid fuels and generally lack reliable, affordable and low-pollution household energy resources. Third, to prevent dangerous climate change, adverse health effects and serious impacts on land, water and biodiversity, energy-related emissions need to be reduced, and the resource-efficiency of the energy systems needs to be improved. Fourth, energy security for all nations and regions must be ensured. Lastly, changes in policies are needed in order to create incentives and to guarantee a long-term commitment to energy investments and financing.

Based on these challenges, it is clear that a major transformation of the energy system is necessary. In this brief, we discuss the multiple challenges and possible sustainable energy pathways to address these challenges in terms of both technologies and policy. The assessment is based on a set of recent, studies, including the Global Energy Assessment (GEA)[1], work on the Representative Concentration Pathways (RCPs)[2], the International Energy Agency's World Energy Outlook[3], several model comparison studies and scientific papers on energy transformations.

THE MAJOR ENERGY ISSUES

Increasing demand for energy services

Global demand for energy has grown rapidly since the industrial revolution, which ignited an explosive growth in material consumption that has been fed mainly by fossil fuels. From 1850 to 2005, global energy demand grew at more than 2% annually. Most 'business-as-usual' energy scenarios (i.e. assuming no major policy changes) anticipate that energy demand will continue to grow worldwide and is likely to at least triple during the 21st century. Growing demand in low-income regions will drive much of this growth.

Most of the business-as-usual scenarios indicate that fossil-fuel energy prices, especially for coal, will remain lower than those of alternative sources for a long time. In the absence of targeted policies, fossil fuels are thus likely to retain their dominant market share. And this is despite the fact that most of these scenarios also anticipate a significant increase in non-fossil energy production. For conventional oil and natural gas, the depletion of easily exploitable reserves will eventually result in price increases. The likely consequence will be a further surge in the exploitation of unconventional resources, such as tar sands and shale rock, which are associated with higher greenhouse gas emissions than conventional petroleum sources.

Energy-intensive lifestyles and the inefficiency of much of the energy system, particularly at the level of energy services, are the major drivers of further growth in energy needs. Although efficiency enhancements are potentially regarded as 'low-hanging fruit', with low or even 'negative' costs, they have proven difficult to realize, as a result of institutional, market and political barriers.

Lack of energy access

The poorest three-quarters of the world's population currently use only one-tenth of the world's energy. Around 1.5 billion people still lack proper access to electricity and around 3 billion are without access to modern fuels and appliances for cooking. Most rural and low-income urban households in developing nations still mostly depend on traditional biomass (including charcoal and, to a lesser extent, coal) to meet their cooking energy needs. Although the percentage of people without clean fuels for cooking has been falling, the absolute number is larger than at any other time in human history. In the absence of dedicated policies and investments in infrastructure, the number of people without access will continue to increase, with an attendant growth in adverse health impacts from household

1. GEA. 2012. *The Global Energy Assessment: Toward a Sustainable Future*. Cambridge University Press, Cambridge and IIASA, Laxenburg.
2. Van Vuuren D.P. et al. 2011. Representative Concentration Pathways: An Overview. *Climatic Change* 109:5–31.
3. IEA. 2011. *World Energy Outlook 2011*. Paris. International Energy Agency.

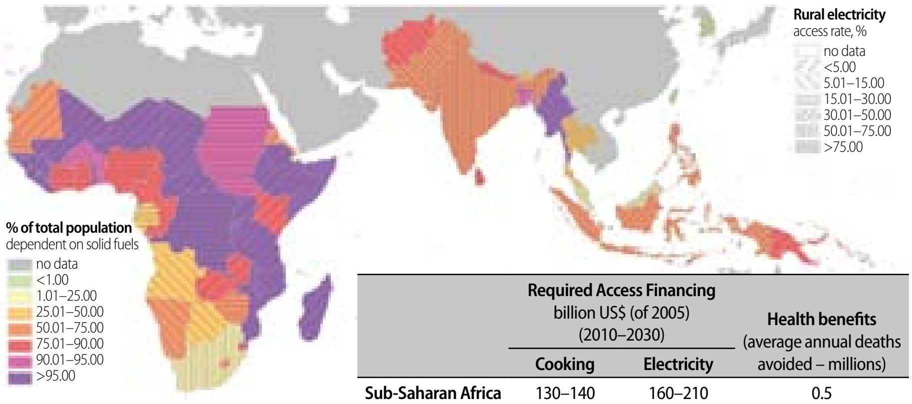
air pollution. Figure 1 shows the hot spots where populations are most severely affected by a lack of access to energy as well as by premature deaths caused by household air pollution.

