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Connecting the sustainable development goals by their energy inter-linkages

David L McCollum[1,2,8], Luis Gomez Echeverri[1], Sebastian Busch[1], Shonali Pachauri[1], Simon Parkinson[1,3], Joeri Rogelj[1], Volker Krey[1], Jan C Minx[4,5], Måns Nilsson[6], Anne-Sophie Stevance[7] and Keywan Riahi[1]

1 International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, 2361 Laxenburg, Austria
2 University of Tennessee, 1640 Cumberland Avenue, Knoxville, TN 37996, United States of America
3 University of Victoria, PO Box 3055 STN CSC, V8W 3P6 Victoria BC, Canada
4 Mercator Research Institute on Global Commons and Climate Change (MCC), Torgauer Strasse 12–15, 10829 Berlin, Germany
5 University of Leeds, Leeds, LS2 9JT, United Kingdom
6 Stockholm Environment Institute (SEI), Linnégatan 87 D, 115 23 Stockholm, Sweden
7 International Council for Science (ICSU), Rue Auguste Vacquerie, 75116 Paris, France
8 Author to whom any correspondence should be addressed.

E-mail: mccollum@iiasa.ac.at

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Abstract

The United Nations' Sustainable Development Goals (SDGs) provide guide-posts to society as it attempts to respond to an array of pressing challenges. One of these challenges is energy; thus, the SDGs have become paramount for energy policy-making. Yet, while governments throughout the world have already declared the SDGs to be 'integrated and indivisible', there are still knowledge gaps surrounding how the interactions between the energy SDG targets and those of the non-energy-focused SDGs might play out in different contexts. In this review, we report on a large-scale assessment of the relevant energy literature, which we conducted to better our understanding of key energy-related interactions between SDGs, as well as their context-dependencies (relating to time, geography, governance, technology, and directionality). By (i) evaluating the nature and strength of the interactions identified, (ii) indicating the robustness of the evidence base, the agreement of that evidence, and our confidence in it, and (iii) highlighting critical areas where better understanding is needed or context dependencies should be considered, our review points to potential ways forward for both the policy making and scientific communities. First, we find that positive interactions between the SDGs outweigh the negative ones, both in number and magnitude. Second, of relevance for the scientific community, in order to fill knowledge gaps in critical areas, there is an urgent need for interdisciplinary research geared toward developing new data, scientific tools, and fresh perspectives. Third, of relevance for policy-making, wider efforts to promote policy coherence and integrated assessments are required to address potential policy spillovers across sectors, sustainability domains, and geographic and temporal boundaries. The task of conducting comprehensive science-to-policy assessments covering all SDGs, such as for the UN's *Global Sustainable Development Report*, remains manageable pending the availability of systematic reviews focusing on a limited number of SDG dimensions in each case.

Introduction

In September 2015, United Nations Member States adopted a comprehensive global development agenda: *Transforming our world: the 2030 Agenda for Sustainable Development*, more commonly known as the Sustainable Development Goals (UN 2015). The SDGs, which can be viewed as a successor to the Millennium Development Goals (MDGs), represent a major shift in the global policy landscape. For the first time, sustainable development, broadly defined and all-encompassing, has been enshrined in international—and, by extension, national—policy discussions. The 17 SDGs cover everything from energy and climate; to water, food and ecosystems; to health and poverty; to jobs and innovation; among a number of other objectives[9]. This represents a major step forward from the MDGs, which, in addition to not being universal in nature, were silent on a number of these dimensions, notably energy. Energy is dealt with primarily by Sustainable Development Goal #7 (SDG7), whose overarching aim is to 'Ensure access to affordable, reliable, sustainable and modern energy for all'. Underpinning this grand objective are three distinct, yet related, pillars ('Targets'):

- 7.1 || By 2030, ensure universal access to affordable, reliable and modern energy services
- 7.2 || By 2030, increase substantially the share of renewable energy in the global energy mix
- 7.3 || By 2030, double the global rate of improvement in energy efficiency

Governments throughout the world have already declared the 17 SDGs and their 169 targets to be 'integrated and indivisible' (UN 2015). Yet, some linkages, notably between the energy and 'non-energy' SDGs, are still not well understood[10]. The scientific community thus has a critical role to play here: first in identifying the character of the key relationships and then in elucidating where they are strong or weak and what they depend on (Howells *et al* 2013). After all, the impacts of energy extraction, conversion, and consumption activities on other sectors (i.e. sustainability domains) can be far-reaching—be those impacts *economic*, *social*, or *environmental* in nature.

