SDG 7 ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE AND MODERN ENERGY FOR ALL

David McCollum
Luis Gomez Echeverri
Keywan Riahi
Simon Parkinson

INTRODUCTION

Access to affordable, reliable, sustainable and modern energy is the focus of SDG7. It is underpinned by three targets: ensuring universal access to energy services (7.1), increasing the share of renewables in the energy mix (7.2), and improving energy efficiency (7.3). The priorities for implementing SDG7 are to enhance international cooperation and promote investment (7.a) and to expand infrastructure and upgrade technology in developing countries (7.b).

While SDG7 contains the fewest number of targets of any SDG (along with SDG13), it is no less important a development priority. Indeed, modern energy is fundamental to human development: it launched the industrial revolution more than two centuries ago and has contributed to the near-continuous economic growth that has been achieved globally since that time. The services that energy makes possible – from mobility to manufacturing, agriculture to heating and lighting – are ubiquitous in the industrialised world, and have been around for so long that people commonly take for granted what makes these services possible. Not everyone has enjoyed the benefits that modern energy forms can provide, however. Energy resources are unevenly distributed around the world, and where they exist and are relatively easy to produce, the necessary energy extraction and conversion infrastructure (e.g. gas drilling, oil refineries, wind turbines, electricity transmission lines) requires significant sums of money to bring online. Constraints to financial and human capital often result in some among us being left out of the modern energy society.

Achieving the targets of SDG7 will impact, and be impacted by, progress along the many other SDG dimensions. Yet, while this is the focus of the current chapter, it is also important to note that there are interlinkages (some positive, others negative) between the three energy targets themselves. For example, distributed sources of renewable energy (solar, biogas) could help rural communities achieve energy access. Doing this via a more centralised, infrastructure-heavy approach would also be possible, but there is a risk that elevated energy prices could cause some households to forego access to the network. The energy efficiency target, meanwhile, is a 'win-win' strategy on essentially all accounts. Every unit of energy saved, either through technological or behavioural/conservation means, is a unit that does not need to be produced. This, in turn, lowers the energy requirements for renewables expansion and universal access provision, thereby easing the burden of attaining each.

The text that follows provides an overview of interactions at the goal level between SDG7 – the 'entry level goal' for this assessment – and the other 16 SDGS. Taking into account all the underlying targets of this entry goal, a set of key interactions is identified between the SDG7 targets and those of other SDGS, principally interactions within the range of the highest magnitude or strongest impacts based on available scientific literature and expert knowledge. The typology and seven-point scale for characterising the range of positive and negative interactions described in the opening chapter to this report is used to assess the selected target-level interactions and the context in which they typically occur. Illustrative examples from different world regions show how these linkages manifest in practice. Policy options are identified for how to maximise positive interactions and minimise negative interactions between now and 2030, and beyond. The chapter concludes with a list of key knowledge gaps related to the interactions studied. An elaborated analysis of these issues is described in McCollum et al. (2017).

KEY INTERACTIONS AT **GOAL LEVEL**

7 + 1

Ensuring the world's poor have access to affordable, reliable and modern energy services enables the goal of poverty eradication. However, decarbonising energy systems by promoting renewables and boosting efficiency could result in price shocks if the costs of transition to a low-carbon economy are not buffered in some way. This could prevent universal energy access, since higher energy prices would add to the challenges of improving the standard of living for the world's poorest. Investment costs for many small-scale renewable energy technologies (such as household solar photovoltaic systems) have decreased considerably in recent years, and in some areas are now the least-cost electricity supply option. If technology innovation trends continue, renewable electricity generation will become profitable in a greater number of regions. This could enable poor communities with electricity transmission access to make use of local clean energy resources, potentially allowing for revenue generation. Moreover, some of the poorer regions of the world possess some of the highest quality renewable energy supplies (e.g. biomass and solar power in Africa). Progress in making use of those potentials could help to reduce poverty, as long as the benefits accrue to local suppliers.

7 + 2

As a renewable energy source, bioenergy is likely to form an increasingly important part of the energy mix. Commercialising bioenergy production could lead to the creation of agricultural and forestry jobs, as well as to higher wages and more diversified income streams for land owners (aiding food security). However, developing agrofuels could also lead to higher global food prices (and thus reduced access to affordable food by the poor) as well as to competition between agrofuels and food crops over scarce agricultural land, water and energy for agrofuels production. Another key interaction is energy for agricultural operations. Providing energy to impoverished farmers is likely to make it easier for them to pump groundwater and mechanise their farm equipment to increase food crop yields, and will enable easier maintenance of cold chains (temperature-controlled supply chains) for marketing produce and thus improving regional diet diversity. Some forms of bioenergy – such as fuels produced from domestic wastes – do not compete with food production, although transportation of waste residues and operation of agrofuel processing plants can be energy-intensive.

7 + 3

The SDG7 targets are directly linked to achieving major reductions in air pollution. Improving air quality, and by extension human health, is especially important for those living in the dense urban centres of both developed and rapidly developing countries. Thermal comfort (heating and cooling) and cooking are key to good health, which highlights the need to ensure access to affordable and reliable energy. Use of energy-efficient appliances such as clean cook-stoves is fundamental to improving indoor air quality. Energy is also essential for refrigeration, which contributes to food conservation along the supply chain and helps avoid the health risks associated with bacterial contamination. Refrigeration enables rural populations to store the medicines and vaccines necessary for ensuring community health. Energy-saving measures related to 'active travel' (cycling and walking) can help improve health and well-being by lowering rates of diabetes, heart disease, dementia, and some cancers; but at the same time can offset efforts to reduce deaths and injuries from road traffic accidents if the infrastructure provided is unsatisfactory.

7 + 4

Well-lit, well-heated, and well-cooled schools and households are essential for creating comfortable learning spaces for children and adults and reduce dependency on natural variations in daylight. The information and communication technologies on which modern learning is based also require energy input. Ensuring energy access in countries where access to reliable energy services may be lacking can therefore reinforce education goals. The level of educational attainment within a society can influence its collective awareness about sustainable development and sustainable lifestyles, including an understanding of why transformative changes in the energy system are necessary. Knowledge and skills in the area of energy sustainability may then influence which technological, financial and political solutions are feasible to implement. Thus, quality education is an enabling factor in achieving SDG7. Energy is also a key element of science education; and better inclusion of energy in school curricula may foster better science literacy at all levels of society.

7 + 5

Access to energy would expand the number and range of opportunities for women, for example enabling women to work from home and thereby generate an independent source of income. Impacts will initially be greatest at the household level, with society-wide implications emerging over time. The more empowered women become, the more likely they are to push local initiatives that directly benefit them from an energy-access perspective, since they are often the ones to gain most from the use of cleaner, easier-to-obtain fuels for cooking and lighting. Access to energy reduces the importance of physical gender differences in the labour force, increasing access to the professions for women. Public outdoor lighting would increase security for women and girls, potentially allowing them to continue autonomous activities outside their households after dark.

7 + 6

Thermal cooling and resource extraction require vast amounts of water; while wastewater from the energy sector releases large quantities of thermal and chemical pollution into aquatic ecosystems. In most cases, a shift from fossil energy technology to renewables and boosting energy efficiency would reinforce the achievement of sustainability objectives related to water access, scarcity, management and pollution. However, some renewable energy sources (including bioenergy and hydropower) could, if not managed correctly, have counteracting effects that compound existing water-related problems. Installing and operating water extraction, transport and treatment systems requires a considerable amount of energy ('energy-for-water'). Expanding these services to poorer populations will be enabled by universal energy access. A shift toward unconventional water supply options (e.g. desalination) in the world's water-stressed regions will generally increase energy demand. This may benefit renewables: if water-related infrastructure and equipment can be used for real-time demand-side power management, developing water and sanitation systems could help grid integration of intermittent electricity sources. However, water-related energy demand increases could be challenging if there are constraints to up-scaling renewables quickly.

7 + 8

Deploying renewables and energy-efficient technologies can spur innovation and reinforce local, regional and national industrial and employment objectives. Active measures may need to be taken to minimise the negative impacts of a large-scale switch to renewable energy on those currently working in the fossil fuels sector: government support may be needed to help businesses re-tool and workers re-train. Workforce migration may also be needed because fossil fuel development is highly concentrated whereas renewable energy projects are distributed across wide geographic areas. To support clean energy efforts, strengthened financial institutions in all countries are necessary for providing capital, credit and insurance to local entrepreneurs attempting to enact change. Decarbonising energy systems through an up-scaling of renewables and energy efficiency could potentially constrain countries' economic growth; but strong growth decoupled from environmental degradation and job growth from installing and maintaining renewable energy and energy efficiency technologies that could more than compensate for economic costs associated with these changes means this interaction seems only mildly counteracting. Decarbonising fossil-fuel based energy sources by technologies such as carbon capture and storage can increase demand for a skilled workforce and create economic growth, although higher energy prices may stimulate energy efficiency related job creation.

7 + 9

Building resilient infrastructure, promoting inclusive and sustainable industrialisation and fostering innovation are a necessary pre-condition for, and indivisible from, achieving the SDG7 targets on access to energy services, increasing the share of renewables in the energy mix, and increasing energy efficiency. Upgrading and retrofitting infrastructure to make it more reliable and sustainable; providing financial and technical support to promote technological development; and encouraging innovation through scientific research funding – will each directly benefit countries' energy industries. Eco nomic, social and environmental benefits could accrue to individuals and firms in urban areas, since this is where most innovation and industrial activity tends to occur, and where recycling and reuse is highly-efficient. One concern could be the early retirement of fossil energy infrastructure (power plants, refineries, pipelines), which may be needed to mitigate related sustainability challenges. Unless targeted policies are used to help alleviate the burden on industry, the economic implications could in some cases be negative. Carbon pricing through a carbon tax or cap-and-trade market mechanism may be used to reduce carbon intensity in industrial processes and provide states with funds to help innovation and compliance in the industrial sector.

7 + 10

Ensuring energy access and increasing the share of some types of renewable energy (such as agriculture and forest-based bioenergy) can enable educational, health and employment opportunities for the rural poor, with positive effects on income and equality. Universal access to energy is key to achieving equality, where all are free to exercise their development options. Good governance will help to avoid clashes between objectives. For example, policymakers must be careful to ensure that energy remains affordable to the poorest, especially if higher-cost renewables are deployed. Ideally, institutional and financial capacity should be locally sourced, although foreign investment and development funding (from rich to poor countries) is also important. Both can foster socio-economic development and help reduce inequalities between countries, as well as within them (across different social, gender, economic, ethnic, religious and racial groups). Locally available sources of renewable energy may also reduce inequalities due to international fossil fuel market variations that could result from political or speculative pressures.

7 + 11

Energy is central to urbanisation; energy allows cities to grow and perform. Clean, efficient energy systems, in particular, create the conditions for cities and human settlements to be inclusive, safe, resilient, less-polluting, and more sustainable. An up-scaling of renewable energy and energy-efficient technologies and infrastructure systems (such as transit-orientated, mixed-use developments) can have a large impact on the sustainability of a given city or community. Similarly, if cities move in a more sustainable direction in terms of transport, housing and urban planning, air quality, resource efficiency, and/or climate change mitigation, then this will create the necessary enabling conditions for achieving SDG7, because renewables and efficiency will need to feature in the portfolio of solutions. Smart grids in cities will improve energy efficiency and facilitate the development of renewable energy at the domestic or neighbourhood scale.

7 + 12

Efforts to reduce waste and pollution, improve resource efficiencies, increase recycling and reuse and promote awareness about more sustainable lifestyles coincide with the requirement for more efficient use of natural resources (fossil and renewable). For example, phasing out inefficient, wasteful, and market-distorting fossil fuel subsidies – in a way that minimises counteracting adverse side-effects on the poor – could reinforce attempts to deploy renewables and energy-efficient technologies and consumption patterns. Responsible consumption triggers responsible production and minimises waste, in turn minimising the amount of energy associated with waste handling and management.

7 + 13

An immediate up-scaling of renewables and energy efficiency is strongly linked to keeping global warming to well below 2°C above pre-industrial levels, the legally binding objective of the Paris Agreement. Achieving SDG7 could put the world on track for meeting this challenge, though it would not be entirely sufficient given the scale of the decarbonisation challenge. In the reverse direction, better integrating climate change measures into national planning, improving education, awareness, and capacity on climate issues, and mobilising funds for mitigation will all go a long way in furthering targets for renewables and energy efficiency. Under certain conditions, providing universal access to modern energy services by 2030 is fully consistent with the Paris Agreement, because it is not expected to have more than a minor effect on global carbon emissions.

7 + 14

Renewable energy generated from offshore wind, wave and tidal power farms is a good resource base for coastal communities. Conserving and sustainably using marine resources (including fossil fuel reserves – much of which are located offshore), calls for increased scientific knowledge of the impacts of their exploitation on aquatic habitats, and for increased research, human and institutional capacity to mitigate the adverse effects of these energy-related activities. Upscaling of renewables and energy-efficient technologies and consumption patterns will help decrease ocean acidification (via lower carbon emissions), accidental impacts from energy-production and transport activities on aquatic habitats, and marine thermal pollution from cooling at coastal power plants. Adverse side-effects of ocean-based energy installations include spatial competition with other marine activities (such as tourism, shipping, resource exploitation) and with marine and coastal habitats and protected areas. Geoengineering projects such as ocean fertilisation may have additional energy impacts, either positive or negative as the need for fertilisers and biomass harvesting are considered.