Environmental risks

Energy use plays a key role in most environmental challenges, ranging from local to global, including climate change, household and regional air pollution and problems related to the unsustainable use of land and water resources.

Climate change

Energy-related emissions from carbon dioxide (CO_2) and other greenhouse gases increased rapidly during the last century. The major share of current greenhouse gas emissions originates from the energy sector and this share is expected to increase further. Without new policies, emissions will continue to grow throughout the 21st century at about the historical rate (Figure 2). This is expected to lead to an increase of global mean surface temperature of 4–5 degrees Celsius (°C) above pre-industrial levels, bringing with it significant risks of damage to unique ecosystems and human wellbeing. To limit climate change, deep reductions in emissions are necessary. Low-emission scenarios, for instance, show that emissions would need to be reduced to around 50% of the 2000 level by 2050 and to around zero by the end of the century in order to achieve at least a 50% probability of meeting the target of a maximum 2°C increase in temperature.



	Required Access Financing billion US$ (of 2005) (2010–2030)		Health benefits (average annual deaths avoided – millions)
	Cooking	Electricity	
Sub-Saharan Africa	130–140	160–210	0.5
South Asia	160–180	55–60	0.8
Pacific Asia	~ 20	10–60	0.3

Figure 1. Illustrative figure for populations lacking access to clean cooking fuel and electricity in major problem regions of sub-Saharan Africa and South and Southeast Asia. Colours denote lack of access to clean cooking fuel and hatched areas denote a lack of access to electricity. The table gives the regional costs and related health benefits that will result from attaining universal access in these regions by 2030. Note that these regions account for over 85% of the total global population without access to electricity and over 70% of the global population that still depends on solid fuels.
Source: Riahi et al., 2012 (see references)

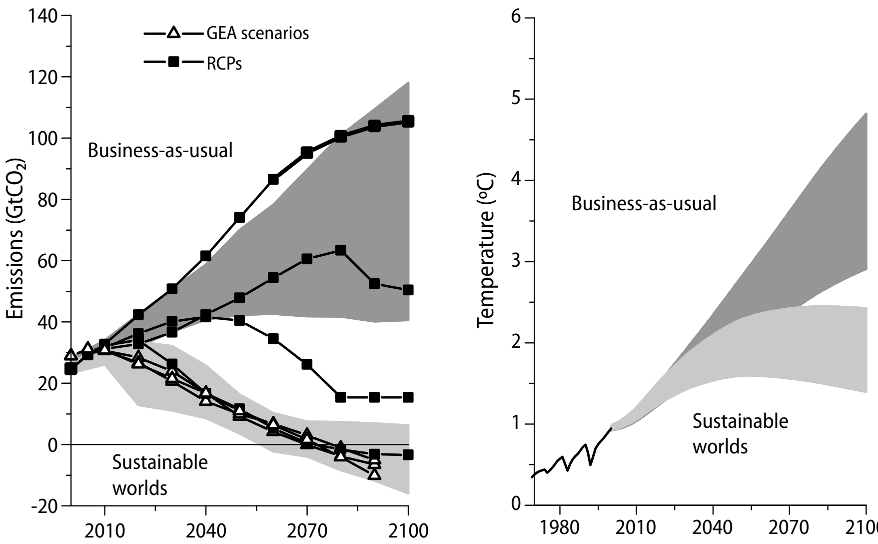


Figure 2. The range in emissions for scenarios without a climate policy, as compared with scenarios that aim to stabilize CO_2 concentrations consistent with a target of 2 °C. For illustration, the scenarios of the Global Energy Assessment (GEA) and the Representative Concentration Pathways (RCP) are shown. The right-hand panel shows the temperature outcome of a typical scenario without a climate policy versus a 450 ppm stabilization scenario (the uncertainty range here represents the uncertainty in carbon cycle and climate sensitivity).
Sources: Riahi et al., 2012 and Van Vuuren et al., (2011); see references.

