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# Mapping synergies and trade-offs between energy and the Sustainable Development Goals

Francesco Fuso Nerini[1,2]*, Julia Tomei[3]*, Long Seng To[4,5], Iwona Bisaga[6], Priti Parikh[6], Mairi Black[4], Aiduan Borrion[6], Catalina Spataru[1], Vanesa Castán Broto[7,8], Gabrial Anandarajah[1], Ben Milligan[9]* and Yacob Mulugetta[4]

**The 2030 Agenda for Sustainable Development—including 17 interconnected Sustainable Development Goals (SDGs) and 169 targets—is a global plan of action for people, planet and prosperity. SDG7 calls for action to ensure access to affordable, reliable, sustainable and modern energy for all. Here we characterize synergies and trade-offs between efforts to achieve SDG7 and delivery of the 2030 Agenda as a whole. We identify 113 targets requiring actions to change energy systems, and published evidence of relationships between 143 targets (143 synergies, 65 trade-offs) and efforts to achieve SDG7. Synergies and trade-offs exist in three key domains, where decisions about SDG7 affect humanity's ability to: realize aspirations of greater welfare and well-being; build physical and social infrastructures for sustainable development; and achieve sustainable management of the natural environment. There is an urgent need to better organize, connect and extend this evidence, to help all actors work together to achieve sustainable development.**

On 5 September 2015, the 193 members states of the United Nations (UN) adopted a new 2030 Agenda for Sustainable Development[1]. The 2030 Agenda succeeds the UN's Millennium Development Goals (MDGs), and features 17 Sustainable Development Goals (SDGs) with 169 targets, which UN member states have committed to implement by 2030. Energy was not explicitly referred to in the MDGs, and came to be referred to as the 'missing' MDG[2]. During the operational period of the MDGs and negotiation of the 2030 Agenda, it was increasingly recognized that energy underpins economic and social development, without which it would not be possible to eliminate poverty. This change in status[3] made sustainable energy provision and access one of the central themes of the 2030 Agenda, whose preamble calls for "universal access to affordable, reliable and sustainable energy" and recognizes that "social and economic development depends of the sustainable management of our planet's natural resources"[1]. SDG7 is accompanied by five targets to be achieved by 2030: ensure universal access to affordable, reliable and modern energy services (7.1); increase the share of renewable energy in the global energy mix (7.2); double the global rate of improvement in energy efficiency (7.3); enhance international cooperation to facilitate access to clean energy research and technology (7.a), and promote investment in energy infrastructure and clean energy technology (7.b).

By understanding the complex links between the SDGs and their constituent targets, researchers can better support policymakers to think systematically about interactions between the different SDGs, including how actions to achieve each goal affect each other within and between sectors[3,4]. Studies to date[4,5] have lacked a target-level approach or have focussed on only a few of the SDGs[6]. Here we present a formative attempt by an interdisciplinary group of researchers to identify the full range of goals and targets in the 2030 Agenda that call for changes in energy systems, and characterize evidence of synergies or trade-offs between delivery of each of the 169 targets and efforts focussed on pursuit of SDG7 and each of its constituent targets. The purpose of this Perspective is not to provide definitive answers. Instead we aim to lay a foundation for systematic (and context-specific) exploration of the interlinkages between each of the SDG targets, in the context of decision-making about development and the transformation of energy systems[1].

## Energy systems and the 2030 Agenda

To assess each of the 169 targets in the 2030 Agenda and their respective interlinkages with energy systems, we undertook an approach designed to answer two questions: (i) Does the target call for action in relation to energy systems?; and (ii) Is there published evidence of synergies or trade-offs between the target and decisions about energy systems in pursuit of SDG7? 'Energy systems' were defined broadly to include all components of anthropogenic and environmental systems related to the production, conversion, delivery and use of energy. A systems perspective is crucial to understanding the practical complexity of energy provision and use, and facilitates effective intervention strategies[6].