7 + 15

Ensuring that the world's poor have access to modern energy services would reinforce the objective of halting deforestation, since firewood taken from forests is a commonly used energy resource among the poor. On the other hand, protecting terrestrial ecosystems, sustainably managing forests, halting deforestation, preventing biodiversity loss and controlling invasive alien species could potentially clash with efforts to expand renewables, if that would mean constraining large-scale use of bioenergy. Land-use changes involved in extensive renewable energy production such as hydroelectric dams may conflict with SDG15. Good governance and sound implementation practices are critical in all such cases. For example, policies could ensure that bioenergy crops are primarily grown on degraded lands, which might mean they have little impact on global agricultural markets and could simultaneously improve soil carbon and terrestrial biodiversity. International coordination is of particular relevance, especially because bioenergy deployment in one country can have indirect land-use change impacts elsewhere in the world.

7 + 16

Effective, accountable and transparent institutions are needed at all levels of government (local, national, international) for creating the conditions necessary to be able to ensure universal energy access, increase the share of renewables and increase energy efficiency. Strengthening the capacity of developing countries to participate at the international level (such as within United Nations agencies, the World Trade Organization, regional development banks and beyond) will be important for issues concerning trade, foreign direct investment, labour migration, policy and institutional arrangements, and technology transfer. Reducing corruption, where it exists, will help these bodies and related domestic institutions maximise their societal impacts and ensure that the optimal mixes of measures for energy access provision, renewable energy and energy efficiency are implemented effectively. Eliminating perverse subsidies for unsustainable energy sources could help to achieve both better governance and sustainable energy goals.

7 + 17

This goal is about strengthening the means of implementation for achieving all SDGS. However, to ensure access to affordable, reliable, sustainable and modern energy for all, it is critical that all countries are able to mobilise the necessary financial resources (such as via taxes on fossil energy, sustainable financing, foreign direct investment, financial transfers from industrialised to developing countries); are willing to disseminate knowledge and share innovative technologies; follow recognised international trade rules while at the same time ensuring that LDCS are able to take part in that trade; respect each other's policy space and decisions; forge new partnerships between their public and private entities and within civil society; and support the collection of high-quality, timely, and reliable data relevant to the furthering of their aims.

KEY INTERACTIONS AT **TARGET-LEVEL**

In terms of its three main elements – ensuring energy access (7.1), increasing the share of renewables (7.2), and speeding up the rate of energy efficiency improvement (7.3) – SDG7 has links with all 16 other sdgs. This section analyses some of these interactions in detail at the target-level for a subset of the SDGS. This selection was based on the strength of the interlinkages and the magnitude and scale of impact in relation to the overall objective of the 2030 Agenda, while ensuring a balanced consideration of the economic, social and environmental dimensions. Target-level interactions are judged to fall within one of seven categories and are scored accordingly: indivisible (+3), reinforcing (+2), enabling (+1), consistent (0), constraining (-1), counteracting (-2), and cancelling (-3). Following a general analysis of the selected interactions, specific examples are provided to illustrate how interactions unfold in different geographical and policy contexts.

Six goals were selected for detailed analysis, with three accompanied by an illustrative example (as noted):

SDG1
SDG2
SDG3
Improving air quality and health for the rural poor in India
SDG6
Groundwater depletion and renewables in Saudi Arabia
SDG8
Renewables and job creation in Germany
SDG13

SDG 7 + SDG 1

TARGETS	KEY INTERACTIONS	SCORE	POLICY OPTIONS
7.1 ⟶ 1.4	Energy is a basic service, therefore universal energy access reinforces the achievement of 1.4	+2	Develop energy access policies that support clean cooking-stove purchases and lower fuel bills Institute capacity building and education programs to support individuals in the energy industry at the local level
7.2, 7.3 ⟶ 1.4	Decarbonising the energy system through renewables and efficiency is consistent with the provision of basic energy services as long as policies help to shield the poor from any fuel price increases that may result. Lacking such policies, 7.2 and 7.3 could constrain the options for achieving 1.4	0/-1	Where necessary, put in place compensation mechanisms that could be required to protect the poor from energy price shocks resulting from efforts to boost the deployment of renewables and energy efficiency
7.2, 7.3 ⟶ 1.5	Renewables and energy efficiency are a necessary pre-condition for limiting global climate change; in turn, exposure of the poor to climate-related extreme events will be reduced	+2	Policies ensuring that the energy system is decarbonised through an upscaling of renewable energy technologies and energy efficiency efforts are critical for limiting the extent of global climate change and, in turn, exposure of the poor to climate-related extreme events

KEY POINTS

SDG7 affects SDG1 through the dimension of energy poverty and the need to provide the world's poor with access to affordable, reliable and modern services

Decarbonising the global energy system by promoting renewables and boosting energy efficiency can lead to major reductions in greenhouse gas (GHG) emissions over the longer term, which may help reduce the exposure of the poor to climate-related extreme events and other environmental disasters

If policy interventions are not managed properly, the poor could experience economic shocks in the form of higher energy prices, thus increasing rather than reducing poverty and impairing the transition to universal energy access to modern fuels

The lack of modern energy services contributes to poverty, not only in absolute terms, but also in terms of GDP (because the energy, personnel and tools involved are often from the 'informal economy'). Thus, accessing modern energy services will improve economic exchanges locally and raise per-capita economic activity and productivity

KEY INTERACTIONS

The principal interactions between SDG7 and SDG1 concern targets **1.4** and **1.5**. Access to modern energy forms (electricity, clean cooking-stoves, high-quality lighting, and sustainable fuels) **(7.1)** is fundamental to human development since the energy services made possible by modern energy forms can provide a solid foundation for escaping the poverty trap, particularly in the poorest parts of developing countries: namely rural and urban communities in South Asia, Southeast Asia, and Sub-Saharan Africa (Pachauri et al., 2012) **(1.4, 1.5)**. Too many people in these locations still rely on polluting and unhealthy fuels (charcoal, firewood, animal dung) for cooking, heating and lighting: roughly 3 billion people, or 40% of the world's population lack modern fuels for cooking while an estimated 1.1 billion people live without electricity (UN, 2016). Clear progress is being made to provide access to these individuals, but in the meantime their health continues to suffer (from the harmful effects of burning 'traditional' fuels indoors), and they are forced to spend too much time acquiring fuel, preparing meals, and/or keeping the lights on. Modern fuels and technologies (such as delivered gas powering a clean cooking-stove), whether made available in a centralised or distributed way, can alleviate these burdens, which often fall disproportionately to women and children. Impacts can be substantial: time is freed up, which may be used to pursue employment, educational, and leisure and wellness opportunities (Pachauri et al., 2012).

Decarbonisation of the global energy system through a major up-scaling of renewables **(7.2)** and energy efficiency **(7.3)** efforts is needed to dramatically cut GHG emissions (Clarke et al., 2014). Such actions are unavoidable if the exposure of the world's poor to increased climate-related extreme events and other environmental disasters is to be significantly reduced

(IPCC, 2014) **(1.5)**. An acknowledged risk of transitioning the energy system away from fossil fuels toward renewables is that energy services could become less affordable for those who need them most. In other words, higher energy prices could hinder the goal of universal energy access and slow down some structural and infrastructural changes among the lesser developed economies (Jakob and Steckel, 2014). Policies must be designed such that they take an integrated and holistic perspective of multiple policy objectives. For example, Cameron et al. (2016) found that poorer populations can be shielded from fuel price rises through access policies (e.g. subsidies) that support clean cooking-stove purchases and lower fuel bills. Funding support for these policies could be derived from carbon tax revenues or financial flows from carbon trading – leveraging the same carbon pricing mechanisms being simultaneously used to incentivise renewables deployment and energy efficiency efforts. In addition, the local production of renewable energy (biomass, solar, wind) could lead to new income streams, which could counterbalance any system-wide energy price rises.

KEY UNCERTAINTIES

(1) The level of local skills and knowledge (technological, business, or otherwise) that will exist within the individual communities in 10 to 15 years, especially concerning the capacity to ensure that energy access provision remains adequate, reliable and affordable. This depends strongly on educational attainment, which itself is affected by energy access in a continuous loop. (2) Exact quantifications for what a proper, decent level of energy access actually entails, in terms of the full range of services required to escape the poverty trap.

KEY DIMENSIONS

Time: Major structural and infrastructural changes will be needed to achieve energy access targets throughout the world, often in hard-to-reach rural areas. Achieving these goals may need a redefinition of strategies and policies in urban capitals, and this could take time given the lack of sufficient resources in many poor countries and the rigidity of the political systems in some nations.

Geography: (1) Lack of energy access is both a rural and an urban problem, and is most acute in the poorest parts of South Asia, Southeast Asia and Sub-Saharan Africa. Modernising the lives of these people, in terms of energy service provision, could have global economic consequences (due to newly created employment and educational opportunities). (2) Increasing energy efficiency and substituting fossil fuel energy by renewables in any country of the world, whether rich or poor, will benefit those in poverty by reducing their exposure to climate-related extreme events and other environmental disasters. However, reducing exposure to climate change-related extreme events is a complex issue where decarbonisation of the energy supply plays a minor role in the short term compared to other land use policies and local governance.

Governance: (1) The supposed trade-off between energy system decarbonisation (renewables/efficiency) and energy access is non-genuine. The trade-off is not intrinsic to the decarbonisation measures themselves, but to poorly designed policies. Compensation mechanisms can be designed to ensure that the poor are shielded from energy price shocks. However renewable energy prices are generally locally determined and tend to decline with technological advancement. This protects the poorest from the highly speculative prices associated with fossil fuel energy. (2) Enabling policies are key to mobilising transformational change in energy systems, with respect to technology investments and infrastructure changes.

Technology: (1) Continued improvements in the design, efficiency, and cost of efficient, portable cooking-stoves and lighting devices are needed, particularly because the up-front capital costs of these technologies can often account for weeks/months of income for the poorest households. If costs are too high, then this could prevent individuals from putting their limited funds toward other useful purposes (such as educational and business opportunities, healthcare, internet and communications tools). However, technical advancement in renewable energy technology (e.g. wind turbines, solar panels, heat exchange devices) drives lower prices for sustainable energy services. (2) Whether new energy systems for the poor are centralised (national grids) or decentralised (local level only) will depend on each country's geographical and governance context, as well as on the existing state of infrastructure in the region.

Directionality: Unidirectional. Energy access provision is necessary (but not sufficient) for delivering the types of service required for escaping the poverty trap (education, employment, healthcare). Yet, in the reverse direction, provision of those services by some other means (such as programmes to regularly transport disadvantaged individuals to more affluent communities for those services) does not guarantee that energy access will be achieved in those communities where it is most needed. Furthermore, demographic pressure is a key issue for energy supply in rural areas as well as urban communities. Without a clear indication of future demand, the supply may never be adequate.

SDG 7 + SDG 2

TARGETS	KEY INTERACTIONS	SCORE	POLICY OPTIONS
7.2 ⟶ 2.1	If not restricted to degraded lands, large-scale global production of purpose-grown energy crops could drive up food prices and so constrain the achievement of ending hunger for the poor	0/-1	Design legislation so that competition of bioenergy crops with land use for other purposes is avoided. This can be done by prioritising bioenergy production on degraded land; maximising energy production from agricultural wastes (from non-bioenergy crops), and investing in research and technologies that lead to higher crop yields
7.2 ⟶ 2.3	Bioenergy production could reinforce initiatives pursuing agricultural jobs creation and higher farm wages. Bioenergy from agricultural wastes also provides higher returns for job creation	+2	Structure policies should be designed so that they promote the creation of bioenergy-related jobs and diversified income streams for farmers, particularly for women, indigenous groups, family farmers and fishers. Policies should favour waste-to-energy projects for bioenergy
7.2, 7.3 ⟷ 2.3, 2.4	Greater agricultural productivities for all types of crops, particularly bioenergy, can aid the achievement of the renewable energy target by allowing as much bioenergy to be produced on as little land as possible, thereby minimising land use competition. Energy efficiency improvements can also reinforce agricultural productivity by reducing the energy inputs needed. Bioenergy production from agricultural and forest wastes could increase productivity and efficiency in rural areas	+2	Put in place mechanisms to manage the energy, land, fertiliser and water inputs to agriculture, thereby helping to mitigate any negative effects on the environment as well as on agricultural prices (and thus on food security)

KEY POINTS

Basic energy availability is a key component in food systems that have the potential to achieve the goal of zero hunger. Energy is also a prerequisite to reduce and recycle food waste, and to preserve the long-term value of edible items.

Interactions could become stronger if bioenergy (especially from agro-fuels) is deployed on a large scale in order to meet the renewable energy targets

If policy interventions are not managed properly, food production could decrease and food prices could increase, thereby reducing access to affordable food. Access to affordable food may also be jeopardised due to long-term soil depletion associated with monocropping of agrofuels, and to hydrological changes or topsoil loss associated with the cultivation of marginal or degraded croplands for agrofuels or to replace food production lost to agrofuel farming

While agricultural productivity can be increased by raising levels of energy inputs into agriculture (fertiliser, agrochemicals, pumped irrigation, machinery, fossil fuels for cultivation and transportation, post-harvest storage), the potential trade-off is higher energy requirements for the sector

Second- and third-generation waste-to-energy technologies are attractive because agricultural, forest and domestic wastes can be used as stockpiles for energy services. These do not require supplemental crop production or forest harvest and provide room for manoeuvring in existing productions. Moreover, fuels from domestic wastes do not depend on prevailing weather conditions and so are resilient to climate change

KEY INTERACTIONS

More mechanised, modern farm practices can have a strong impact on farm yields, and thus livelihoods (**2.3**). Large-scale bioenergy production could play an increasingly important role as renewable energy (**7.2**) is ramped up in scale toward 2030 and beyond. Because of open questions surrounding bioenergy, the following discussion focuses on its benefits and consequences. Most closely interacting with SDG7 are targets **2.1** and **2.3**/**2.4**, the latter supported by increasing the speed of energy efficiency improvements in the agriculture sector.