Air pollution

The GEA estimates that current energy systems are responsible for around 5 million premature deaths annually and more than 8% of all ill health (loss of healthy life years, due to both illness and premature death), as a result of air pollution and other energy-related causes. Outdoor air pollution from energy systems alone is currently responsible for around 2.7 million premature deaths each year in urban and rural populations, particularly in developing countries. Household pollution from the incomplete combustion of solid fuels is estimated to cause some 2.2 million additional premature deaths annually as well as contributing a significant percentage of outdoor pollution in many areas. Implementing existing air pollution control policies would globally result in only modest emission reductions and in many developing countries still imply increasing emissions compared to today. The further tightening of such policies or their integration into related policies (in particular climate policy) are needed to reduce the burden of disease from the energy sector.

Land and water systems

Both fossil fuels and renewable forms of energy can have serious impacts on land and water systems. Bioenergy production using dedicated crops could require vast land areas and increase freshwater use as well as compete with other uses of scarce productive land, such as food production and biodiversity. Bioenergy may also be associated with substantial greenhouse gas emissions from the use of nitrogen fertilizers as well as CO_2 emissions from direct and indirect land-use change. The impact of bioenergy use, however, depends on several factors, such as the type of crop (e.g. first versus second generation crops), assumed yields and the selection of specific bioenergy chains. Other renewable sources (e.g. hydropower and wind power) may also affect land use, although their impacts are likely to remain localized.

Energy security

The uninterrupted provision of vital energy services – 'energy security' – is a high priority for every nation, city and community. For most industrialized countries, energy security is related to import dependency and aging infrastructure, while many emerging economies have additional vulnerabilities, such as insufficient capacity, high energy-intensity and rapid growth in demand. Energy security is most pertinent for oil, which currently plays a dominant role in the transport system worldwide, but whose resources are geographically concentrated in only a few countries and regions. Moreover, limited production capacities result in price volatilities that affect low-income countries in particular. For natural gas, supply concerns are mostly regional and continental.

Lack of long-term investments

One factor that amplifies the issues described above is the lack of a long-term focus in current energy policies. For example, RD&D investments have for decades seriously lagged behind the growth in energy consumption, although this trend has reversed in recent years. Investments in the energy system and infrastructure should be consistent with a long-term vision, given the tendency to inertia. Ensuring sufficient finance through appropriate mechanisms will thus be a key challenge in the near future, particularly given the current instability in financial markets (see Table 1).

Table 1: Energy investments needed to achieve sustainability objectives (limiting climate change to 2°C, reducing energy-related air pollution, improving energy security and achieving universal energy access by 2030) and supportive policy mechanisms for mobilizing financial resources. Source: Riahi et al., 2012 (see references).

	Investment (billion USD/year)		**Policy mechanisms**			
	2010	2010–2050	Regulation, standards	Externality pricing	Carefully designed subsidies	Capacity building
Efficiency	n.a.[1]	290–800[2]	Essential (elimination of less efficient technologies every few years)	Essential (cannot achieve dramatic efficiency gains without prices that reflect full costs)	Complement (ineffective without price regulation; multiple instruments possible)[3]	Essential (expertise needed for new technologies)
Nuclear energy	5–40[4]	15–210	Essential (regulation of waste disposal and of fuel cycle to prevent proliferation)	Uncertain (GHG pricing helps nuclear energy but prices reflecting nuclear risks would hurt)	Uncertain (has been important in the past, but with GHG pricing perhaps not needed)	Desired (need to correct the loss of expertise in recent decades)[5]
Renewable energy	190	260–1010	Complement (feed-in tariff and renewable portfolio standards in order to overcome implementation barriers)	Essential (GHG pricing is key to rapid development of renewables)	Complement (tax credits for R&D or production can complement GHG pricing)	Essential (expertise needed for new technologies)
CCS	<1	0–64	Essential (CCS requirement for all new coal plants and phased in for existing plants)	Essential (GHG pricing is essential, but even this is unlikely to suffice in the near term)	Complement (would help with first plants while GHG price is still low)	Desired (expertise needed for new technologies)[5]
Infrastructure[6]	260	310–500	Essential (security regulation critical for some aspects of reliability)	Uncertain (neutral effect)	Essential (customers must pay for reliability levels they value)	Essential (expertise needed for new technologies)
Access to electricity and cleaner cooking[7]	n.a.	36-41	Essential (ensure standardization but must not hinder development)	Uncertain (could reduce access by increasing the costs of fossil fuel products)	Essential (grants for grid, microfinancing for appliances, subsidies for cooking fuels)	Essential (create enabling environment: technical, legal, institutional, financial)