Here we assess the scientific literature exploring the impacts that the kinds of energy solutions enumerated by SDG7 (renewables, efficiency, energy for the poor) could potentially have on the various other SDGs, or vice-versa the effects that actions and policies in these other domains could have on the energy SDG targets[11]. Based on this review, we then score the interactions identified—in terms of whether it is positive or negative and to what extent—by employing a simple scale (see later section for methodological details). We conduct this scoring exercise at the level of the SDG targets, and we do it for all of the targets other than those relating to 'means of implementation' (i.e. SDG17 and the 'lettered' targets within each SDG, such as '1.A'; see Stafford-Smith *et al* 2017). This approach, which is consistent with Le Blanc (2015), leaves us with 107 individual targets to analyze: three for SDG7 (Energy) and then 104 others.

The study's aims are two-fold: firstly, to highlight for decision makers how energy policy choices may affect other SDG objectives and especially those contexts in which implementation practices are pivotal in shaping those interactions, and secondly, to provide researchers with the current 'lay of the land' regarding SDG interactions studies relevant for energy, pointing to critical knowledge gaps the scientific community will need to fill over the coming years.

Because the SDGs are relatively new as a framing concept, and perhaps also because they are so extensive in their reach, there have been few reviews of the SDG interactions literature to date. This is particularly true for the energy dimension of the SDGs. Some reports, such as ICSU-ISSC (2015), SDSN (2015) and UN (2016a), present and/or review indicators for monitoring progress along the various SDGs. While the comprehensiveness of these publications is noteworthy, they did not provide an assessment of SDG interactions. Le Blanc (2015) presents a 'political mapping' of the SDGs, using network analysis to show which thematic areas are connected to each other (based on the specific wording of the individual SDG targets); however, the nature and strength of the interactions are not assessed. Other reviews, such as the *Global Sustainable Development Report* 2016 (UN 2016b) and the *Global Education Monitoring Report* (UNESCO 2016), also discuss SDG interactions in brief, though, like the others, not through the lens of energy (focusing instead on infrastructure-inequality-resilience and education, respectively). In addition to these publications, von Stechow *et al* (2015 and 2016), Jakob and Steckel (2016), IPCC (2011), and Riahi *et al* (2012) assess the synergies and trade-offs of climate change mitigation efforts and non-climate sustainability objectives, but only for a subset of dimensions (primarily air pollution, energy security, land use and biodiversity, water use and pollution, energy poverty, and employment). Finally, Fuso Nerini *et al* (2017) summarize the synergies and trade-offs between SDG7 and other SDGs, yet their review is not meant to be systematic or comprehensive, and the nature and strength of the identified relationships are not discussed in detail. Our assessment of the literature goes beyond all of these aforementioned studies in important ways, thus filling a notable gap in the energy and sustainability literature. Firstly, starting from the SDG7 entry point, our analysis explores in detail the various energy-related interactions with all the other SDGs, and we do this by conducting a systematic assessment of the relevant

[9] See the following URL for the UN's original 2030 Agenda text spelling out the details of all SDGs: https://sustainabledevelopment.un.org/sdgs.

[10] We recognize that the terminology 'non-energy SDGs' is somewhat of a misnomer here, given our assertion that all of the SDGs do in fact relate to the SDG7 (Energy) targets in some way or another. Yet, for conciseness and ease-of-interpretation, we continue to use this simplified wording.

[11] To be sure, more emphasis is placed on studies exploring the former relationship. Also, except in isolated cases, we do not consider the effects of *avoided climate change* on certain SDG dimensions, even if energy-related actions are a key driver in reducing greenhouse gas emissions and, by extension, limiting harmful effects in other areas of sustainability. An example exception would be the SDG14 target related to ocean acidification: deployment of renewable energy and improvements in energy efficiency globally can reduce emissions, and this, in turn, will slow rates of ocean acidification.