The impacts of increased bioenergy utilisation on food and agriculture systems are complex and context-dependent. The effects may be positive or negative, depending on the type of bioenergy supplied, its source, and the size of the operation (Smith et al., 2014). Creutzig et al. (2013) and others have shown that producing bioenergy crops can contribute positively to local economies, for example by creating jobs in rural areas. Higher wages, and more diversified income streams for farmers, are additional benefits (Gohin, 2008). This is true, for instance, of the Brazilian sugarcane ethanol industry, where average farm incomes are greater than in most other agricultural sectors in the country (de Moraes et al., 2010; Satolo and Bacchi, 2013). Good governance and careful planning are key to ensuring that the benefits go to those that deserve them. If poorly regulated, large-scale bioenergy deployment could end up harming the very farmers that SDG2 attempts to support, particularly if the revenues accruing from the sale of bioenergy go to company owners and investors rather than to small-scale, local landowners and tenants, or if the revenues are not shared equally between parties (van der Horst and Vermeylen, 2011). In the worst case, small-scale farmers could even be displaced, either from their lands or in local business networks, or both. In other words, the distributional impacts of bioenergy deployment – while still uncertain, given their situational dependencies – could be non-trivial (Davis et al., 2013; Muys et al., 2014). The topic requires future study, at the empirical/case-study level and by national- and global-scale integrated modelling frameworks.

A potential risk of large-scale bioenergy deployment is that crops grown for energy purposes could compete with existing crops grown for other purposes, such as food production (Smith et al., 2014). Such concerns are often captured in the 'food versus fuel' debate; more specifically, concerning food security (higher or more volatile food prices) and the displacement of communities and their agro-economic activities. While impacts are felt most acutely locally, global market dynamics may be the ultimate driver, with bioenergy deployment in one country creating ripple effects that propagate worldwide (so-called 'indirect land-use change'). In fact, bioenergy deployment could lead to co-benefits in one country, but adverse side-effects elsewhere. Good governance, in the form of well-designed policies, is key to avoiding adverse impacts, or at least minimising them to the extent possible. Certain types of crops, either for energy or food production, are more land-intensive than others. Hence, decreasing the area needed for growing crops also decreases the risk of land competition, and by extension the threat of food insecurity and community displacement, as well as deforestation. Policies, agricultural research, and extension programmes that incentivise and promote greater agricultural productivities (improved and sustainable crop yields, that do not sacrifice long-term productivity for short-term yields) can all help. They can also direct farmers toward producing bioenergy on degraded and marginal land. Another key approach is to maximise energetic valorisation of agricultural residues and organic wastes. Both strategies would largely avoid competition between bioenergy and other land-use purposes, although there are limits to how much bioenergy can be produced by these means. Food prices may still rise even if care is taken to avoid such an outcome; yet, according to several integrated models, the potential price effects induced by unconstrained levels of climate change and the resultant water and temperature impacts are far greater than the bioenergy-induced effects (Lotze-Campen et al., 2014). While bioenergy, strictly speaking, is not necessary to meet **target 7.2**, its availability could help in certain dimensions, such as for reducing the global aggregate costs of climate mitigation (Clarke et al., 2014).

KEY UNCERTAINTIES

(1) It is not yet clear how quickly traditional food systems can be modernised and mechanised, or what the energy use implications of this would be (such as for food conservation via different energy-related processes, drying facilities for harvests, establishing cold chains during transport and distribution, and refrigeration at the household level, among others). (2) There are large uncer-

tainties in terms of the type of indirect land-use change impacts that might arise through deployment of bioenergy in a given country context (that is, which types of agricultural lands throughout the world are converted to other purposes in response to changing food/crop prices).

KEY DIMENSIONS

Time: Some impacts may be short-term in nature (i.e., over a few years or crop cycles), with a sustainable equilibrium then again be reached. Other impacts may be longer term in nature, perhaps even irreversible over the course of a generation (such as if forests are cleared for crop production).

Geography: (1) Some areas could benefit while others are, simultaneously, negatively impacted. For example, in Scandinavia farmers and foresters have benefitted from bioenergy production through the diversification of markets. However, to the extent these producers have changed food export patterns, or do so in the future, then food security globally could be affected. (2) While the impacts of large-scale bioenergy production are felt most acutely locally, global market dynamics may be the ultimate driver, with bioenergy deployment in one country creating ripple effects that propagate worldwide. In such situations, it is likely that the most benefits will be obtained when bioenergy is obtained from waste, rather than primary agricultural production.

Governance: (1) Good governance and careful planning are key to ensuring the benefits of bioenergy production accrue to small-scale farmers and their local communities. Well-designed policies are also needed to ensure that adverse side-effects of large-scale bioenergy utilisation are minimised or avoided, including incentives and support mechanisms that (i) promote greater agricultural productivities (improved and sustainable crop yields) and (ii) direct farmers toward producing bioenergy on degraded lands and maximising energy production from agricultural wastes (from non-bioenergy crops). (2) Adverse effects of demand-side driven policies (such as a mandatory percentage of ethanol or biodiesel in fuels) may be more important than their energy security or climate change mitigation effects.

Technology: Greater agricultural productivities (improved and sustainable crop yields), both for bioenergy and food crops can help minimise or avoid direct competition of different crop types for land in different countries. Waste-to-energy technologies and biorefineries are also important options and would benefit from increased R&D effort.

Directionality: Bidirectional. Large-scale utilisation of agrofuels can affect food production, and thus the goal of ending hunger. In the reverse direction, ending hunger may impose limits as to how much cropland is available for bioenergy production; greater agricultural productivities for all types of crops can minimise or avoid land competition and degradation.

SDG 7 + SDG 3

TARGETS	KEY INTERACTIONS	SCORE	POLICY OPTIONS
7.1 ⟶ 3.8	Universal energy access enables the provision of food, medicines and vaccines because mechanised refrigeration is essential for effective storage	+1	Develop energy access policies to facilitate the spread of refrigeration in rural areas, which will be beneficial for food preservation (to reduce the amounts of food that normally go to waste) and the storage of life-saving medicines and vaccines
7.1, 7.2, 7.3 ⟶ 3.9	In most cases, efforts to provide energy access, expand renewables, and promote energy efficiency will lead to simultaneous reductions in air pollutant emissions; thus the targets are reinforcing	+2	Draw up legislation promoting renewable energy and energy efficiency across multiple sectors to reduce negative impacts on the health of rural and urban populations. Pay particular attention to those sectors that are currently the most energy-intensive and energy-polluting, such as buildings, industry and transport in densely populated urban areas, as well as those rural areas with a high use of chemicals for agricultural production Energy access policies that promote the use of cleaner energy and which are less-polluting can significantly reduce premature mortality. Policies targeting those sectors of the population with highest exposure to indoor and outdoor pollution will be most beneficial
7.3 ⟶ 3.4	Energy-saving measures related to 'active travel' (cycling and walking) can lead to improved health and well-being by lowering rates of diabetes, heart disease, dementia, and some cancers	+1	Where possible, ensure urban planning and land use management policies encourage energy-saving 'active travel' modes (cycling and walking). This will benefit community health, in terms of lower rates of diabetes, heart disease, dementia, and some cancers
7.3 ⟶ 3.6	Energy-saving measures related to 'active travel' (cycling and walking) can constrain efforts to reduce deaths and injuries from road traffic accidents, if the provided infrastructure is unsatisfactory and if higher air quality standards are not required	0/-1	Build cycling and walking infrastructure that is safe for all, to reduce deaths and injuries from road traffic accidents

KEY POINTS

Providing energy access, promoting renewables and boosting efficiency can lead to major reductions in air pollution, and by extension significant improvements in air quality and human health, particularly in the dense urban centres of the rapidly developing world

Elevating levels of walking and cycling ('active travel') in cities can also lead to better health and well-being among the local population

Energy is vital to providing thermal comfort in buildings. Energy access is also needed for refrigeration, which is essential for maintaining food quality along the supply chain for providing city markets with healthy products. Refrigeration is also critical for rural populations; for storing food, medicines and vaccines

KEY INTERACTIONS

The principal interactions between SDG7 and SDG3 concern target **3.9**. Present-day fossil energy extraction, conversion, and end-use activities emit a range of air pollutants, as do some traditional bio-fuels (dung, wood, waste, and peat or charcoal prepared and burned in traditional ways) many of which are harmful to humans, leading to respiratory and cardiovascular diseases and even cancer. Thus, increased efforts to move the world's poor towards clean renewables and to significantly increase energy efficiency (i.e. lower the requirements for energy of all types) would drive major reductions in emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_X), black carbon (BC), fine particulate matter (PM2.5), and mercury, among others. Targets **7.2** and **7.3** primarily affect outdoor (ambient) air pollution, whereas target **7.1** would most affect indoor (household) pollution. The level of exposure of a given population to energy-consuming activities (power plants, factories, cars, kilns) significantly influences the human health effects of air pollution – and, by extension, the improvements that can be attained by meeting or exceeding the three energy targets. The dense cities of the rapidly developing world (Beijing, Delhi, and many others) have the most to gain; large metropolitan centres in the industrialised world (London, Los Angeles) could also benefit substantially.

Several forward-looking, integrated scenario studies have estimated the air quality co-benefits that could be achieved – in diverse contexts – by providing energy access, promoting renewables, and boosting efficiency. For example, Rose et al. (2014) found that in China strong efficiency and decarbonisation efforts could result in SO_2 emissions reductions of 15–75% below reference levels by 2030 and 40–80% by 2050. Chaturvedi and Shukla (2014) drew similar conclusions for India: reductions of 10–80% in the long term, depending on the scenario and pollutant under consideration. At the global level, Rafaj et al. (2013) found reductions of 40% (SO_2), 30% (NO_X), and 5% (PM2.5), relative to a baseline scenario, are possible by 2030. Meanwhile, Riahi et al. (2012) showed the importance of providing modern energy access (fuels, electricity, clean cooking-stoves) for improving indoor air quality in the developing world. They estimated global reductions of 50% (SO_2), 35% (NO_X) and 30% (PM2.5) by 2030 in scenarios that include a rapid up-scaling of renewables and energy efficiency measures. This could help reduce globally-aggregated disability-adjusted life years (DALYS) by more than 10 million over the next one and a half decades, mostly in developing countries. Similar conclusions were reached by the IEA (2016). It should be noted, however, that not all energy-saving measures are beneficial for air quality: such as when switching from gasoline to diesel vehicles. Similarly, although biofuels are a form of renewable energy, they are not necessarily low-polluting in their life cycle.

There has been some attempt to monetise the air quality co-benefits of energy efficiency and decarbonising the energy system (Nemet et al., 2010). West et al. (2013) estimated the co-benefits of avoided mortality to be USD 50–380 per tonne CO_2 globally (70–840 for China and 20–400 for India). Benefits of this magnitude are similar to the costs of ramping up renewables and energy efficiency over the coming decades (Clarke et al., 2014).

Energy-saving measures, such as integrated transport and urban planning strategies that promote 'active travel', can also lead to better health and well-being, including lower rates of diabetes, heart disease, dementia, and some cancers (Woodcock et al., 2009; Haines, 2012; Shaw et al., 2014) **(3.4)**. However, if the provided infrastructure is unsatisfactory, increased 'active travel' could increase risk of death and injuries from road traffic accidents **(3.6)**.

Moreover, though not well researched up to this point in time, a potential risk of certain forms of clean energy is that some pathways may create new health issues, either within the region of production or elsewhere (e.g. siloxane emissions from biogas plants, growing hazardous waste flow due to photovoltaics or battery production and disposal).

KEY UNCERTAINTIES

(1) The future climate impacts on local atmospheric conditions affects are a key uncertainty affecting ambient concentrations of harmful pollutants. (2) The long-term effects of current/recent investments in dirty fossil energy infrastructure and vehicles, and the possibilities for retrofitting those facilities to make them less polluting are also unknown. (3) How consumer behaviour and preferences might change over time is unclear, especially with respect to adopting more active lifestyles that are less dependent on motorised transport. (4) Some forms of clean energy production could potentially create new health issues.

KEY DIMENSIONS

Time: Transformational changes in energy systems take a considerable amount of time to effect, given the long-lived infrastructure. While vehicles and other consumer appliances may have lives of 5 to 15 years, power plants and factories can last for 50 years or more. This influences how quickly existing infrastructure can replaced and how quickly air quality levels can be improved.

Geography: (1) Dense urban areas in both developing and industrialised countries stand to gain the most from renewable energy and energy efficiency policies that improve outdoor air quality, while providing energy access (upgrading to modern fuels and clean cook-stoves) would most benefit the indoor air quality of rural households in the least-developed countries (LDCs). (2) Air quality is principally a local/regional problem, although air pollutant emissions can travel across city/state/country borders and affect other populations. (3) The potential for renewables differs widely, which means different renewable energy technologies will be the focus of air pollution mitigation strategy in different regions.

Governance: (1) Air quality is principally a local/regional problem, although national energy policies can help or hinder the situation. (2) Enabling policies are central to transformational change in energy systems, especially for changes in technology investment (efficiency and reduced emissions) and infrastructure.

Technology: (1) Technological change is a critical enabler for improved air quality via energy access provision, renewables deployment, and efficient devices. (2) Behavioural change is also important if societies are to adopt more active lifestyles that are less dependent on motorised transport and to embrace the latest technological advances in equipment and appliances.

Directionality: Bidirectional, but asymmetric. Energy use impacts health and well-being. And in the reverse, the collective health and well-being of a society could potentially influence what transformational changes in the energy system they have an appetite to pursue. The former causality is stronger than the latter and is therefore focused upon in this report.