1. Global investments into efficiency improvements for the year 2010 are not available. The best-guess estimate for investments into energy components of demand-side devices is by comparison about 300$ billion per year (GEA). Uncertainty range is between US$100 billion and US$700 billion annually for investments in components. Accounting for the full investment costs of end-use devices would increase demand-side investments by about an order of magnitude.
2. Estimate includes efficiency investments at the margin only and is thus an underestimate compared with demand-side investments into energy components given for 2010 (see note 1).
3. Efficiency improvements typically require a basket of financing tools.
4. Lower-bound includes traditional deployment investments in about 2 GW capacity additions in 2010. Upper-bound also includes investments for plants under construction, fuel reprocessing, and estimated costs for capacity lifetime extensions.
5. Depending on the social and political acceptability of these options, capacity building may become essential for achieving the high estimate of future investments.
6. Overall electricity grid investments, including investments for operations and capacity reserves, back-up capacity, and power storage.
7. Annual costs for almost universal access by 2030 (including electricity grid connections and fuel subsidies for clean cooking fuels).

A VISION TOWARDS 2050

Policy objectives

Our vision of a sustainable energy future recognizes the importance of the energy system for human development and the need to maintain the integrity of the Earth's biophysical systems. Such a vision should entail the following elements: [4]

- **Universal access to electricity and clean cooking by 2030**. Achieving this would reduce the current reliance of a large percentage of the population in developing countries on traditional biomass.
- **Energy for development by 2050.** Provision of affordable energy of sufficient quantity and quality is crucial to support the long-term economic development of all countries.
- **Reducing air pollution in compliance with the World Health Organization air quality guidelines**[5] for the majority of the world population by 2030.
- **Limiting global average temperature change to 2°C by 2100 above pre-industrial levels with a likelihood of more than 50%.**[6]

Global and regional policy frameworks need to guide the implementation of measures towards achieving the above objectives simultaneously. International cooperation will be important for several reasons: 1) measures can be more effective; 2) parties can agree on a fair burden-sharing, avoiding free-riding or competition; 3) measures may often be implemented at lower costs, and; 4) countries lacking capacity will need international support.

At the same time, however, the current negotiations within the United Nations Framework Convention on Climate Change (UNFCCC) show that competing national interests can stifle progress. Therefore, binding international policies should not be considered the only way to move towards a more sustainable energy system. For the foreseeable future, national and regional initiatives, including bottom-up initiatives by civil society, the private sector or cities and local governments, will be equally important in advancing agendas toward the sustainability objectives.

Integration

Only an integrated approach to energy policy can simultaneously fulfil the policy objectives mentioned above. Such an approach can address both the trade-offs and synergies, which are often overlooked, both in policy development and in actual investments on the ground. In most countries, separate ministries and agencies deal with individual policy objectives, rather than engage in the integrated policy-making that is required for coherent solutions. A related problem is that economic benefits, especially those accrued over longer periods of time – e.g. from energy-efficient buildings or health improvements from cleaner energy supply – are often not recouped by investors or policy-makers.