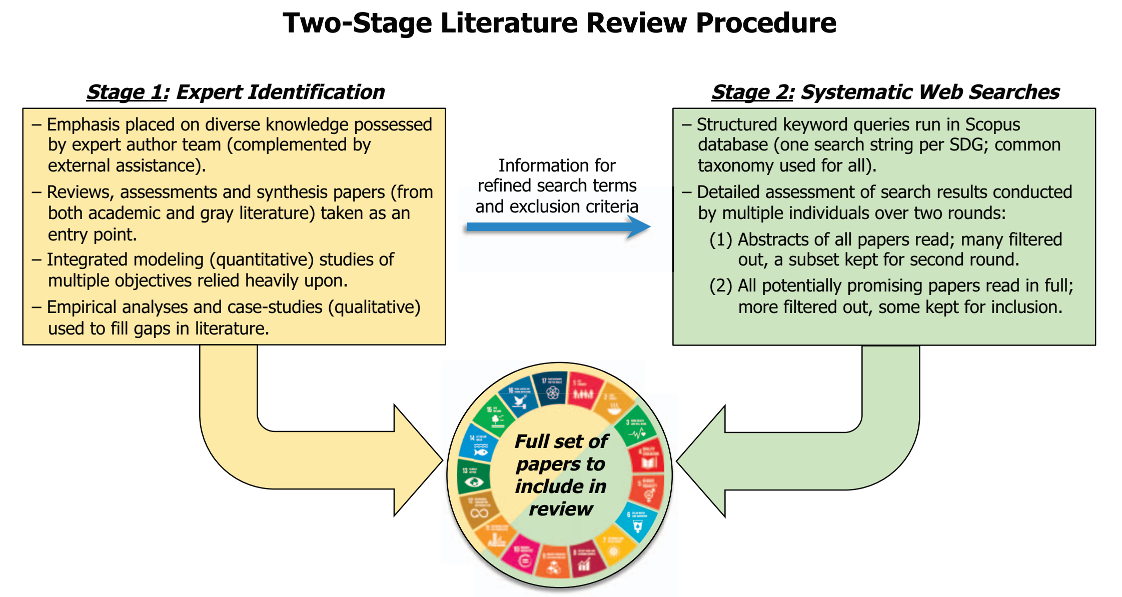

Figure 1. Overview of the two-stage literature review procedure utilized for selecting the evidence featured in this review.

literature. Moreover, by (i) evaluating the nature and strength of the interactions identified, (ii) indicating the robustness of the evidence base, the agreement of that evidence, and our confidence in it, and (iii) highlighting critical areas where better understanding is needed or context dependencies should be considered, our review points to potential ways forward for both the policy making and scientific communities.

Selection of evidence featured in the review

The focus of our literature search was on studies that have assessed the interactions between two or more sustainable development objectives simultaneously (e.g. food and water, poverty and inequality, and/or employment and innovation, among other combinations), as opposed to studies that have focused on singular objectives in isolation. In order to establish an expansive and representative set of interactions studies for the fifteen relevant SDGs, literature identification and selection proceeded along two routes, in line with commonly applied systematic review procedures (Cooper *et al* 2009, Ringquist 2013). As illustrated schematically in figure 1, we first leveraged the diverse and deep knowledge of the author team across relevant fields of the literature, in order to establish an initial set of (key) studies. (This was complemented by assistance from experts outside the author team in a few instances; see the acknowledgements section.) Subject matter expertise among the authors includes economics and policy issues related to energy, climate change, transport, natural resources, and development; water infrastructure and hydrology; poverty and inequality; air quality and health; investments and financing; energy and climate systems modeling; integrated assessment; and scenario analysis. Second, we conducted a systematic literature review using structured keyword search queries in Scopus, in order to supplement our expert assessment procedure. Further details on this two-stage literature review approach are provided below.