Figure 1 illustrates our methods. To answer our first question, method (A) focused on identifying the normative implications of each Target for energy systems. A consensus-based qualitative content analysis was undertaken to identify each Target's explicit (i.e. written in the text) normative content. The analysis was informed by Hall and Wright (2008)[7]. To answer our second question, method (B) focused on identifying evidence of empirical relationships (synergies or trade-offs) between the achievement of each Target, and decisions about energy systems in pursuit of SDG7 (defined by its Targets 7.1, 7.2, 7.3, 7.a, 7.b). Synergies and trade-offs were identified and characterised using a consensus-based expert elicitation process, undertaken by the authors. Design of the expert elicitation

研究内容

[1]UCL Energy Institute, University College London, London, UK. [2]Unit of Energy Systems Analysis (dESA), KTH Royal Institute of Technology, Stockholm, Sweden. [3]Institute for Sustainable Resources (ISR), University College London, London, UK. [4]Department of Science, Technology, Engineering and Public Policy (UCL STEaPP), University College London, London, UK. [5]Department of Geography, Loughborough University, Leicestershire, UK. [6]Department of Civil, Environmental and Geomatic Engineering (CEGE), University College London, London, UK. [7]Development Planning Unit (DPU), University College London, London, UK. [8]Faculty of Social Sciences, ICOSS, University of Sheffield, Sheffield, UK. [9]Faculty of Laws, University College London, London, UK.
*e-mail: francesco.fusonerini@energy.kth.se; j.tomei@ucl.ac.uk; b.milligan@ucl.ac.uk

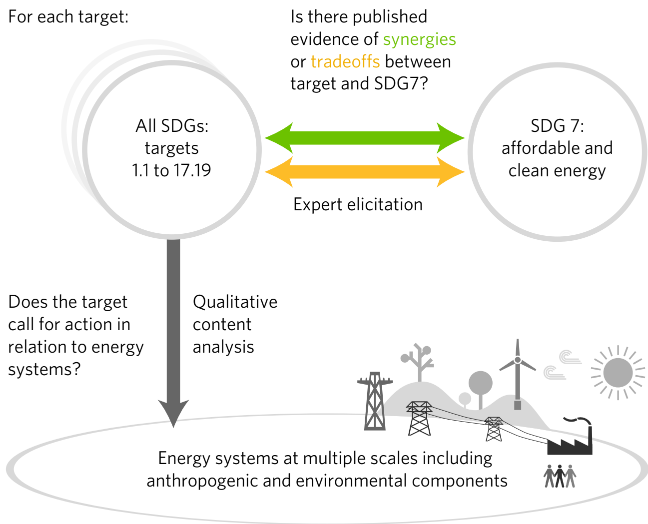


**Fig.1 | Assessing interlinkages between energy systems and the 2030 Agenda.** A graphical illustration of the methods undertaken to assess interlinkages between energy systems and the 169 targets in the 2030 Agenda for Sustainable Development.

process was informed by Butler et al. (2015) and Morgan (2014)[8,9]. The process involved the search for published studies in academic and peer-reviewed grey literature (e.g. UN reports). Group members did not undertake a systematic review of evidence relevant to each Target. Instead, a single item of relevant published evidence was deemed sufficient to indicate the presence of a synergy or trade-off between a Target and SDG7. During regular group meetings over a period of approximately twelve months, results of methods A and B for all 169 Targets were presented and refined through facilitated discussion until a consensus was reached. All results were reviewed iteratively by all experts. The experts (the authors of this paper) consisted of academics from diverse disciplines spanning engineering, natural and social sciences. Results of the assessment for each target are reported in full in Supplementary Table 1, and summarized in Fig. 2.

We found that 113 targets (~65%) require actions to be taken concerning energy systems (A). Given the broad definition of energy systems mentioned above, these actions are diverse and include efforts to: address climate change (for example, Target 13.2), reduce deaths from pollution (for example, Target 3.9), and end certain human rights abuses (for example, Target 8.7). This gives a strong indication of the substantial changes needed in global energy systems in order to deliver the SDGs.

We also identified evidence of synergies or trade-offs between at least 143 targets (~85%, spanning all of the SDGs) and actions in pursuit of SDG7 (B). There are more than twice as many synergies between SDG7 and other targets, than trade-offs (143 synergies, 65 trade-offs). Nearly all trade-offs relate to the tension between the need for rapid action to address key issues for human well-being (for example, poverty eradication, access to clean water, food and modern energy, and so on), and the careful planning needed to achieve efficient energy systems with a high integration of renewable energy. We did not attempt to map these comprehensively, and indicate only whether or not there was evidence of synergies or trade-offs (see Supplementary Table 1). Our review of evidence suggested that there are likely to be multiple synergies and trade-offs within each Target, and that identification of these relationships is highly context specific. The coarse-grained synergies and trade-offs that we identified can be categorized into three broad domains, where decisions about energy systems affect humanity's ability to achieve three goals: first, realize individual and collective aspirations of greater welfare and well-being; second, build physical and social infrastructures for sustainable development; and finally, achieve sustainable management of the environment and natural resources. This is consistent with goal-level analyses done in other contexts[10,11]. The identified evidence concerning synergies and trade-offs (B) is summarized below, together with limited selected examples, and reported in full in Supplementary Table 1.