There are several examples of areas where integration could provide benefits. For instance, decarbonization of the energy system will also lead to improved air quality and greater energy security. In the case of bioenergy, policies can only be successful if they consider the impacts on climate, energy security, food systems and biodiversity. Emissions of short-lived climate forces (e.g. black carbon) offer another example of how emission reductions may lead to both health and climate benefits (see the Solutions section for more on integration).

DEVELOPING A 'SOLUTIONS SCIENCE' FOR THE ENERGY SYSTEM

Energy pathways that fulfil the space

Several studies show that different combinations of measures can lead to energy pathways that would stabilize greenhouse gas concentration below 450 parts per million (ppm) of CO_2 equivalent (ppm CO_2 eq) (a level required to keep global mean temperature at less than 2°C above pre-industrial levels with a likely chance). These pathways indicate the need for greenhouse gas emission reductions of 40–60% by 2050.

Improving energy efficiency is the single most important option, as it can create benefits across multiple policy objectives simultaneously. This is shown across a wide set of different projections by the EMF-22 model comparison study and the Energy Modelling Forum scenarios. Successful strategies should include a rapid introduction of strict building

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4. *Improving energy security* is an important policy goal, but because this notion is interpreted so differently in different countries and regions, we have not set a universal goal.
5. *Annual $PM_{2.5}$ concentration < 10 µg/m³*. Particles that are small enough to penetrate into the deep lung ($PM_{2.5}$) are considered the best indicator of the risk of pollution from combustion sources.
6. The likelihood of 50% refers to physical climate change uncertainties and thus depicts the chances that a specific greenhouse gas pathway would stay below the 2°C temperature target. The likelihood does not imply any political or technological probability of staying below the target.

codes and retrofit of buildings, the introduction of efficient transport modes (or replacement of transport by virtual communication) and the widespread adoption of the best-available technologies in industry and appliances.

Energy demand can also be reduced by changing consumption patterns and lifestyles (e.g. adopting vegetarian diets and using more public transport) and a lower population growth, particularly in the long-term. While such measures can be effective, introducing these changes may not be easy to induce through government policies as they affect societal and cultural traditions and norms. Examples of policies that have affected population growth in the past include improvements in female education and free access to reproductive health services.

On the supply side, there are several important options. Across a set of 450 ppm CO_2-eq scenarios, the share of unabated fossil fuel use declines from 80% of total primary energy in the baseline to only 35% by 2050. The rest of the supply would come from bioenergy, other renewables and nuclear and fossil-fuel energy combined with CCS.

Although many options help address a specific objective, they may also stifle sustainability in other areas. For instance, CCS and nuclear power can help reduce greenhouse gas emissions, but may face problems of safe CO_2 storage and local opposition. Renewables also have limitations, for example, with respect to their land use. Still, they can reduce greenhouse gas emissions, improve energy security and offer both centralized and off-site energy conversion. Most renewables, however, are also intermittent and require storage or back-up capacities (usually natural gas or hydropower). This, along with high up-front capital costs, keeps renewable energy prices high, despite low long-term costs. And while all energy can theoretically be produced from renewable sources, there are large economic and infrastructural constraints to achieving this.

Long-term investments need to be scaled up

Achieving the energy transformation requires dedicated efforts to increase global energy-related investments. Present investment is neither sufficient for, nor compatible with, a sustainable investment portfolio. The global investments required for achieving a set of sustainability targets are estimated at US$1.7–2.2 trillion annually (to achieve adequate supply and efficiency), compared with the present level of some $1.3 trillion (less than 2% of current world gross domestic product). For comparison, annual global fossil-fuel subsidies are estimated to be more than US$0.4 trillion, while current spending on environmental policies in OECD countries is around 1–2% of GDP. Investment priorities include renewables, efficiency and infrastructure (see Table 1); these investments are an order of magnitude larger than those required for achieving universal energy access.

There are four main short-term actions needed to finance the long-term transformation of energy systems: 1) provide stable framework conditions for energy investments, based on stable policy framework conditions with ambitious targets; 2) open up new financing sources for developing and newly industrializing countries within the scope of the UNFCCC; 3) strengthen mechanisms to encourage private investment; and 4) encourage new business models to overcome the high up-front investment burden for individual investors.