In the first stage of our literature search—the expert identification procedure—more than 170 studies were identified and reviewed. We initially located synthesis papers, by way of expert judgement and Web searches, focusing on different SDG-related dimensions (both from the academic and gray literature) that had already undertaken substantive reviews on particular topics and could therefore be used as guides for deeper investigation of the evidence (e.g. Aether 2016, Aranda *et al* 2014, Bhattacharyya 2013, Cook 2011, Pueyo *et al* 2013, Raji *et al* 2015, Saunders *et al* 2013, Shaw *et al* 2014, Smith *et al* 2013, Sola *et al* 2016, WBGU 2013). These papers may or not have used the specific language of the SDGs within their text—in fact prior to 2015, this language did not even exist. Next, we sought out papers that explore integrated solutions for meeting multiple sustainable development objectives simultaneously *and* that are globally and/or regionally comprehensive in nature. This specifically included forward-looking, quantitative scenario studies with a systems focus in the multi-objective solution space, not limited to those explicitly mentioning the SDGs or using the SDGs for framing. (To draw a distinction here, engineering-level analyses detailing the effects of individual technologies on different SDG dimensions in particular locales were in most cases not included in our review, since they lack the necessary systems perspective—for example, a study of the food security and economic effects of growing a particular species of giant reed in southern Italy, as described in one study that our database queries initially identified.) The review of multi-regional, integrated modelling studies allowed us to draw out some of the more robust insights for SDG interactions that present themselves in locations throughout the world, recognizing of course that the strength and nature of interactions can be location-specific (see later section on 'Context-dependencies and the nature of SDG interactions'). Lastly, because globally comprehensive integrated assessments (of the impacts of meeting particular sustainability objectives on others) do not yet exist for all dimensions related to the SDGs, we utilized expert judgement (both inside and outside the author team) and Web searches to identify qualitative papers that have assessed any SDG interactions from a more historical/empirical/case-study perspective. Most of these analyses take a national or sub-national focus. Of particular note, this strategy was employed for SDG1 (No Poverty), SDG4 (Quality Education), SDG5 (Gender Equality), and SDG10 (Reduced Inequalities).

Following the first-stage expert elicitation, we initiated a set of structured keyword searches in Scopus—the aim being to ensure our set of 'hand-selected' studies was representative of the wider literature dealing with interactions between two or more sustainable development objectives simultaneously. Scopus is the largest database of peer-reviewed literature in existence and therefore provides a powerful tool for identifying such literature. In particular, we constructed fifteen unique queries: one for each SDG (other than SDG7 and the 'means of implementation' SDG17). These queries share a common taxonomy that always consists of four parts:

- **Entry point**: SDG7, thus using search terms like 'energy', 'electricity', 'fuel' and other context-related synonyms specific to a particular SDG (in order to distinguish direct vs. indirect or irrelevant relationships).
- **Search context**: sustainable development goals
- **Type of interaction**: synergies, trade-offs, and linkages, among other similar search terms
- **Sustainability dimension**: SDG 'X', thus using search terms specific to a particular SDG (derived from the UN's official SDG target and indicator language, as well as the keywords identified through our first-stage expert identification procedure)

The keywords selected for application at each level of the taxonomy were initially constructed by three of the authors based on knowledge gained through the first-stage expert identification process. Keywords were further refined iteratively, by reviewing the quality of the search results in order to isolate the types of studies we were targeting in our work (see earlier discussion). Finally, other authors were consulted for further review and modifications. In Scopus, the four query components of the taxonomy were connected with the 'AND' operator; we specifically mined the titles, abstracts and keywords of papers. Queries were run in Scopus during the period between November 13 and 24, 2017, and the complete set of queries is reproduced in the supplementary material available at stacks.iop.org/ERL/13/033006/mmedia. Importantly, by including the contextualizing search term 'sustainable development goals', our queries focus mainly on more recent studies (post-2014/2015, after the SDGs as a concept were recognized and subsequently adopted) that either deal with the SDGs explicitly or whose analysis is placed within an SDG framing. We consider such studies most relevant for our purposes.