ILLUSTRATIVE EXAMPLE
IMPROVING AIR QUALITY AND THE HEALTH OF THE RURAL POOR IN INDIA

India is the third largest economy in the world, with its 1.3 billion people making up nearly 20% of the global population. Yet, in terms of energy use, it consumes only 6% of the world's primary energy. Meanwhile, some 240 million Indians lack access to electricity (IEA, 2015). Recent commitments to address climate change and the prospects for rapidly increasing energy demand, which is expected to double in India within the next two decades, have triggered a wave of planned reforms of the energy system. These include boosting the share of renewables in the country's energy mix **(7.2)** and expanding efforts to provide universal access to modern energy forms **(7.1)**, particularly to those in rural areas relying on traditional and dirty fuels (firewood, charcoal, crop residues, and dung; Bonjour et al., 2013) for cooking and heating. The number of premature deaths in India due to indoor and near-household air pollution from the use of traditional solid fuels is around 1 million annually, the highest of any country in the world (IHME, 2015). Globally, the figure is around 3.9 million (Smith and Sagar, 2014). The main cause is exposure to poor combustion of solid fuels in inefficient cooking-stoves.

India has tried to address this issue by providing subsidised LPG (liquefied petroleum gas) as an interim cleaner substitute for traditional solid fuels. This programme has recently accelerated, making India one of the world leaders in a 'health-centred strategy for air pollution' (Sagar et al., 2016). Three national initiatives were launched in 2014 to provide LPG to 50 million more families by March 2019 (Smith, 2016). This major new campaign could ultimately contribute to India reaching its SDG goals for health and energy simultaneously. Elements include over US$ 1 billion committed directly by the national government, with much more provided to state governments from alternative sources, a large share of the middle class population voluntarily giving up subsidies to contribute to the programme, wide-scale use of information technology, use of social marketing and social media, and support for the programme at the highest levels of Indian decision-making, ranging from the Prime Minister to the private sector, community groups and major agencies.

SDG 7 + SDG 6

TARGETS	KEY INTERACTIONS	SCORE	POLICY OPTIONS
7.2 ⟵ 6.1, 6.4	Increased utilisation of unconventional water supply options to satisfy growing demands for safe, affordable freshwater supplies could constrain renewable energy deployment if those options (e.g. desalination) are highly energy-intensive	-1	Ensure that unconventional water supply options (e.g. desalination, wastewater recycling and inter-basin water transfers) do not generate excessively high loads on regional power systems, particularly if the goal is to integrate high shares of renewables into those systems
7.2, 7.3 ⟵ 6.1, 6.4	Increased electricity demands from the water sector could enable the integration of variable wind and solar resources, if developed in combination with real-time demand-side power management of water-related infrastructure and equipment	+1	Better integrate water and energy systems development planning in order to capture the benefits of real-time demand-side power management of water process equipment for the integration of intermittent solar and wind resources. Coupling water and energy markets, which have historically managed their operations separately, could also be potentially beneficial
7.2, 7.3 ⟶ 6.1, 6.4, 6.5	Renewables and energy efficiency will, in most instances, reinforce targets related to water access, scarcity and management by lowering water demands for energy production (compared to a less-efficient fossil energy supply system)	+2	Ensure that energy policies and water resource management plans for renewable energy options, such as bioenergy and hydropower, do not result in adverse side effects either nationally or beyond national borders, particularly in water-scarce regions Take care that policies promoting energy efficiency in the electricity generation, buildings, transport agriculture and industry sectors do not temper growth in water demand. Pay particular attention to energy-intensive operations with significant lighting, heating and cooling loads
7.2, 7.3 ⟶ 6.3, 6.6	Renewables and energy efficiency will, in most instances, reinforce targets related to water pollution and aquatic ecosystems by reducing levels of chemical and thermal pollution (compared to a less-efficient fossil energy supply system)	+2	Align energy and water-management policies so that negative effects on aquatic ecosystems are minimised (such as thermal and chemical pollution). Policies limiting once-through cooling offer an example

KEY POINTS

Ramping up renewables and boosting energy efficiency can help ensure water availability for all, reduce the number of people suffering from water scarcity, minimise water pollution, and protect water-related ecosystems. Exceptions could be the large-scale deployment of agrofuels and hydropower, if not managed properly, and the use of solar or wind pumps for groundwater irrigation, as these can accelerate groundwater depletion

Shifts toward unconventional water supply options in water-stressed regions will generally increase energy demand; this may be challenging to accommodate in low-carbon energy systems. On the other hand, increased electricity demands from the water sector may present opportunities for real-time demand-side power management, which would benefit the integration of variable wind and solar resources, as well as energy efficiency measures

KEY INTERACTIONS

Freshwater resources throughout the world are facing increased pressures, with four billion people living in regions of water scarcity (Mekonnen and Hoekstra, 2016). The global energy system currently requires a large amount of water ('water-for-energy'); it also releases a large amount of pollution (thermal and chemical) **(6.3)** back into freshwater and marine systems **(6.6)** (Chuang et al., 2009; Stewart et al., 2013). If these water demands and pollution impacts increase, then existing ecosystem problems could be exacerbated, particularly in areas that are already stressed and where demand growth is likely to be high, such as countries in the Middle East, South Asia, and Sub-Saharan Africa (Luo et al., 2015). Fossil energy extraction (e.g. hydraulic fracturing for oil and natural gas) often demands significant water inputs. So too do fossil (coal, gas, oil) and nuclear power plants, which use freshwater for thermal cooling. In fact, about half of all water withdrawals in the United States and Western Europe in 2009 were for power-plant cooling (EEA, 2009; Maupin et al., 2010). Coal-fired plants are of particular concern because their numbers have been increasing rapidly in developing countries, with consequent demands for water. Retrofitting thermal cooling technologies to be more water-efficient **(6.4)** can provide significant reductions in energy sector water use (Davies et al., 2013; Byers et al., 2014; Fricko et al., 2016) and vulnerability of the power sector to water scarcity and climate change (van Vliet et al., 2016). Potential measures include minimising on-site losses (such as from storage tanks and pipes), increasing the amount of water recycled internally, moving towards air-cooling technology, and improving the efficiency of the inherent energy conversion processes. However, there are trade-offs with alternative cooling technologies, including increased water consumption and investment costs, as well as reduced operating efficiency (Webster et al., 2013).

In general, renewable electricity generation, particularly solar photovoltaic and wind, impacts local/regional water supplies less than fossil and nuclear plants. Thus, ramping up these forms of renewable energy by 2030 **(7.2)** should ease pressures on local water availability **(6.1)** and contribute to improved water quality **(6.3)** (Davies et al., 2013; Fricko et al., 2016). The effects are less clear-cut for some other types of renewable energy, namely bioenergy and hydropower.

Depending on water management practices, freshwater withdrawal and consumption could be significantly higher, especially for the latter two options. For bioenergy from agrofuels, the effects depend on the type of crop being grown, how much water it requires for growth, and where that water comes from (rainwater vs. irrigated water from a river, lake or underground aquifer) (Gerbens-Leenes and Hoekstra, 2009; Smith et al., 2014; Hejazi et al., 2015). For hydropower, the main concern is evaporation from the surface of the contained reservoir, as any water lost to the atmosphere is no longer available for downstream use (whether for municipal, industrial, or agricultural use). Energy efficiency **(7.3)** at the end-use level can also have major implications for water demand: any unit of fossil energy, bioenergy, or electricity that does not need to be supplied means a certain quantity of water that can be saved **(6.4)** or a given amount of thermal/chemical pollution that can be avoided **(6.3)** (Vidic et al., 2013; Miara et al., 2014; Fricko et al., 2016).

In the reverse direction ('energy-for-water'), reliable access to energy **(7.1)** is essential for the supply and treatment of water. A future shift toward unconventional water supply options **(6.1, 6.4)** (e.g. desalination, wastewater recycling, interbasin water transfer) in water-stressed regions will generally increase energy demand, because the associated technologies are more energy-intensive than conventional supply options (i.e. pumping from local surface and groundwater resources). These increased demands could be additionally challenging to accommodate from the perspective of climate change and air pollution objectives. Greater energy demand will necessitate lower emissions per unit of energy supplied in order to achieve emission levels anticipated prior to water sector transformations. This means that different combinations of energy technologies are likely to be required to achieve climate and air pollution targets under concurrent water SDGs (Parkinson et al., 2016).

Nevertheless, increased energy demand from expansion of unconventional water supply options **(6.1, 6.4)** can potentially support the integration of intermittent wind and solar energy resources **(7.2)**. Operational schedules for water pumps and processes are relatively flexible, and these scheduling features could allow water sector demand to absorb wind and solar variability in real-time (Strbac, 2008). Providing this service in line with demand could displace the need to develop costly dedicated energy-storage technologies, such as batteries. Likewise, waste-heat from thermal power plants can be used in some desalination processes, thereby reducing water sector energy requirements and, by extension, power plant cooling loads. Critical to achieving these efficiency gains will be (i) the integration of water and energy systems development planning, and (ii) the coupling of water and energy markets, which have historically managed their operations separately. Whether tapping into these synergies can outweigh the trade-offs associated with increased water-related energy demand remains an open research question.

A few scenario studies utilising integrated modelling frameworks have recently studied the water-energy nexus, with an eye toward how a rapid up-scaling of renewables and energy efficiency could impact future water demands. The PBL Netherlands Environmental Assessment Agency (2012), for instance, showed that total global water demands **(6.4)** could be reduced by around 25% by 2050, relative to a baseline scenario, if renewable **(7.2)** and efficient technologies **(7.3)** were to be widely deployed. The number of people living in severely water-stressed regions worldwide was estimated to decline from 3.7 to 3.4 billion in this case. Hanasaki et al. (2013) and Hejazi et al. (2013) arrived at similar conclusions using other integrated models.

KEY UNCERTAINTIES

(1) The magnitude of future water demands for non-energy purposes (i.e. municipal, industrial, agricultural) can be difficult to predict. (2) Major uncertainties surround the impacts of the future climate on local hydrological conditions, and this affects water availability. (3) The quality of local governance on water management issues is uncertain, particularly in developing countries that may have a short history with these institutions. Good governance is itself dependent on local skills and capacities.

KEY DIMENSIONS

Time: Water and energy supply technologies have long lifetimes. Thus, the demands of these technologies, once built, can persist far into the future. Retrofits and adapted management practices are possible, but this becomes more difficult after the technologies have been installed.

Geography: (1) Water demands are mostly of local/regional concern (water basin level). Areas already under water-stress, and where demand growth is likely to be high, include countries in the Middle East, South Asia, and Sub-Saharan Africa. (2) Exporting freshwater from distant areas is energy intensive and will limit the potential of distant basin transfers. (3) Not coordinating management of transboundary flows can lead to conflict between countries.

Governance: (1) Strong local institutions are crucial for successful water resource policies and regulatory practices. In industrialised countries, such institutions largely exist, but this may not be the case in many developing countries. (2) Integrated planning of water and energy supply is needed to ensure that cross-sector impacts are not adverse.

Technology: (1) Water demands from renewable energy depend strongly on the type of technology employed. Solar and wind power can cut local water demands and drastically reduce thermal pollution in surrounding aquatic ecosystems. Bioenergy and hydropower, on the other hand, if not managed properly could drive up water demand. (2) Energy efficiency at all parts of the product chain, but especially at the end-use level, is a win-win strategy: if less energy needs to be supplied to consumers, then water demand can be reduced in upstream energy conversion processes. (3) Water supply technologies can be combined with emerging real-time energy demand management technologies to enable increased operational flexibility in the electricity system.

Directionality: Bidirectional. Energy conversion activities require freshwater for cooling (more or less depending on the technology) and can damage local aquatic ecosystems through thermal and/or chemical pollution ('water-for-energy'). In the reverse direction ('energy-for-water'), a future shift toward unconventional water supply options (e.g. desalination, wastewater recycling, interbasin water transfer) in water-stressed regions will generally increase energy demand, because the associated technologies are more energy-intensive than conventional supply options (i.e. pumping from local surface and groundwater resources).

ILLUSTRATIVE EXAMPLE **RENEWABLE ENERGY DEPLOYMENT AND GROUNDWATER DEPLETION IN SAUDI ARABIA**

The Kingdom of Saudi Arabia (KSA) boasts some of the highest quality solar energy resources on the planet. As solar technology costs are anticipated to improve significantly in the coming decades, KSA is planning to exploit its abundant solar potential in a big way **(7.2)**: more than 40 GW of new installed solar energy capacity are planned for development by 2030 (KACARE, 2013). The aim is to supply increasing electricity demands for a rapidly expanding urban population and industrial sector while simultaneously displacing the current electricity generation fleet. This consists mainly of oil-burning power plants, which are extremely carbon-intensive and can require considerable amounts of water for cooling.

The abundance of renewable energy is contrasted, however, by extreme water scarcity **(6.1, 6.4)**. The region can be classified almost entirely as a desert environment and receives very little precipitation annually. Implications for water availability are substantial: on average there are less than 50 m^3 of surface water available on a per capita basis each year (FAO, 2008). For perspective, the historical per capita demand for freshwater across all sectors is more than 900 m^3 annually (FAO, 2008). To make up this massive shortfall, KSA relies heavily on alternative water resources, of which pumping water from underground aquifers is most prevalent (FAO, 2008). Extracted groundwater in KSA can be classified as 'fossil' groundwater, due to the very slow recharge rates that accompany negligible annual precipitation. The non-renewable nature of fossil groundwater means that current extraction rates are rapidly depleting the available groundwater resource. The estimated rate of groundwater depletion is alarming: more than 20 times the estimated recharge is currently extracted from the region's most important aquifers each year (Gleeson et al., 2012). Unless measures are taken to significantly reduce groundwater use in KSA, severe shortages are likely to develop over the coming decades.