**Aspirations of greater welfare and well-being.** The provision of affordable, reliable, sustainable and modern energy for all is vital for ensuring well-being. The contribution of energy to this domain is illustrated by this analysis, which identified 60 and 34 targets with synergies and trade-offs respectively with SDG7 across all goals.

Energy has a fundamental role to play in efforts to end poverty[12] (SDG1). Provision of modern energy services (Target 7.1) will support the achievement of other goals. For example, raising living standards through provision of basic services, including healthcare, education, water and sanitation (SDG2–4, 6–7, 9); improved household incomes (SDG8); and resilient rural and urban livelihoods (SDG1, 11). For instance, a focus on SDG4 (education) reveals the multiple synergies between well-being, energy and education at local, national and global levels. Target 4.2 requires that all girls and boys complete free, equitable and good-quality primary and secondary education. Achieving this target depends on supply of electricity to schools, as well as to homes[13]. There is evidence that electricity access affects educational attainment[14]. Electricity is also vital for provision of information and communication technologies, which underpin adult education and global citizenship (Target 4.6, 4.7)[15]. This will be critical to eliminate local and global inequalities by providing access to information and technology, and empowering the social, economic and political inclusion of all (Target 10.2)[16].

Realising greater welfare and well-being cannot be achieved without peaceful societies and equal access to justice (SDG16). There is great potential for justice-based approaches to aid energy decisions[17,18]. Rather than just being an analytical concept, framing energy decisions in justice terms can help to elicit the relationship between individual and public values, map and resolve disputes, and give directional input to make better choices[19]. This is strongly recognized in the SDGs, for example, in terms of delivering improvements in governance of energy systems, including just institutions, strengthened rule of law, greater participation, transparency and accountability, access to information, and the reduction of corruption (Targets 9.c, 16.1, 16.3, 16.5, 16.7, 16.8, 16.10, 16.a, 16.b). For instance, development of many large-scale hydropower plants has been mired in social and political conflicts as a result of poor consultation with, and consideration of, livelihood conditions of affected local communities[20]. Similar impacts have been documented concerning the land used to produce biofuels[21,22], and extraction of coal, gas and oil[23]. These examples highlight the vital role of natural resources in securing well-being (see below).

**Physical and social infrastructures.** Physical and social infrastructures link aspirations for well-being and welfare with the underpinning natural resources[10,24]. There is published evidence of 109 targets with synergies and 47 with trade-offs between SDG7 and infrastructures. Energy is a core component of the physical and social infrastructures needed to end poverty and support economic growth (SDG1, 8).

Existing energy infrastructures will need to be significantly upgraded to achieve SDG7[25,26]. Nearly 1.2 billion people in the world lack access to electricity and ~3 billion people lack access to clean cooking facilities[26,27]. A mix of locally appropriate centralized and decentralized energy infrastructures will be needed to achieve universal energy access (Target 7.1)[28]. Infrastructures required for energy access depend on access to financial services and markets