In total, our systematic search queries yielded 823 results. Yet, only a subset of these studies were judged relevant to be included in our analysis. Carrying out this include/exclude procedure was done in two rounds. First, we reviewed all 823 abstracts, and based on a transparent set of exclusion criteria, which were designed in line with the first-stage expert selection process outlined above (see supplementary material for specifics), we removed a large number of studies from the subset to be analyzed further. The review of abstracts was primarily conducted by two people, with help from others on an as-needed basis. Due to the substantial number of abstracts to be sifted through, it was necessary to split them up (by SDG area) between the two individuals. In order to ensure consistency in the independent assessments carried out, these two individuals first chose two SDG areas and then both independently reviewed the abstracts of each. After doing this separately, the two discussed their independent assessments and why they 'graded' each paper the way they did (i.e. which papers should be included or excluded and for what reasons). This initial 'rubric-defining' process helped the two individuals to 'get on the same page' early on about how to conduct their assessments independently. The outcome of this abstract review process was a subset of 100 'potentially relevant' papers to be analyzed further in a second step. We scrutinized the full manuscripts of these 100 studies, in order to determine whether each really should be included in our review. This assessment was carried out by the same two individuals as in the first round (abstract review), again with assistance from other co-authors on an as-needed basis. As before, the papers were split up evenly and assessed independently. The sorting and splitting up of papers was designed in a way such that each individual received a mix of papers to review (i.e. from a variety of SDG areas), thus ensuring that some (random selection of) papers not assessed by one individual during the abstract review round would now in fact be seen by this same individual during the full manuscript review. In the end, 53 of these 'potentially relevant' studies were classified as 'definitely relevant': i.e. were ultimately included as references in our paper, thereby complementing those included from the first-stage expert identification process. Throughout this multi-stage process, our efforts to involve multiple people in the search query definition and abstract and manuscript review exercises were geared to ensure consistency in literature selection across members of the team, as well as a decent level of reproducibility of our efforts by others in future efforts.

Evaluating the nature of SDG interactions using established methodologies

The general conversation on interactions between SDGs has until now been limited either to establishing the presence of a link or, at best, an identification of 'trade-offs' and 'synergies'. There are, however, more nuanced ways in which interactions can be understood, and for this reason an alternative, more delineated (while still clear and straightforward) framework is needed. After all, varying grades of synergies and trade-offs exist. For instance, providing electricity access to the poor makes it easier for pupils to study after dark but does not guarantee they will actually study, whereas the substitution of renewable energy for fossil fuels definitely results in lower carbon dioxide emissions and therefore furthers climate change mitigation goals.

In this review, we utilize the typology and seven-point scale presented in Nilsson *et al* (2016) (see table 1) to assess linkages among SDG targets from the vantage point of energy. We rely on our assessment to arrive at these evaluations, taking each of the non-energy SDGs in turn and summarizing the principal interactions (their nature and directionality) between the underlying targets of these SDGs and those of SDG7 (Energy). As evidenced through the use of the seven-point scale, interactions may be scored as either positive ('indivisible', 'reinforcing' or 'enabling') or negative ('constraining', 'counteracting' or 'canceling'); or the respective SDG targets may be entirely 'consistent' with each other, incurring no significant positive or negative interactions whatsoever, perhaps not interacting at all. Figure 2 lays out the results of our scoring exercise graphically, while table 2 provides support for how we arrived at our score determinations based on the literature review. The values for the interactions scores were generated based on an internal 'expert elicitation' amongst subsets of authors within our team. In most cases at least three or four individuals reviewed a given interaction and provided their assessment of what the score 'should be'. Small-group discussions were then held between those authors, in order to reach agreement on a single score. Of particular note, it was precisely in those instances of initial disagreement where some of the most insightful conversations took place.