Water conservation at end-use is acknowledged as the best way to avoid groundwater shortages **(6.4, 6.5)**; however, such measures can only go so far. Thus, expansion of unconventional water resources will probably be needed to support future growth in urban and industrial water demand, even if existing water-intensive agricultural practices are eventually outsourced to other counties. Desalination of water extracted from the adjacent Red Sea and Persian Gulf has already emerged as a key technology in KSA's water supply portfolio. The national fleet of desalination plants is the largest in the world, and includes an interprovincial water conveyance network that transfers treated water to major inland urban areas. Industrial and municipal wastewater recycling also plays an increasingly important role in managing increased water demand, especially where lower quality water can be used in place of water treated to potable standards.

Wastewater recycling, desalination, and long-distance water transport all require more energy than conventional surface and groundwater supply systems for providing the same amount of freshwater to end-users. Thus, widespread use of these technologies to mitigate groundwater depletion is likely to increase energy demand, which could in turn lead to higher levels of GHG emissions if the additional water supply requirements are met by the existing fossil fuel-intensive national energy mix. Recent analysis suggests that a transition away from non-renewable groundwater use by 2050 could increase electricity demands by more than 40% relative to 2010 conditions, and would require investment of a similar magnitude to a transition away from fossil fuel electricity generation in support of the country's renewable energy goals (Parkinson et al., 2016). Thus, a key challenge facing KSA over the coming decades will be identifying a healthy balance of trade-offs across its objectives for water supply and sustainable energy. Alternatively, KSA will need a suitable financing scheme for the massive infrastructure investment costs that accompany fulfilment of multiple sustainable development objectives concurrently.

Potential synergies between KSA's water and energy sustainability objectives can be expected in future scenarios that include a rapid up-scaling of solar photovoltaic (PV) and wind energy (7.2). Transitioning to a national power system based largely on these generation technologies will avoid thermal water pollution released from existing fossil-fuelled power plants, which typically use seawater for cooling. Moreover, increased energy demand from expansion of unconventional water supply technologies can potentially support KSA in the large-scale integration of intermittent wind- and solar-energy resources. Real-time demand-side power management technologies will provide electricity system operators with increased flexibility to accommodate variable generation sources, and many of the processes in KSA's existing and future water supply systems are ideal candidates for this type of technology application (Al-Nory and El-Beltagy, 2014).

SDG 7 + SDG 8

TARGETS	KEY INTERACTIONS	SCORE	POLICY OPTIONS
7.1 → 8.3, 8.5, 8.6	Having access to modern energy services allows individuals in poorer communities, particularly women and children, to spend more time at work and school, thus enabling employment and education opportunities	+1	[8.5/8.6] Undertake assessments to determine the areas where lack of energy access limits educational attainment, employment acquisition, and economic growth. Where this is the case, design policies to remove these obstacles, such as by providing the necessary energy access, promoting greater equality in per capita income, and supporting small businesses [8.5/8.6] Design energy access policies in such a way that they are equitable and inclusive, thereby increasing employment for all without regard to gender, age or ability
7.2, 7.3 → 8.1, 8.4	Decarbonising energy systems through an up-scaling of renewables and energy efficiency could constrain countries' economic growth, if only slightly. However, strong growth decoupled from environmental degradation is possible	0/-1	Changes in tax codes could help to ensure that household consumption and economic growth is minimally affected by policies attempting to decouple environmental degradation (e.g. GHG emissions production) from these growth metrics. For instance, income taxes could be reduced if the same revenue streams can be sourced from carbon taxation
7.2, 7.3 ↔ 8.2, 8.3, 8.5, 8.6, 8.10	Design, manufacture, and installation of renewables and energy efficient technologies can create conditions for new and higher-paying jobs; although some businesses will need to re-tool, and some workers will need to re-train. Strengthened financial institutions in developing country communities are necessary for providing capital, credit, and insurance to local entrepreneurs attempting to enact change	+1	[8.2/8.3/8.10] Policies promoting the deployment of renewable energy and energy-efficient technologies can help spur innovation, economic diversification, and new and higher-paying jobs. Governments can assist businesses that need to re-tool and workers that need to re-train. Support of small- and medium-sized enterprises, particularly new business ventures, is critical [8.2/8.3/8.10] Stable legislation that fosters strengthened financial institutions at the community level, especially in developing countries, is also key, as these institutions provide the means for local entrepreneurs to access capital, credit, and insurance. Capacity-building would assist these local financial institutions in undertaking assessments of climate change impacts and high-impact actions in order not only to assess financial and other risks but also to mobilise funding for projects to address climate change
7.2, 7.3 ↔ 8.5	Phase-out of fossil fuels especially coal and tar sands may represent a permanent loss of jobs in mining regions. What these jobs are replaced by will determine the net impact.	0/-1	

KEY POINTS

SDG7 and SDG8 are closely interlinked through employment and education (particularly among the poor), innovation and jobs, and environmentally sustainable economic growth

Achieving universal energy access will create opportunities for many employment and educational opportunities in the world's poorest communities

Deploying renewables and energy-efficient technologies/consumption patterns can spur innovation and have an impact on local, regional and national employment; indications are that the net impacts could be slightly positive

Carefully designed policies can help decouple economic growth from environmental degradation in the coming decades; reductions in annualised GDP/consumption growth rates are expected to be small

Energy-related curricula can improve science literacy in populations, especially for the poorest, giving access to better, more skilled jobs

KEY INTERACTIONS

The energy sector is a major contributor to the economy for many countries. Energy also accounts for a significant amount of consumer (household and business) expenditure: more in some countries than others and more in some parts of society than others (namely the urban and rural poor in developing countries). Hence, transformative change in the ways that societies produce and consume energy over the period to 2030 will touch upon every financial and monetary aspect of daily life. In this sense, SDG7 and SDG8 are closely interlinked, with the interactions falling into three main groups: full and productive employment, and number of youth in employment, education, and training **(8.5, 8.6)**; high levels of economic productivity, innovation, and job creation **(8.2, 8.3, 8.10)**; and sustained economic growth globally, but especially in LDCs, while at the same time decoupling growth from environmental degradation **(8.1, 8.4)**.

Provision of universal access to affordable, reliable, and modern energy services can enable the achievement of targets **8.5** and **8.6**. Some of the poorest individuals in society (primarily in parts of South Asia, Southeast Asia, and Sub-Saharan Africa) are forced to spend a significant amount of time acquiring fuel for cooking and keeping the lights on. Modern fuels and technologies (such as delivered gas powering a clean cooking-stove), whether made available in a centralised or distributed way, can alleviate these burdens, which often fall disproportionately to women and children. Impacts can be substantial as time is freed up, which may be used to pursue employment, educational, and leisure and wellness opportunities (Anenberg et al., 2012; Pachauri et al., 2012; Raji et al., 2015). Access to modern energy means children can attend school without having to make a sacrifice for the household (as their labour is often needed on the family farm, etc.), and electric lighting makes it easier to complete homework at home outside daylight hours. Information and communication technologies (e.g. computers and internet servers) can be used to enhance the learning process. Street lighting via electrification can enhance safety, allowing women to attend adult-education classes after dark where they might otherwise feel it is unsafe to do so. In all cases, local economies would benefit over the short and long term, as resident knowledge and capacity can be built up and institutionalised within communities.

Ramping up renewables and boosting energy efficiency efforts (with new technologies or via structural changes) can directly benefit certain segments of local, regional, and national economies. Solar and wind power, in particular, can be key to boosting economic growth in developing regions where the resource potentials are high (e.g. Northern Africa). At the same time, strengthened financial institutions in developing country communities are necessary for providing capital, credit, and insurance to local entrepreneurs attempting to enact change. Innovative technologies like solar and wind power, biofuels, and other renewable energy technologies have the potential to raise wages and create new jobs, either directly or indirectly, in the countries where they are installed and/or manufactured (Gohin, 2008; Creutzig et al., 2013; IRENA, 2016). Yet, if fossil fuel sectors contract as a result, then some businesses will need to re-tool and some workers will need re-training. Thus, it is important to consider the net employment impacts of an expansion in renewable energy and energy-efficient technologies/consumption patterns. Complicating factors include (i) the cost of the jobs created and how this may displace other jobs in capital-constrained environments (Frondel et al., 2010); (ii) the share of the technologies that are designed, engineered, or manufactured within a country versus imported from abroad, because this affects the trade balance; (iii) the existing skills in the local labour force and the capacity of individuals to be re-trained, as this has an impact on real wages (Babiker and Eckaus, 2007; Fankhauser et al., 2008; Guivarch et al., 2011); and (iv) the influence of subsidies and tax revenue re-distribution (such as from carbon pricing in an effort to reduce labour taxes) on the fuel and technology choices of businesses and individuals, especially for labour- vs. energy-intensive goods and services (Clarke et al., 2014). In today's solar power industry, for instance, solar panels are largely produced in developing countries (e.g. China) but are widely purchased and installed by households and businesses in wealthier nations (e.g. Japan, North America, Western Europe, Australia/New Zealand). It still takes local expertise to install such devices, however; and that can provide much local benefit. The same may be the case for energy-efficiency measures, such as building retrofits or operating public transit, even if the materials and vehicles are manufactured elsewhere (Aether, 2016). With these context dependencies in mind, an analysis and review of the literature by Blyth et al. (2014) showed a small increase in net employment as renewable energy and energy efficiency are ramped up over time, primarily because these are generally more labour-intensive (in terms of electricity produced) than the fossil electricity systems they replace. However, any stranding of fossil assets during the transition process could hamper the competitiveness of energy providers, at least for a time (Bertram et al., 2015; Johnson et al., 2015). At the macro-level, global context, it is not clear whether scaling up renewables and energy efficiency (or more generally, strengthening environmental regulations) will adversely affect a given country's international competitiveness: although empirical evidence of past and existing regulations suggests competitiveness impacts may be fairly small, at least compared to other factors such as prevailing market conditions or the quality of the local workforce (Dechezleprêtre and Sato, 2014).

Long-term scenario studies using forward-looking energy-economic modelling tools indicate that economies can continue to grow while simultaneously decarbonising their energy systems through an up-scaling of renewables and energy efficiency (Clarke et al., 2014). Essentially all of these analyses have focused their attention either at the global level or on individual countries that are either already industrialised or are rapidly developing; none have done the same for LDCs, for which **target 8.1** aims to achieve an annual growth of at least 7% of GDP. The global studies are nevertheless useful for providing context, as they take into account all countries simultaneously, and consider trade and spill-over effects between them. As stated in its Fifth Assessment Report, the Intergovernmental Panel on Climate Change concluded (Clarke et al., 2014) that in the most stringent climate change mitigation pathways, where the expansion of renewables and efficiency measures is largely consistent with the SDG7 targets, global consumption losses amount to 1–4% in 2030 (median: 1.7%) and 2–6% in 2050 (median: 3.4%), relative to scenarios without substantial action to decarbonise the economy. Such losses correspond to an annual average reduction in household consumption growth of 0.06–0.20%-points between now and 2030 (median: 0.09) and 0.06–0.17%-points through 2050 (median: 0.09). In other words, annual reductions in growth are miniscule compared to the 7% per year growth target for LDCs, or the lower growth rates characteristic of more developed economies (e.g. 1–5% per year).

KEY UNCERTAINTIES

The distributional effects of the energy system transformation, both within and across countries are unknown. These are important for understanding which populations benefit more or less, in terms of employment opportunities and income.

KEY DIMENSIONS

Time: (1) In LDCs, well-targeted policies and measures may take time to implement, but once established the effects are long-lasting. (2) For employment, the impacts of an energy system transformation may be more pronounced in the short term, before macro-economic adjustments (geographical and sectoral reallocations) have time to once again reach a stable equilibrium.

Geography: (1) Individuals in poor urban and rural areas of LDCs will derive the most benefit from energy access provision, in terms of increased educational and employment opportunities. (2) The employment impacts from deploying renewables and energy-efficiency measures are most likely to be felt in those countries that have the capacity to design, engineer, and manufacture them (i.e. more advanced economies). (3) Potentials of renewables vary throughout the regions of the world, and these differences will affect employment options.

Governance: (1) Governments (at local, regional, and national levels) can create incentives for innovative businesses to establish operations in their respective jurisdictions. (2) Governments may need to support businesses and workers during the energy transition. Policies that facilitate labour mobility (e.g. flexible labour markets, reasonably priced housing, and targeted re-training) can help minimise negative effects for those workers who are displaced. The removal of fossil fuel subsidies can allow renewables to compete in the market more fairly.

Technology: Different renewable and energy-efficient technologies/consumption patterns will have different local impacts on jobs and the economy. An important consideration is what shares of a given technology are designed, engineered, or manufactured within a country/region versus imported from abroad. This depends entirely on the decisions of countless business leaders and is effectively impossible to predict from the outset.

Directionality: Bidirectional. The up-scaling of renewables and energy-efficient technologies/consumption patterns can spur innovation and influence local, regional, and national employment. At the same time, the countries and cities likely to attract these industries will need to have strong economies and pre-existing skills and capacity within the labour force; a strengthening of financial institutions in lesser developed countries can aid such efforts.

ILLUSTRATIVE EXAMPLE
RENEWABLE ENERGY DEPLOYMENT AND JOB CREATION IN GERMANY

Germany is one of the most advanced countries in the world in terms of renewable energy. Over the past few decades, it has seen some of the greatest deployment of wind, solar, bioenergy, and other forms of renewables of any major economy **(7.2)**, and is a major producer of renewable energy technologies **(8.2, 8.3)**. The so-called 'Energiewende', has also had a marked impact on employment within Germany – in most ways positive.

Germany was the first country to enact a green electricity feed-in tariff (FIT) scheme when it did so in 1991 with the Electricity Feed-in Act. This was later followed by the Renewable Energy Sources Act in 2000; several incarnations of this Act ('Erneuerbare-Energien-Gesetz' in German) have since followed, each preserving the aim of promoting renewable electricity generation, even if the FIT approach is currently being phased out.