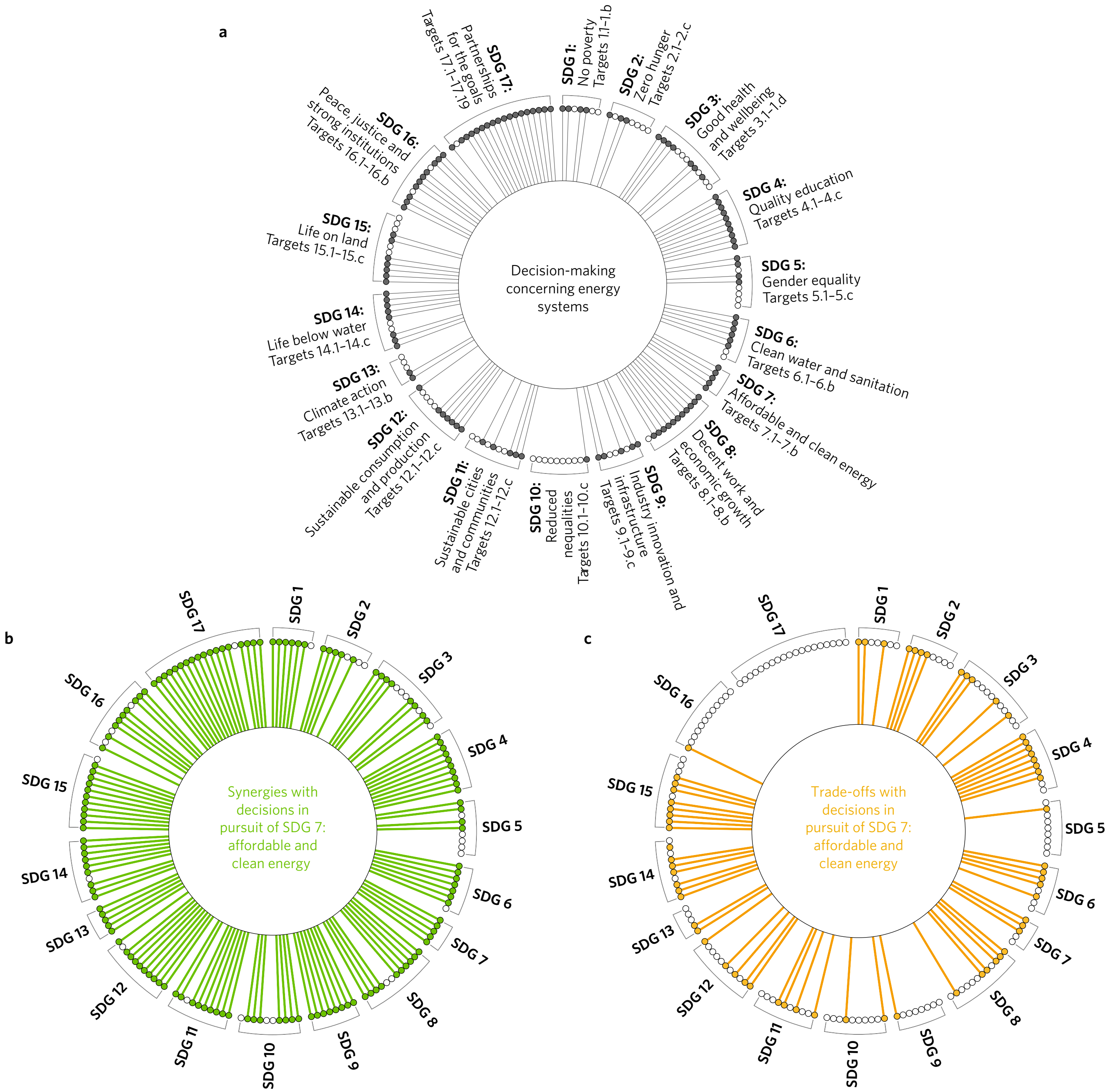


**Fig. 2 | Interlinkages between energy systems the SDGs and targets. a–c**, Specific targets recognized in the 2030 Agenda for Sustainable Development are grouped together under each associated SDG. Targets are ordered clockwise; for example, Target 1.1 in each diagram is represented by the leftmost circle in the group associated with SDG1. **a**, Targets highlighted black (and indicated with black lines) call for action in relation to energy systems. **b**, For targets highlighted green (and indicated with green lines), we identified published evidence of synergies with decisions in pursuit of SDG7. **c**, For targets highlighted orange (and indicated with orange lines), we identified published evidence of trade-offs with decisions in pursuit of SDG7. In **b** and **c**, the absence of highlighting indicates the absence of identified evidence. This does not necessarily indicate the absence of a synergy or trade-off between the relevant target and SDG7. Full results of the assessment for each target can be found in Supplementary Table 1.

(Target 9.3), knowledge (Target 9.5, 9.a), and strong institutions and international cooperation (SDG17). Many targets are underpinned by energy access (Target 7.1) — energy is needed to power food systems[29] (Target 2.1–2.4), medical facilities[30] (Target 3.1–3.4, 5.6), and water treatment and distributions systems (Target 6.1–6.3). Efficient water infrastructure can also reduce energy usage[26,31] (Target 6.4, 6.5). More broadly, energy in its various forms is needed in cities (SDG11) where the spatial patterns influence the way we use energy, and vice-versa[32].

Energy contributes to the resilience of infrastructure, sustainable industrialization (SDG9) and sustainable production and consumption (SDG12). For example, resilient and sustainable infrastructures (Target 9.1) require reliable energy systems with limited environmental impacts that mitigate adverse effects of climate change[33].