In addition to scoring the interactions, we also evaluated the robustness of the evidence base in each SDG dimension as well as the degree of agreement of that evidence. This then allowed us to arrive at a measure of confidence in the interaction scores assigned—or put another way, an indication of the current 'state of the science.' We followed an established approach in arriving at these evaluations, observing guidelines on the consistent treatment of uncertainties provided by the Intergovernmental Panel on Climate Change for its Fifth Assessment cycle (Mastrandrea *et al* 2011). Specifically, we describe the validity of a finding in the literature by assessing the type, amount, quality, and consistency of the evidence supporting that finding ('limited,' 'medium,' or 'robust'). We then utilize our author team's collective expertise to assess the extent to which the present body of literature is in agreement on a particular finding ('low,' 'medium,' or 'high'). Finally, based on these two aspects, we offer our assessment of the current level of confidence that can be assigned to each energy-related SDG interaction that has heretofore been identified by the scientific community ('very low,' 'low,' 'medium,' 'high,' and 'very high'). These assessments are based on the authors' judgment, and we were able to arrive at them only after having taken stock of the relevant literature for each SDG dimension. As described above for the interactions scores, we developed our assessments based on internal 'expert elicitation' amongst subsets of authors within our team (three or four individuals + small-group discussions).

In deriving our assessments of the 'evidence', we paid particular attention to the number of studies that have looked into a given interaction and then what kinds of studies these were. For example, in the latter case empirical studies and empirically informed modeling analyses were given greater weight than less quantitative 'thought pieces'. Publication type was also taken into consideration, with seminal review papers, high-impact papers, and major assessment exercises garnering greater attention than very technology- and place-specific studies—unless the latter formed the bulk of analyses that have been done on a particular topic. To be sure, no explicit/quantitative weights were given to the papers and reports we assessed: in other words, we did not explicitly rank papers by journal type or by the methodology utilized. The weighting was more implicit/qualitative in nature, based on knowledge accumulated throughout our project and indeed well before it. This collective accumulation of knowledge was also critical in informing our assessments of 'agreement' and 'confidence'. The former was decided upon based primarily on the number of studies reaching a particular conclusion for a given SDG interaction vis-à-vis the number reaching different conclusions. Also here, we gave greater implicit weights to studies judged by us to be of higher quality (in terms of those studies' methodology and format—with reviews, assessments, and high-impact papers rating highest in these respects). The 'confidence' assessment is subsequently derived from the 'evidence' and 'agreement' assessments. More precisely, 'confidence' is linked to 'agreement', with 'evidence' playing a moderating role. For example, if, hypothetically, the literature suggested 'high agreement' for a particular SDG interaction but there were only, say, two papers in that literature ('limited evidence'), we would likely assign a lower

Table 1. Scale used to assess the nature of the interactions between SDG7 (Energy) and the non-energy SDGs. The table is adapted from Nilsson (2017) and shown here with permission.

INDIVISIBLE	+3	The strongest form of positive interaction in which one objective is inextricably linked to the achievement of another. For example, achieving "End all forms of discrimination against all women and girls every-where" (5.1) would in itself lead to the achievement of "Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision- making in political, economic and public life" (5.5).
REINFORCING	+2	One objective directly creates conditions that lead to the achievement of another objective. For example, strengthening resilience and adaptive capacity to climate-related hazards (13.1) will directly reduce losses caused by disasters (11.5). Providing access to electricity reinforces water-pumping and irrigation systems. The SDG targets and goals provide numerous possibilities for synergies.
ENABLING	+1	The pursuit of one objective enables the achievement of another objective. For example, providing electricity access in rural homes facilitates the pursuit of education for all, as it allows the rural poor who have to work after school to do homework at night with the aid of electric lighting. Outdoor electric lighting also increases safety in the streets, enabling more women to attend evening courses or school at night.
CONSISTENT	0	A neutral relationship where one objective does not significantly interact with another or where interactions are deemed to be neither positive nor negative.
CONSTRAINING	-1	A mild form of negative interaction when the pursuit of one objective sets a condition or a constraint on the achieve-ment of another. For example, efficiency objectives for agricultural water use set conditions for how access to irrigation can be provided. And the climate change mitigation objective limits the options as to how to pursue energy access objectives. In the 2030 Agenda, many targets impose constraints on others.These are important since they can help ensure that development strategies are sustainable over time, help achieve targets with minimum mitiga-tion or rehabilitation costs for other objectives and help ensure that they respect boundaries of the natural resource base. Of course, ensuring that conditionalities are taken into account requires that these have been appropriately mapped.
COUNTERACTING	-2	The pursuit of one objective counteracts another objective. For example, pursuing policies to boost consumption in order to promote economic growth may counteract the objectives to reduce waste and greenhouse gas emissions. Increasing human habitation in flood-prone areas or agriculture into drought-prone areas may increase important social targets in the SDGs but can lead to decreased resilience against climate-related events such as flooding or drought.
CANCELLING	-3	The most negative interaction is where progress in one goal makes it impossible to reach another goal and possibly leads to a deteriorating state of the second. A choice has to be made between the two. For example, national security objectives make it impossible to have fully transparent and democratically accountable decision-making in govern-ment. Another example is the full protection of nature reserves versus public access for recreational purposes, or access by pastoralists who traditionally traverse the reserve during their seasonal migrations. Here, a balance needs to be struck based on both political judgement and scientific assessment.