These key pieces of energy legislation have led to considerable job creation in Germany **(8.2, 8.3, 8.5, 8.6)**. The gross employment effects within the renewable energy sector have been estimated at 160,500 new jobs (2004), 277,300 (2007), 399,800 (2012), and 371,400 (2013) (Lehr et al., 2015) – for reference, Germany's total workforce over this period was around 40 million. Wind power and bioenergy have been the biggest contributors to job growth, with hydropower and geothermal energy playing relatively small roles. In all cases, the number of jobs has grown fairly consistently over time. Solar power is a notable exception: employment in this sector rose quickly until 2011/2012 but has since declined.

The rise and fall of Germany's solar power industry is well known, often held up as an example of how an industry can fail before reaching self-sufficiency. However, this telling of the story masks important details underlying the macro-level dynamics (Pahle et al., 2016). The explanations typically given are that solar companies were too optimistic about future demand, leading to an overcapacity in production, and that strong competition from low-cost producers in other parts of the world, notably China, made it difficult for German firms to compete (BMWi, 2012; Lehr et al., 2015). Yet, what is often forgotten is that other sub-sectors of Germany's solar industry have performed well over the past decade. German PV equipment producers, for instance, achieved a 50% share of the world market as recently as 2015 (VDMA, 2015).

The German wind energy industry, which has had sustained success in recent years, provides a counterexample to the broader solar industry dynamics. Why is this sector different? As Claudy et al. (2010) noted, German companies responsible for manufacturing wind turbines and related equipment (e.g. Siemens and ENERCON) have long been established worldwide; they also have strong comparative advantages vis-à-vis their global rivals. This was generally not the case for Germany's solar industry as a whole. The critical question is whether Germany's comparative advantages can be sustained over the long term and this depends on the skills of the work force and the ability of domestic firms to innovate technologically. Estimates of the net employment effects of renewable energy deployment in Germany provide a less clear-cut picture than for gross employment. Different assessments yield different answers: overall job creation (net of jobs lost in other sectors outside of renewable energy) may have been either positive or negative over the past decade (Blazejczak et al., 2013; Lutz et al., 2014). Job creation has been described as a 'welcome side effect' of Germany's major policies to support renewable energy deployment (Pahle et al., 2016). Employment was never the express intent of those policies; the main objective has always been environmental concerns (such as reducing emissions causing climate change) and this continues to be the case. Nevertheless, employment aspects are thought to have played a role in creating political support for the 'Energiewende', especially with organised labour (e.g. trade groups) (Joas et al., 2016). Federal and state policies that attempt to nurture domestic job growth and industrial development are now emerging, either explicitly or implicitly, including financial tax incentives, favourable customs duties, export credit assistance, quality certification, and special loan structures (Lewis and Wiser, 2007; Kuntze and Moerenhout, 2012; Pahle et al., 2016).

SDG 7 + SDG 13

TARGETS	KEY INTERACTIONS	SCORE	POLICY OPTIONS
7.1 ⟶ SDG13*	The universal energy access target is fully consistent with the goal of combatting climate change, as it is likely to have only a minor effect on global carbon emissions	**0**	
7.2, 7.3 ⟶ SDG13*	Decarbonising energy systems through an up-scaling of renewables and energy efficiency is a necessary but not sufficient condition for combatting climate change, since less fossil energy means lower GHG emissions	**+2**	To achieve the temperature targets outlined in the Paris Agreement, all countries will need to decarbonise their energy systems through an up-scaling of renewables and energy efficiency. The pledged Nationally Determined Contributions (NDCs) provide a good start, but these will need to be strengthened considerably over time
7.2, 7.3 ⟵ 13.2, 13.3, 13.a	To aid the rapid deployment of renewables and energy-efficiency measures, countries will benefit from integrating climate change measures such as carbon pricing into national planning, improving relevant education and awareness, and mobilising funds for mitigation	**+2**	[13.2] Sponsor careful assessments of high-impact areas for climate action and identify where the use of renewable energy and energy efficiency can make the most cost-effective interventions. Policies should then be designed to promote the incorporation of this knowledge into national and regional strategies and planning. Energy and climate policies must be interlinked and must consider the entire lifecycle of energy services in order to avoid policy inconsistencies between reaching NDCs [13.3] Provide funding for education, training and public-awareness programmes to help in informing local communities, in both industrialised and developing countries, about the importance of climate change mitigation and the positive contributions that renewable energy and energy efficiency efforts can make. This should be done within the broader context of national development strategies, considering all other SDGs [13.a] Developing countries should design their climate action programmes such that they attract and use available international funding sources (e.g. from the Green Climate Funds). By strengthening their institutions and capacities to ensure their domestic programmes are financially viable and transparent, these countries should be able to increase the likelihood of obtaining funding support

**The 2030 Agenda text on SDG13 does not specifically mention a long-term temperature goal, but it does refer to the United Nations Framework Convention on Climate Change (UNFCCC) process, and the stated objective of the 2015 Paris Agreement is "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C".*

KEY POINTS

Replacing a fossil-dominated energy system by a cleaner, more efficient system would contribute to major reductions in GHG emissions globally

A dramatic, essentially immediate up-scaling of renewables and energy efficiency is necessary to limit global climate change to 2°C, or well below, over the long term, the stated goal of the Paris Agreement. If achieved by all countries, the SDG7 targets could put the world on track to meeting this challenge

Pursuing the SDG13 targets for better integrating climate change measures into national planning, improving education, awareness, and capacity on climate issues, and mobilising funds for mitigation will help ensure that the SDG7 targets for renewables and energy efficiency are achieved

Achieving universal access to modern energy services by 2030 will not exacerbate climate change

KEY INTERACTIONS

SDG7 has a direct interaction with SDG13, since today's fossil-dominated energy system is the main contributor to global GHG emissions. While the SDG13 targets do not mention specific goals for stabilising global climate, they do acknowledge that the United Nations Framework Convention on Climate Change (UNFCCC) is the primary international, intergovernmental forum for negotiating the global response to climate change. That forum has of course already taken action, with the result being the Paris Agreement of December 2015 (UNFCCC, 2015), which endeavours to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change" (Art. 2). Informing that debate were many scientific studies considered by the Intergovernmental Panel on Climate Change in its latest assessment (Clarke et al., 2014). The IPCC concluded that a dramatic, essentially immediate up-scaling of renewables and energy efficiency is necessary to limit global climate change to below 2°C over the long term. To achieve this, the vast majority of the world's countries have pledged Nationally Determined Contributions (NDCs) – individualised plans for how each nation intends to reduce its emissions over the next few years. Renewables (7.2) and energy efficiency (7.3) are essential elements in nearly all cases. Hence, from this standpoint target 13.2 is already on its way to being achieved; and this will help underpin the SDG7 targets. Similarly, targets 13.3 and 13.a are also critical for enabling the successful, rapid deployment of renewable and energy-efficient technologies and consumption patterns, especially in developing countries where financial capital may be in short supply, institutions weaker, and information about climate solutions scarcer.

Of particular importance to the poor in developing countries (in South Asia, Southeast Asia, and Sub-Saharan Africa), the scientific literature indicates that ensuring universal access to modern energy services by 2030 **(7.1)** is fully consistent with the SDG13 and Paris Agreement climate goals. In other words, energy access provision will not exacerbate climate change, as it is likely to have only a minor effect on global carbon emissions, even if the modern fuels being supplied are still fossil fuels (e.g. natural gas, kerosene, LPG) (PBL Netherlands Environmental Assessment Agency, 2012; Riahi et al., 2012; Rogelj et al, 2013). Although this may seem counter-intuitive, it should be remembered that, for instance, advanced (fossil) cooking-stoves are many times more efficient than the outdated (renewable) biomass cooking-stoves they replace. Decentralised renewable systems (e.g. solar panels, small-scale wind, micro-hydro) offer additional low-carbon possibilities (Kaundinya et al., 2009; Reddy et al., 2009). In discussing energy access for the world's poorest **(7.1)**, it is important to distinguish this target from the broader goal of sustained economic growth (SDG8). Unless economic growth is decoupled from carbon emissions, which the scientific literature shows is feasible, then emissions are likely to rise considerably as the wealth and livelihoods of developing country households improve. The concern is that the world's rural and urban poor – those living on less than US$ 1.25 per day – could fail to join this wave of welfare improvement. And for this reason, dedicated energy access policies are critical for ensuring that, at the very least, their basic needs for energy services are met.

KEY UNCERTAINTIES

(1) The speed with which countries are willing to decarbonise their energy systems through a rapid up-scaling of renewables and energy-efficient technologies/consumption patterns is unknown, as is the ambition of such actions post-2030. It is the latter that will ensure that long-term climate goals are met. (2) Also unknown are the exact quantifications for what a proper, decent level of energy access actually entails, in terms of the full range of services required to escape the poverty trap. These threshold levels, in combination with fuel and technology choices, will determine the carbon emissions of the world's poorest.

KEY DIMENSIONS

Time: While transforming the global energy system will be a decades-long process, near-term and immediate actions promoting renewables and boosting energy efficiency are critical, given tight cumulative budgets for GHG emissions for staying well below the 2°C threshold. A unit of carbon released into the atmosphere by the energy system between now and 2030 will still be there next century and beyond.

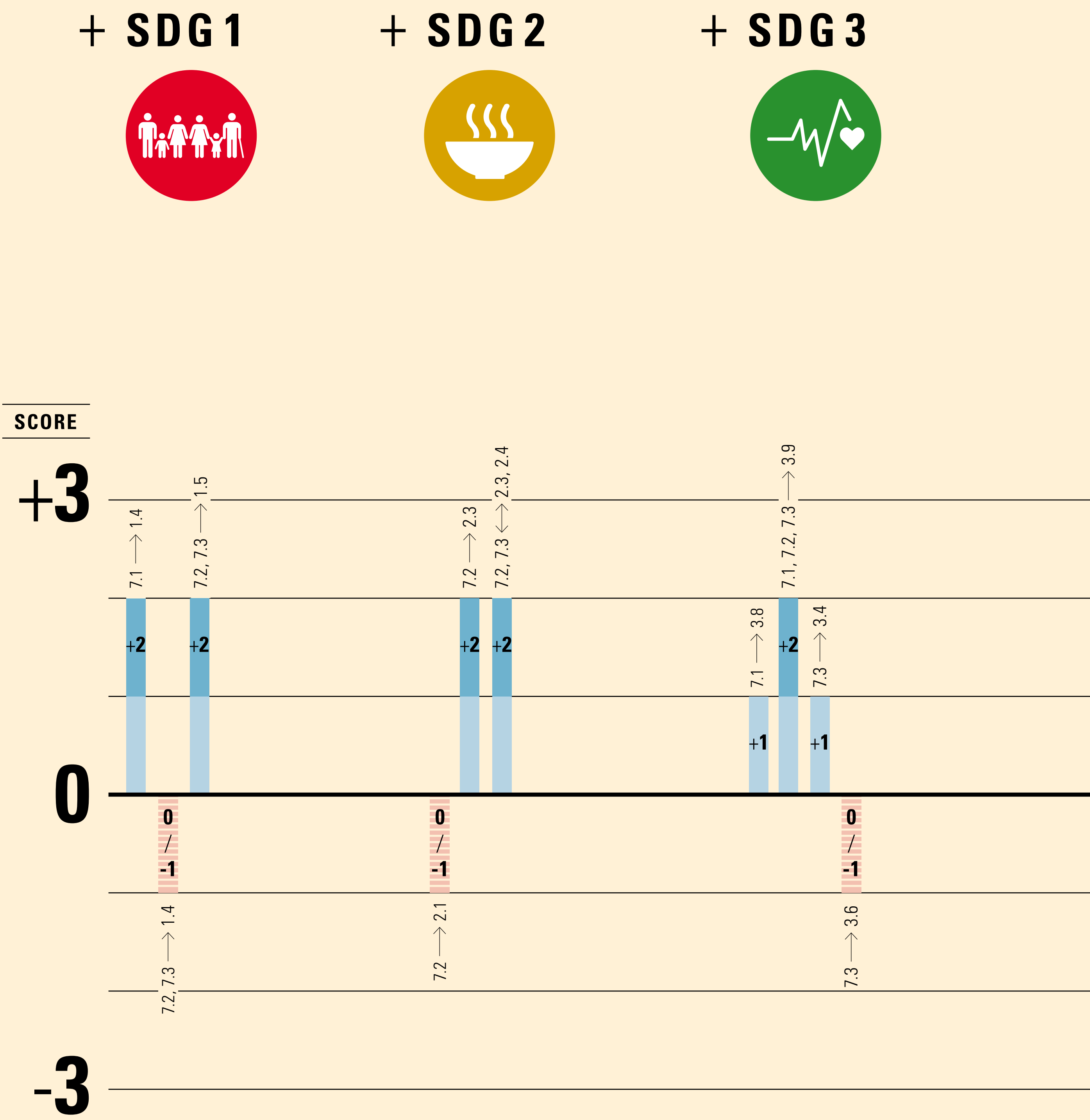
Geography: Actions to promote renewables and boost energy efficiency in one part of the world are just as important as in any other, since climate change is a global problem. But some countries have bigger energy systems than others, some have more carbon-intensive energy systems, and some rely more on transportation of goods for their GDP; while some counties have two or all three of these conditions. Such countries can have a larger impact on mitigating climate change through their national actions (e.g. China, India, USA, Europe, Brazil, Russia, Australia, Canada).

Governance: (1) Renewables and energy efficiency can be fostered and incentivised by a range of policy approaches, including market- and policy-based measures. Many measures have already been tested at local, regional, and national level. Experience gained in one jurisdiction can help to inform policy in another. Moreover, energy and climate policy must be accorded to phase out fossil fuels. Fossil fuel producing states must acknowledge their climate responsibility over the full lifecycle of their resources and act accordingly. (2) With regard to energy access provision, well-designed policies are needed to influence consumer preferences and ensure that households make fuel- and technology-purchasing decisions that are optimal both for them and for society as a whole.