Climate change can affect the production of electricity from hydropower and thermal power plants in several regions of the world[34]. Achieving sustainable management and efficient use of natural resources (Target 12.2) will require changes to how energy systems use natural resources to minimize adverse impacts[31].

**The environment and natural resources.** Natural environments are the foundation of human well-being and development — they are comprized of biotic and abiotic stocks of natural resources, which provide flows of valuable, and in some cases irreplaceable, goods in addition to ecosystem services[35,36]. Energy systems are underpinned by, and profoundly impact upon, these environmental stocks and flows[37]. There are 46 environment-related targets with synergies, and 31 with trade-offs, with SDG7.

At a global scale, energy systems produce ~60% of total anthropogenic emissions of greenhouse gases[38], and are consequently a core focus of urgent action to combat climate change and its impacts (SDG 13). Investment in low-carbon energy systems (Target 7.2, 7.a) will be fundamental to achieving the 2 °C–1.5 °C mitigation goals of the 2015 Paris Agreement on climate change[33]. Reliable energy services underpinned by research, technology and infrastructure (Target 7.1, 7.a, 7.b) can contribute to climate-change adaptation, natural hazard reduction and resilience (SDG3, 9, 13). Use of natural resources by globalized energy systems (for example, for fuel or raw materials) has impacted on ecosystem services that underpin food and water security (SDG2, 6), and human health[36] (SDG3). The need to increase energy supply responding to growing demand must be reconciled with the need to protect and restore critical ecosystems that support development in other sectors. This will depend on technology, behaviour and policy changes that dramatically decrease the natural resource-intensity of energy systems (Target 7.3, SDG 12) as part of broader efforts to decouple adverse environmental impacts from economic growth[39] (Target 8.4).

There are complex trade-offs between the natural resource dependencies of energy, food and water systems, and environmental threats including biodiversity loss, climate change and localized air and water pollution[31,40,41]. Water quality and sanitation (SDG6, 14–15) are fundamental to social vulnerability (SDG1) and healthy lives (SDG3). Energy is needed to restore water-related ecosystems (Target 6.6, Goal 14–15), sustainably manage irrigation in food systems (Target 2.4), increase water efficiency (Target 6.4, 9.4, 11.b)[26,42], access and mobilize natural resources to end poverty (Target 1.4), and increase food production (Target 2.3, 2.4)[43,44]. Lack of access to modern energy services can drive ecosystem loss and degradation (Target 15.2) — for example any deforestation and forest degradation associated with use of fuelwood[45,46].

Energy systems can have direct impacts (for example, local pollution or competition for space with energy infrastructure) and indirect impacts (for example, ocean acidification or climate change[47]) on conservation, restoration and enhancement of marine and terrestrial ecosystems and other natural resources (SDG9, 14–15)[48,49]. SDG15 is intertwined with the nature of energy transitions, especially where livelihoods are dependent on ecosystem goods and services[50]. Energy systems that fully account for these interdependencies including the multiple benefits and values of the environment (Target 15.9, 17.9) can minimize adverse impacts of energy use on ecosystems and biodiversity[51] (Target 12.2).

## Empowering action to deliver the 2030 Agenda

Our analysis highlights how energy systems are a foundation of social and economic development, and affect delivery of outcomes across all SDGs. It is also not possible to deliver SDG7—ensuring access to affordable, reliable, sustainable and modern energy for all—without understanding how energy systems affect and depend on well-being, infrastructure and the environment. The SDGs represent a new framework for examining these linkages and making decisions that balance them effectively. Our analysis represents a first step towards mapping relationships between energy systems, SDG7, and other goals in the 2030 Agenda. It reveals the tremendous complexity of links between energy systems and well-being, infrastructure and the environment, which means that SDG7 cannot be achieved in sectoral isolation. We have shown that all SDGs and ~65% of targets require action to change energy systems.

We found evidence of synergies between 143 targets and efforts to achieve SDG7, meaning that ~85% of 2030 Agenda targets are mutually reinforcing with SDG7. We also found evidence of trade-offs between SDG7 and ~35% of the 2030 Agenda targets. Many of these trade-offs relate to tensions between the need to rapidly expand access to basic services, and the need for efficient energy systems underpinned by renewable resources. These synergies and trade-offs will manifest differently in different settings, and the impacts for different social groups will need to be understood and accommodated. Considerations of rights, justice and equity must be integrated into the exploration of solutions for these complex energy dilemmas[19] to ensure we leave no one behind. Every target counts, and no single target should be overlooked in efforts to achieve SDG7. This will be a challenging task that will require collaboration between diverse actors across every domain.