level of 'confidence' to that interaction than if it were backed up by two dozen studies ('robust evidence'). This would be especially true if there would be intimations of uncertainty in those limited number of studies.

Interactions between energy and non-energy SDGs and targets

Table 2 presents the sum result of our literature review efforts, along with the interactions scores and uncertainty assessment. As seen, single interactions scores for clusters of SDG targets are generally the norm; though, in some cases ranges are given. The latter can be more fitting either when a given effect depends strongly on context (e.g. jurisdictional unit where policy is implemented, the exact instruments utilized) or when the prevailing science tends not to agree regarding the nature of the particular interaction (i.e. when there is uncertainty).

A key insight that emerges from our analysis is that, as gleaned most easily from figure 2, positive interactions between SDG7 (Energy) and the other SDGs clearly outweigh the negative ones, both in number and magnitude. (Note that the figure shows only one positive or negative score per SDG. In instances where multiple interactions are present at

Table 2. Overview of the assessed literature and conclusions drawn on interactions between the targets of SDG7 (Energy) and those of the non-energy SDGs. The table summarizes (i) literature we assessed in our review, (ii) key insights from the literature, (iii) robustness of the evidence base for a given SDG interaction, (iv) agreement within the literature for that interaction, and (v) our level of confidence in the scores assigned and the conclusions reached. As put forward in Mastrandrea *et al* (2011), the following language can be used to describe the validity of a finding in the literature: the type, amount, quality, and consistency of evidence (summary terms: 'limited,' 'medium,' or 'robust'), and the degree of agreement (summary terms: 'low,' 'medium,' or 'high'). This then leads to our assessment of the level of confidence in a finding (summary terms: 'very low,' 'low,' 'medium,' 'high,' and 'very high').