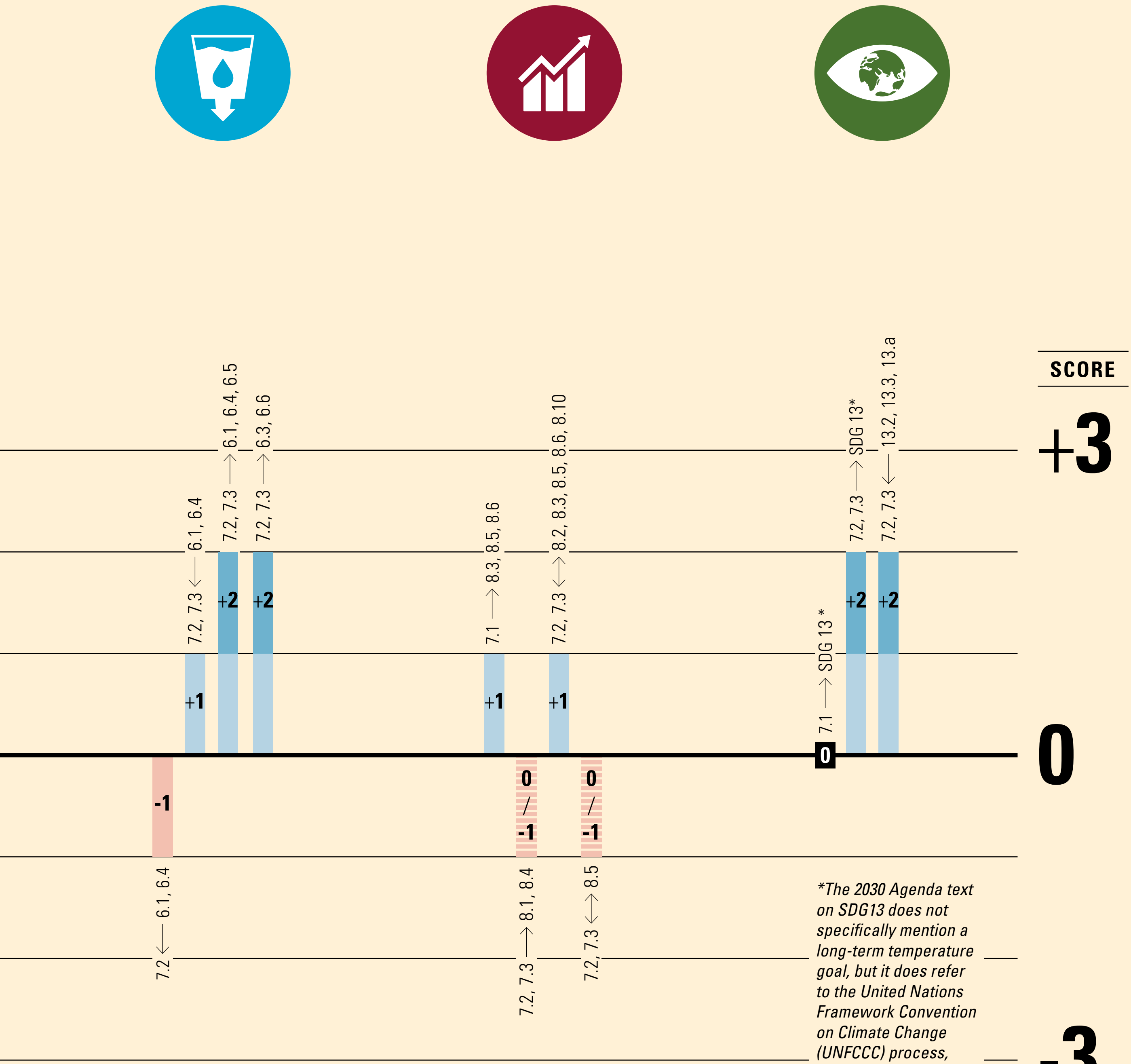
Technology: (1) Advancements in technology are critical for decarbonising the global energy system, namely in the adoption of renewables on the supply side (solar, wind, hydro, geothermal electricity generation; biofuels). Carbon capture and storage technologies must be deployed on fossil fuel plants as well as on biomass-to-energy plants in order to provide opportunity for negative emissions capacity worldwide. The demand side is more complex: designing more energy-efficient devices is necessary, but just as importantly technology adoption depends heavily on human behaviour and consumer preferences. However, it is the sector where some of the most important abatement on emissions can be achieved. (2) Similarly, for the provision of energy access, poverty largely determines the willingness and likelihood of low-income households to adopt modern fuels, cooking-stoves, and lighting technologies.

Directionality: Bidirectional. A dramatic, essentially immediate up-scaling of renewables and energy efficiency is necessary to limit global climate change to well below 2°C over the long term, the stated goal of the Paris Agreement. The SDG7 targets, if achieved by all countries, could put the world on track to meeting this challenge. In the reverse direction, pursuing the SDG13 targets for better integrating climate change measures into national planning; improving education, awareness, and capacity on climate issues; and mobilising funds for mitigation will go a long way in ensuring that the SDG7 targets for renewables and energy efficiency are achieved.

KEY INTERACTIONS
SDG 7 WITH OTHER GOALS



+ SDG 6 + SDG 8 + SDG 13



**The 2030 Agenda text on SDG13 does not specifically mention a long-term temperature goal, but it does refer to the United Nations Framework Convention on Climate Change (UNFCCC) process, and the stated objective of the 2015 Paris Agreement is "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C".*

KNOWLEDGE GAPS

The state of science is not yet robust enough to score some target-level interactions or identify their particular dependencies (i.e. with respect to time, geography, governance, technology, and direction). As the science advances and the evidence base grows, a more comprehensive assessment should be possible. This also implies, by extension, that the target-level interaction scores reported here could change in the future as the evidence base advances.

To provide decision-makers with a more holistic view of the complex web of interactions affected by SDG7, this section identifies a number of knowledge gaps where scientists should focus their analytical attention in the coming years. This list is not intended to be exhaustive as it draws only from the target-level interactions considered in the previous section. Moreover, transcending these SDG-specific knowledge gaps are the more general uncertainties related to a number of transformational driving forces that are already shaping the future, such as 'big data', the Internet of Things, and 3D printing, among others. Real questions remain regarding the knowledge gaps that will arise from such innovations.

Filling the gaps in knowledge summarised here will require collaborative work between scientists across multiple disciplines, especially in the social sciences (sociology, anthropology, demography, human geography, education, political science, law, communication studies, economics), natural sciences (climate sciences, agricultural sciences, hydrology, atmospheric chemistry, health sciences), engineering, and integrated systems modelling.

7 + 1

Researchers and analysts still have some work to do in determining what a proper, decent level of energy access actually entails, in terms of the full range of services required to escape the poverty trap.

7 + 2

The indirect land-use change impacts of large-scale bioenergy utilisation, and the resultant impacts on food prices, access to food, and farm incomes. Research should include empirical studies (for past and existing policy) and national- and global-scale integrated modelling frameworks (for future policy).

7 + 3

The distributional impacts of air quality co-benefits of renewables and energy efficiency (for different socio-economic groups in different parts of cities/regions).

The impacts of 'active travel' (walking and cycling) on health and well-being. Research should focus on observational/empirical studies.

7 + 6

The magnitude of future water demands for non-energy purposes: municipal, industrial, agricultural. It is especially difficult to predict the future water consumption 'needs' of developing country households.

The impacts of the future climate on local hydrological conditions, as this affects water availability.

The potential benefits of real-time demand-side power management of water process equipment for integrating intermittent solar and wind resources into the energy grid.

7 + 8

The net employment and competitiveness impacts of the energy system transformation on local, regional and national economies, particularly over the near term. The distributional effects of the energy system transformation, within and across countries. This is important for understanding who benefits more and who benefits less, for instance in terms of employment opportunities and incomes. What empirical case studies of past and existing energy policy interventions show about the net impacts on local, regional and national employment and competitiveness

The lack a welfare metric that goes beyond the strictly economic formulation of GDP.

How energy related curricula can help science literacy and promote better employment and competitiveness?

How to minimise adverse side-effects on those that may lose from the energy system transformation (principally businesses and workers in fossil energy extraction and conversion).

The role of social innovation in decoupling of energy consumption from economic growth.

7 + 13

The role of human behaviour in the adoption of energy-efficient, low-carbon technologies/consumption patterns and how policies can influence consumer preferences toward choices that are beneficial for both individuals and wider society.

How best to increase awareness and capacity about solutions to climate change. The potential for the democratisation of the low-carbon energy system, including greater decentralisation, such as energy cooperatives and other community-based energy initiatives, bioenergy villages and renewable energy municipalities.

CONCLUDING COMMENTS

With so many interactions between the various SDG targets, it is clear that government-led actions and policies will be important for ensuring that the positive outcomes are achieved as frequently as possible and negative outcomes are minimised or avoided. More than ever, this requires policy frameworks that take an integrated, holistic perspective. Pro-active engagement and enhanced coordination across government departments and ministries, as well as across different levels of government (from international to national to local) will be required for this to happen effectively. Otherwise, the 'silo approach' to policymaking could persist indefinitely. This would not serve the achievement of the SDGs well.

The six summary tables in the target-level interactions section provide options for how policy could address the specific target interactions in practice, in such a way that the targets of the various SDGs are pursued in concert, with potential conflicts avoided or minimised as far as possible. Although addressed to specific target interactions, many of these policy options are also relevant for other interactions.

REFERENCES

Aether, 2016. Scoping study on the co-benefits and possible adverse side effects of climate change mitigation: final report. Prepared by Aether Ltd for the UK Department of Energy and Climate Change (DECC).

Al-Nory, M. and M. El-Beltagy, 2014. An energy management approach for renewable energy integration with power generation and water desalination. Renewable Energy, 72:377-385.

Anenberg, S.C., K. Balakrishnan, J. Jetter, O. Masera, S. Mehta, J. Moss and V. Ramanathan, 2012. Cleaner cooking solutions to achieve health, climate, and economic cobenefits. Environmental Science and Technology, 47:3944-3952.

Babiker, M.H. and R.S. Eckaus, 2007. Unemployment effects of climate policy. Environmental Science and Policy, 10:600-609.

Bertram, C., N. Johnson, G. Luderer, K. Riahi, M. Isaac and J. Eom, 2015. Carbon lock-in through capital stock inertia associated with weak near-term climate policies. Technological Forecasting and Social Change A, 90:62-72.

Blazejczak, V.J., J. Diekmann, D. Edler, C. Kemfert, K. Neuhoff and W. Schill, 2013. Energiewende erfordert hohe Investitionen. No: DIW Wochenbericht. p. 26.

Blyth, W., R. Gross, J. Speirs, S. Sorrell, J. Nicholls, A. Dorgan and N. Hughes, 2014. Low Carbon Jobs: The Evidence for Net Job Creation from Policy Support For Energy Efficiency and Renewable Energy. UK Energy Research Centre.

BMWi, 2012. Bericht des Bundesministeriums für Wirtschaft und Technologie zur Lage der deutschen Photovoltaikindustrie. Berlin, Germany: Federal Ministry for Economic Affairs and Energy.

Bonjour, S., H. Adair-Rohani, J. Wolf, N.G. Bruce, S. Mehta, A. Pruss-Ustun,M. Lahiff, E.A. Rehfuess, V. Mishra and K.R. Smith, 2013. Solid fuel use for household cooking: country and regional estimates for 1980-2010. Environmental Health Perspectives, 121:784-790.

Byers, E.A., J.W. Hall and J.M. Amezaga, 2014. Electricity generation and cooling water use: UK pathways to 2050. Global Environmental Change, 25:16-30.

Cameron, C., S. Pachauri, N.D. Rao, D. McCollum, J. Rogelj and K. Riahi, 2016. Policy tradeoffs between climate mitigation and clean cook stove access in South Asia. Nature Energy, 1:15010, doi:10.1038/nenergy.2015.10.

Chaturvedi, V. and P.R. Shukla, 2014. Role of energy efficiency in climate change mitigation policy for India: Assessment of co-benefits and opportunities within an integrated assessment modeling framework. Climatic Change, 123:597-609.

Chuang, Y.L., H.H. Yang and H.J. Lin, 2009. Effects of a thermal discharge from a nuclear power plant on phytoplankton and periphyton in subtropical coastal waters. Journal of Sea Research, 61:197-205.

Clarke, L., K. Jiang, K. Akimoto, M. Babiker, G. Blanford, K. Fisher-Vanden, J.-C. Hourcade, V. Krey, E. Kriegler, A. Löschel, D. McCollum, S. Paltsev, S. Rose, P. R. Shukla, M. Tavoni, B. C. C. van der Zwaan, and D.P. van Vuuren, 2014. Assessing transformation pathways. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Claudy, P., M. Gerdes and J. Ondraczek, 2010. Die deutsche Photovoltaik-Branche am Scheideweg. Herausforderungen und Chancen für Unternehmen entlang der Wertschöpfungskette. pwc.

Creutzig, F., E. Corbera, S. Bolwig and C. Hunsberger, 2013. Integrating place specific livelihood and equity outcomes into global assessments of bioenergy deployment. Environmental Research Letters, 8:035047, doi:10.1088/1748-9326/8/3/035047.

Davies, E.G., P. Kyle and J.A. Edmonds, 2013. An integrated assessment of global and regional water demands for electricity generation to 2095. Advances in Water Resources, 52:296-313.