**Implications for researchers.** For the research community, this task depends on transdisciplinary collaboration. This includes understanding the interactions between disciplines and diverse actors, and will require generation of, and access to, data and knowledge on energy and other sectors. Current knowledge concerning energy and sustainable development is isolated in many different institutions, locations and disciplines. The isolation is compounded by the fact that many people, in all countries, cannot or have not been empowered with skills needed to access this knowledge. To address this, the evidence on the linkages between energy systems, SDG7 and other goals need to be organized and connected in a manner that informs and enables efforts to achieve the 2030 Agenda. Our analysis provides a useful framework for researchers and decision-makers to design and evaluate specific interventions in energy systems to achieve sustainable development. However, this needs to be done as an inclusive, collaborative and open initiative to link energy research back to specific targets and goals. Such collaboration is already taking place in other contexts, for example the Future Earth Knowledge Action Networks[52].

**Implications for decision-makers.** For decision-makers in public and private sectors, the 2030 Agenda highlights that well-being for all can only be realized by transforming vertical silos and current modes of resource use, and by paying proper attention to supporting infrastructures and the natural environment. To this end the complexity of interrelationships between SDG7 and other goals challenges conventional structures and processes of decision-making in government and private entities. Decision-makers can no longer think in silos, and will need to find ways of widening participation, creating collective ownership and building consensus. In practice, this will require a transformation in the structure of decision-making, including the integration of vertical and horizontal planning and a long-term perspective. This requires strong local and national visions that are sensitive to the need for global collaboration. Given that energy cuts across all SDGs, structured analyses such as the one presented here can help to ensure that actions to achieve SDG7 are compatible with local and national development priorities. In so doing, this type of analysis can help the design of policies that balance synergies and trade-offs across well-being, infrastructure and environment in specific settings.

Policymakers responsible for energy matters need to collaborate with colleagues in other portfolios and vice-versa, and establish governance structures to enable and sustain such coordination. However, the principle of working across sectors and disciplines does not come naturally as it challenges entrenched institutional and sectoral behaviours. Cross-sectoral conversations on these institutional challenges will help advance this integrated Agenda. The approach presented here can help policymakers to review existing institutional architectures and sector-specific policies to determine whether they are compatible with delivery of the 2030 Agenda. International organizations, including development banks, have an important role to play by coordinating action, measuring progress, facilitating dialogue and providing finance[45,53].

**A call to action.** Finally, each and every actor has a role to play in achieving sustainable development. For SDG7, there is a tension between the need for action required to rapidly address urgent energy-related issues (for example, energy access), and the careful planning of complex energy systems that underpin long-term development outcomes. Balancing these needs will require new skills and capacity to build country-specific and regional strategies. A more level playing field across actors and countries is required, recognising that developing countries will need to build further capabilities around production, transmission, distribution and energy consumption. The research community can help build and provide the knowledge and capacity needed for other actors to operationalize SDG7 at national and sub-national levels. This includes developing and sharing flexible and appropriate tools. We envisage that applications of this approach to specific contexts can help identify key gaps in knowledge—where collaboration between actors may help to address knowledge gaps and to structure action. A strategy that brings all actors together to craft appropriate policies that balance synergies and trade-offs between SDG7 and the other goals is essential.

We encourage all actors to contribute to this discussion—by enriching our analysis with additional evidence, and applying it to energy policies, programmes and projects so that their design accounts for the complexity of the 2030 Agenda. Our analysis is intended to serve as a basis for dialogue and iterative action to deliver SDG7, in a manner that realizes well-being through provision of key infrastructures, and conservation, restoration and enhancement of the natural environment and its resources.

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## Author Contributions
F.F.N. coordinated inputs from other authors, designed and contributed to the expert elicitation process, and wrote the paper. J.T., B.M., L.S.T. and Y.M. designed and contributed to the expert elicitation process, and wrote the paper. I.B., P.P., M.B., A.B., C.S., V.C.B. and G.A. contributed to the peer-reviewed expert elicitation process, and writing sections of the paper.

## Competing interests
The authors declare no competing financial interests.

## Additional information
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**Correspondence and requests for materials** should be addressed to F.F.N. or J.T. or B.M.

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