The need for policy incentives

Different policy mechanisms must be put in place to implement various technology options and attract the required level of resources. The correct combination of policy mechanisms depends on the types of technologies and objectives. Table 1 identifies policy mechanisms that can support a transition towards sustainable energy systems. These include regulations and technology standards in combination with other instruments, such as externality pricing (e.g. a carbon tax to promote diffusion of renewables, CCS or efficiency) and targeted subsidies that may promote specific options and improve affordability.

Transformation is based on RD&D effort

There is a pronounced mismatch between the RD&D focus and the technologies that would be required to enable the transformation. In particular, there is a supply-side bias, with too little RD&D and investment in demand-side efficiency. Efficiency requires significant up-front investments, the returns from which will only be seen in the long term. Financing efficiency is thus a challenge under current market conditions, which demand high and immediate rates of return. Enhanced public RD&D efforts, spurred by policy frameworks that offer incentives, can help reduce the costs and make the transformation more attractive. Further, to be effective in the context of sustainable development transitions, RD&D policies need to become more integrated, simultaneously stimulating the development and adoption of efficient and cleaner energy technologies and measures.

Integrated policymaking delivers more for less

The sum of required investments for resolving three energy-related global challenges independently of each other – mitigating climate change, reducing pollution and increasing energy security – is much larger than the costs of taking an integrated policy approach to achieve the same three targets simultaneously. Whether such an approach can work depends partly on the question of whether institutional and political impediments to achieving more integrated policy-making can be overcome, given vested interests.

Energy policy must account for differences

About half of the world's population lives in urban areas, which account for 60–80% of global economic output and energy use. This share is expected to increase further. Given these trends, energy use in cities will dominate future energy demand. Urbanization may provide opportunities, such as higher efficiency as compared with rural settings and easier access to finance. In a rural situation, other forms of energy demand are more dominant (e.g. irrigation and transport). Successful energy policies need to account for this heterogeneity.

Better governance and societal support

Reworking the incentive structures and governmental machinery from the 'top down' for more integrated decision-making is only part of the solution. 'Bottom-up' societal support will also be an essential element of a successful transformation. However, local interests do not always mesh with global interests (e.g. opposition to CCS and wind power in parts of Europe). Gaining acceptance for major changes in the energy system will depend on transparent and accountable decision-making, which needs to occur as part of an overall strengthening of the institutional capacities for governing energy systems development.

In the transition towards sustainable energy systems, the state is a central agent, but not the only one. The transition should mobilize drivers of change from society as a whole. In this context, the state plays a role as goal setter, enabler and regulator as well as a key source of capital for necessary investments in infrastructure and RD&D. The capacity of governments to provide timely regulatory mechanisms and incentives to promote analysis, feedback, learning and adjustment of enacted policies will be crucial for transforming energy systems. It is also important that instruments for governing technological transformations are differentiated, depending on the stage and maturity of the technology.

International cooperation to speed up implementation

Most of the increase in energy use is expected to take place in low-income countries, which is where most investments will have to be made. However, developing countries carry substantial barriers to implementation, such as lack of capital and appropriate financial mechanisms. International cooperation – partly based on existing financial instruments developed to support international climate policy – can help remove these barriers. Furthermore, stable institutional conditions are essential for reducing perceived high risks by investors. The increasing role of emerging economies, through which much global economic development will take place, will be a focus of international negotiations, and must be accounted for in institutional arrangements. More generally, global cooperation to enable the energy transformation depends to some extent on nation states putting global concerns and the common good before their own short-term interests.

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Acknowledgements

Most authors of this paper contributed to the Global Energy Assessment (GEA) and have benefited greatly from interactions and joint work with other GEA authors. The indirect contribution of other GEA authors to this paper is acknowledged with appreciation.

The three coordinating authors are employed by the PBL Netherlands Environmental Assessment Agency (PBL) and the International Institute for Applied System Analysis (IIASA), whose contribution is gratefully acknowledged.

Editing, design and layout: Green Ink, UK (www.greenink.co.uk)