Davis, S.C., R.M. Boddey, B.J.R. Alves, A.L. Cowie, B.H. George, S.M. Ogle, P. Smith, M. van Noordwijk and M.T. van Wijk, 2013. Management swing potential for bioenergy crops. GCB Bioenergy, 5:623-638.

de Moraes, M.A.F.D., C.C. da Costa, J.J.M. Guilhoto, L.G.A. de Souza and F.C.R. de Oliveira, 2010. Social externalities of fuels. In: Ethanol and Bioelectricity: Sugarcane in the Future of the Energy Matrix. pp. 44-75. UNICA Brazilian Sugarcane Industry Association, Sao Paulo, Brazil.

Dechezleprêtre, A. and M. Sato, 2014. The Impacts of Environmental Regulations on Competitiveness. Grantham Research Institute Policy Brief.

EEA, 2009. Water Resources across Europe: Confronting Water Scarcity and Drought. European Environment Agency (EEA).

Fankhauser, S., F. Sehlleier and N. Stern, 2008. Climate change, innovation and jobs. Climate Policy, 8:421-429.

FAO, 2008. AQUASTAT country profile for Saudi Arabia. United Nations Food and Agriculture Organization (FAO).

Fricko, O., S. Parkinson, N. Johnson, M. Strubegger, M.T.H. van Vliet and K. Riahi, 2016. Energy sector water use implications of a 2°C climate policy. Environmental Research Letters, 11:034011.

Frondel, M., N. Ritter, C.M. Schmidt and C. Vance, 2010. Economic impacts from the promotion of renewable energy technologies: The German experience. Energy Policy, 38:4048-4056.

Gerbens-Leenes, W., A.Y. Hoekstra and T.H. van der Meer, 2009. The water footprint of bioenergy. Proceedings of the National Academy of Sciences, 106:10219-10223.

Gleeson, T., Y. Wada, M.F. Bierkens and L.P. van Beek, 2012. Water balance of global aquifers revealed by groundwater footprint. Nature, 488:197-200.

Gohin, A., 2008. Impacts of the European biofuel policy on the farm sector: A general equilibrium assessment. Applied Economic Perspectives and Policy, 30:623-641.

Guivarch, C., R. Crassous, O. Sassi and S. Hallegatte, 2011. The costs of climate policies in a second-best world with labour market imperfections. Climate Policy, 11:768-788.

Haines, A., 2012. Health benefits of a low carbon economy. Public Health, 126:S33-S39.

Hanasaki, N., S. Fujimori, T. Yamamoto, S. Yoshikawa, Y. Masaki, Y. Hijioka, M. Kainuma, Y. Kanamori, T. Masui, K. Takahashi and S. Kanae, 2013. A global water scarcity assessment under Shared Socio-economic Pathways: Part 2 Water availability and scarcity. Hydrology and Earth System Sciences, 17:2393-2413.

Hejazi, M.I., J. Edmonds, L. Clarke, P. Kyle, E. Davies, V. Chaturvedi, J. Eom, M. Wise, P. Patel and K. Calvin, 2013. Integrated assessment of global water scarcity over the 21st century; Part 2: Climate change mitigation policies. Hydrology and Earth System Sciences Discussions, 10:3383-3425.

Hejazi, M.I., N. Voisin, L. Liu, L.M. Bramer, D.C. Fortin, J.E. Hathaway, M. Huang, P. Kyle, L.R. Leung, H.Y. Li and Y. Liu, 2015. 21st century United States emissions mitigation could increase water stress more than the climate change it is mitigating. Proceedings of the National Academy of Sciences, 112:10635-10640.

IEA, 2015. India Energy Outlook. International Energy Agency (IEA), Paris, France.

IEA, 2016. World Energy Outlook Special Report: Energy and Air Pollution. International Energy Agency (IEA), Paris, France.

IHME, 2015. GBD Compare (website). Institute for Health Metrics and Evaluation, University of Washington. Institute for Health Metrics and Evaluation (IHME).

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

IRENA, 2016. Renewable energy benefits: measuring the economics. International Renewable Energy Agency (IRENA), Abu Dhabi.

Jakob, M. and J.C. Steckel, 2014. How climate change mitigation could harm development in poor countries. WIREs Climate Change, 5:161-168.

Joas, F., M. Pahle, C. Flachsland and A. Joas, 2016. Which goals are driving the Energiewende? Making sense of the German Energy Transformation. Energy Policy, 95:42-51.

Johnson, N., V. Krey, d.L. McCollum, S. Rao, K. Riahi and J. Rogelj, 2015. Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants. Technological Forecasting and Social Change A, 90:89-102.

KACARE, 2013. Saudi Arabia's Renewable Energy Strategy and Solar Energy Deployment Roadmap. King Abdullah City for Atomic and Renewable Energy (KACARE).

Kaundinya, D.P., P. Balachandra and N.H. Ravindranath, 2009. Grid-connected versus stand-alone energy systems for decentralized power – A review of literature. Renewable and Sustainable Energy Reviews, 13:2041-2050.

Kuntze, J. and T. Moerenhout, 2012. Local Content Requirements and the Renewable Energy Industry – A Good Match? International Centre for Trade and Sustainable Development, Geneva.

Lehr, U., D. Edler, M. O'Sullivan, F. Peter and P. Bickel, 2015. Beschäftigung durch erneuerbare Energien in Deutschland: Ausbau und Betrieb, heute und morgen. GWS, DLR, DIW, Prognos, ZSW.

Lewis, J.I. and R.H. Wiser, 2007. Fostering a renewable energy technology industry: an international comparison of wind industry policy support mechanisms. Energy Policy, 35:1844-1857.

Lotze-Campen, H., M. von Lampe, P. Kyle, S. Fujimori, P. Havlik, H. van Meijl, T. Hasegawa, A. Popp, C. Schmitz, A. Tabeau, H. Valin, D. Willenbockel and M. Wise, 2014. Impacts of increased bioenergy demand on global food markets: an AgMIP economic model intercomparison. Agricultural Economics, 45:103-116.

Luo, T., R. Young and P. Reig, 2015. Aqueduct Projected Water Stress Country Rankings. Technical Note. World Resources Institute, Washington, D.C.

Lutz, C., D. Lindenberger and A. Kemmler, 2014. Endbericht Gesamtwirtschaftliche Effekte der Energiewende. gws, Prognos, EWI.

Maupin, M.A., J.F. Kenny, S.S. Hutson, J.K. Lovelace, N.L. Barber and K.S. Linsey, 2010. Estimated Use of Water in the United States in 2010. Circular 1405. United States Geological Survey (USGS).

McCollum, D.L., L. Gomez Echeverri, S. Busch, S. Pachauri, S. Parkinson, J. Rogelj, V. Krey, K. Riahi, M. Nilsson, A.S. Stevance, 2017. Connecting the Sustainable Development Goals by their energy inter-linkages. IIASA Working Paper (WP-17-006). International Institute for Applied Systems Analysis, Laxenburg, Austria.

Mekonnen, M.M. and A.Y. Hoekstra, 2016. Four billion people facing severe water scarcity. Science Advances, 2:1500323.

Miara, A., C. Tarr, R. Spellman, C.J. Vörösmarty and J.E. Macknick, 2014. The power of efficiency: Optimizing environmental and social benefits through demand-side-management. Energy, 76:502-512.

Muys, B., L. Norgrove, T. Alamirew, R. Birech, E. Chirinian, Y. Delelegn, A. Ehrensperger, C.A. Ellison, A. Feto, B. Freyer, J. Gevaert, S. Gmünder, R.E.E. Jongschaap, M. Kaufmann, J. Keane, M. Kenis, B. Kiteme, J. Langat, R. Lyimo, V. Moraa, J. Muchugu, A. Negussie, C. Ouko, M.W. Rouamba, I. Soto, M. Wörgetter, R. Zah and R. Zetina, 2014. Integrating mitigation and adaptation into development: the case of Jatropha curcas in sub-Saharan Africa. GCB Bioenergy, 6:169-171.

Nemet, G.F., T. Holloway and P. Meier, 2010. Implications of incorporating air quality co-benefits into climate change policymaking. Environmental Research Letters, 5:014007.

Nilsson, M., D. Griggs and M. Visbeck, 2016. Map the interactions between Sustainable Development Goals. Nature, 534:320-322.

Pachauri, S., A. Brew-Hammond, D.F. Barnes, D.H. Bouille, S. Gitonga, V. Modi, G. Prasad, A. Rath and H. Zerriffi, 2012. Energy access for development. In: Global Energy Assessment – Toward a Sustainable Future. Cambridge University Press.

Pahle, M., S. Pachauri and K. Steinbacher, 2016. Can the green economy deliver it all? Experiences of renewable energy policies with socio-economic objectives. Applied Energy, 179:1331-1341.

Parkinson, S.C., N. Djilali, V. Krey, O. Fricko, N. Johnson, Z. Khan and A.H. Almasoud, 2016. Impacts of groundwater constraints on Saudi Arabia's low-carbon electricity supply strategy. Environmental Science and Technology, 50:1653-1662.

PBL, 2012. Roads from Rio+20: Pathways to Achieve Global Sustainability Goals by 2050. Netherlands Environmental Assessment Agency (PBL), The Hague.

Rafaj, P., W. Schöpp, P. Russ, C. Heyes and M. Amann, 2013. Co-benefits of post-2012 global climate mitigation policies. Mitigation and Adaptation Strategies for Global Change, 18:801-824.

Raji, B., M.J. Tenpierik and A. van den Dobbelsteen, 2015. The impact of greening systems on building energy performance: A literature review. Renewable and Sustainable Energy Reviews, 45:610-623.

Reddy, B.S., P. Balachandra and H.S.K. Nathan, 2009. Universalization of access to modern energy services in Indian households – Economic and policy analysis. Energy Policy, 37:4645-4657.

Riahi, K., F. Dentener, D. Gielen, A. Grubler, J. Jewell, Z. Klimont, V. Krey, D. McCollum, S. Pachauri, S. Rao, B. van Ruijven, D.P. van Vuuren and C. Wilson, 2012. Energy pathways for sustainable development. In: Global Energy Assessment – Toward a Sustainable Future. pp. 1203-1306. Cambridge University Press.

Rogelj, J., D.L. McCollum and K. Riahi, 2013. The UN's "Sustainable Energy for All" initiative is compatible with a warming limit of 2°C. Nature Climate Change, 3:545-551.

Rose, S.K., R. Richels, S. Smith, K. Riahi, J. Strefler and D. van Vuuren, 2014. Non-Kyoto radiative forcing in long-run greenhouse gas emissions and climate change scenarios. Climatic Change, 123:511-525.

Sagar, A., K. Balakrishnan, S. Guttikunda and K.R. Smith, 2016. India leads the way: A health-centered strategy for air pollution. Environmental Health Perspectives, 124(7): doi:10.1289/EHP90.

Satolo, L. and M. Bacchi, 2013. Impacts of the Recent Expansion of the Sugarcane Sector on Municipal per Capita Income in São Paulo State. ISRN Economics, 2013:828169.

Shaw, C., S. Hales, P. Howden-Chapman and R. Edwards, 2014. Health co-benefits of climate change mitigation policies in the transport sector. Nature Climate Change, 4:427-433.

Smith, K., 2015. Changing Paradigms in Clean Cooking. Ecohealth, 12:196-199.

Smith, K., 2016. The Story of the National LPG Program of India. 12 September 2016. Cooking for Life. www.cooking-for-life.org/mediaroom/178/32/The-Story-of-the-National-LPG-Program-of-India

Smith, K. and A. Sagar, 2014. Making the clean available: escaping India's Chulha Trap. Energy Policy, 75:410-414.

Smith P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N. H. Ravindranath, C. W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, and F. Tubiello, 2014. Agriculture, forestry and other land use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Stewart, R.J., W.M. Wollheim, A. Miara, C.J. Vörösmarty, B. Fekete, R.B. Lammers and B. Rosenzweig, 2013. Horizontal cooling towers: riverine ecosystem services and the fate of thermoelectric heat in the contemporary Northeast US. Environmental Research Letters, 8(2): 025010.

Strbac, G., 2008. Demand side management: Benefits and challenges. Energy Policy, 36:4419-4426.

UN, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development (A/RES/70/1). United Nations, New York.

UN, 2016. The Sustainable Development Goals Report 2016, United Nations, New York.

UNFCCC, 2015. Paris Agreement. United Nations Framework Convention on Climate Change (UNFCCC), 21st Conference of the Parties of the UNFCCC, Paris, France.

van der Horst, D. and S. Vermeylen, 2011. Spatial scale and social impacts of biofuel production. Biomass and Bioenergy, 35:2435-2443.

van Vliet, M.T., D. Wiberg, S. Leduc and K. Riahi, 2016. Power-generation system vulnerability and adaptation to changes in climate and water resources. Nature Climate Change, 6:375-380.

VDMA, 2015. Photovoltaik-Produktionsmittel: Investitionen außerhalb Asiens ziehen an. German Mechanical Engineering Industry Association (VDMA). http://pv.vdma.org/en/article/-/articleview/11180819

Vidic, R.D., S.L. Brantley, J.M. Vandenbossche, D. Yoxtheimer and J.D. Abad, 2013. Impact of shale gas development on regional water quality. Science, 340(6134):1235009.

Webster, M., P. Donohoo and B. Palmintier, 2013. Water-CO2 trade-offs in electricity generation planning. Nature Climate Change, 3:1029-1032.

West, J.J., S.J. Smith, R.A. Silva, V. Naik, Y. Zhang, Z. Adelman, M.M. Fry, S. Anenberg, L.W. Horowitz and J.-F. Lamarque, 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nature Climate Change, 3:885-889.

Woodcock, J., P. Edwards, C. Tonne, B.G. Armstrong, O. Ashiru, D. Banister, S. Beevers, Z. Chalabi, Z. Chowdhury, A. Cohen, O.H. Franco, A. Haines, R. Hickman, G. Lindsay, I. Mittal, D. Mohan, G. Tiwari, A. Woodward and I. Roberts, 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. The Lancet, 374:1930e43.