SDG	Target Category	Supporting Literature	Interactions Identified	Score	Evidence	Agreement	Confidence
1 NO POVERTY	Poverty and Development (1.1/1.2/1.3/1.4)	Akter et al. (2017); Bonan et al. (2014); Burlig and Preonas (2016); Casillas and Kammen (2010); Cherian (2015); Cook (2011); Haines et al. (2017); Kirubi et al. (2009); Pachauri et al. (2012); Pueyo et al. (2013); Rao et al. (2014); Schwerhoff and Sy	Access to modern energy forms (electricity, clean cook-stoves, high-quality lighting) is fundamental to human development since the energy services made possible by them help alleviate chronic and persistent poverty. Modern energy access can also help to free up resources (e.g. time, money) for other productive uses. The strength of the impact varies in the literature.	[+2]	robust	high	***very high***
		Cameron et al. (2016); Casillas and Kammen (2012); Fay et al. (2015); Hallegate et al. (2016); Hirth and Ueckerdt (2013); Jakob and Steckel (2014); Schwerhoff et al. (2017)	The distributional costs of new energy policies (e.g., supporting renewables and energy efficiency) are dependent on instrument design. For example, the recycling of carbon pricing revenues offers an option to compensate poor households in the event energy prices rise. If costs do fall disproportionately on the poor, then this could impair progress toward universal energy access and, by	[0,-1]	robust	high	***high***
	Exposure and Vulnerability (1.5)	Hallegatte et al. (2016); IPCC (2014); Riahi et al. (2012); Schwerhoff and Sy (2017)	Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of the world's poor to climate-related extreme events, negative health	[+2]	robust	high	***high***
2 ZERO HUNGER	Food Security and Agricultural Productivity (2.1/2.4)	Acheampong et al. (2017); Asaduzzaman et al. (2010); Cabraal et al. (2005); Das (2017); Dodds and Bartram (2016); Finco and Doppler (2010); Gao and Bryan (2017); Hasegawa et al. (2015); Kline et al. (2017); Lotze-Campen et al. (2014); Msangi et al. (2010); Rasul (2016); Ringler et al. (2013); Ringler et al. (2016); Schwerhoff and Sy (2017); Smith et al. (2013); Smith, P. et al. (2014); Sola et al. (2016); Tilman et al. (2009); van Vuuren et al. (2009); Whitmee et al. (2015); Zhang et al. (2018)	Modern energy access is critical to enhance agricultural yields/productivity, decrease post-harvest losses, and mechanize agri-processing - all of which can aid food security. The introduction of best-practice production methods, such as rice intensification, in non-bioenergy agriculture can reduce energy demand in the agricultural sector. However, large-scale bioenergy and food production may compete for scarce land and other inputs (e.g., water, fertilizers), depending on how and where biomass supplies are grown and the indirect land use change impacts that result. If not implemented thoughtfully, this could lead to higher food prices globally, and thus reduced access to affordable food for the poor. Enhanced agricultural productivities and integrated resource management can ameliorate the situation by allowing as much bioenergy to be produced on as little land as possible. Third- and fourth-generation biofuels (e.g., algae) may have lower agricultural market impacts, since they can utilize land that is otherwise unsuitable for food	[-1,+1]	robust	medium	***medium***
	Farm Employment and Incomes (2.3)	Balishter et al. (1991); Creutzig et al. (2013); de Moraes et al. (2010); Gohin (2008); Rud (2012); Satolo and Bacchi (2013); van der Horst and Vermeylen (2011)	Large-scale bioenergy production could lead to the creation of agricultural jobs, as well higher farm wages and more diversified income streams for farmers. Modern energy access can make marginal lands more cultivable, thus potentially generating on-farm jobs and incomes; on the other hand, greater farm	[+2]	robust	high	***high***
		Corbera and Pascual (2012); Creutzig et al. (2013); Davis et al. (2013); Muys et al. (2014); van der Horst and Vermeylen (2011)	Large-scale bioenergy production could alter the structure of global agricultural markets in a way that is, potentially, unfavorable to small-scale food producers. The distributional effects of bioenergy production are underexplored in the	[0,-2]	medium	high	***medium***
3 GOOD HEALTH AND WELL-BEING	Disease and Mortality (3.1/3.2/3.3/3.4)	Akter et al. (2017); Amegah and Jaakkola (2016); Amegah and Agyei-Mensah (2017); Aranda et al. (2014); Cherian (2015); Collste et al. (2017); Galvão et al. (2016); Haby et al. (2016); Haines et al. (2017); Lam et al. (2012); Lim et al. (2012); Smith et al	Access to modern energy services, including but not limited to distributed renewables, can contribute to fewer injuries and diseases related to traditional solid fuel collection and burning and to the utilization of kerosene lanterns.	[+2]	robust	high	***very high***

Table 2. *Continued.*

	Road Traffic Accidents (3.4/3.6)	Creutzig et al. (2012); Figueroa and Ribeiro (2013); Haines and Dora (2012); Haines et al. (2017); Saunders et al. (2013); Shaw et al. (2014); Watts et al. (2017); Woodcock et al. (2009)	'Active travel modes' (such as walking and cycling) represent strategies not only for boosting energy efficiency but also, potentially, for improving health and well-being (e.g., lowering rates of diabetes, obesity, heart disease, dementia, and some cancers). However, a risk associated with these measures is that they could increase rates of road traffic accidents, if the provided infrastructure is unsatisfactory. Overall health effects will depend on the severity of the injuries	[-1,+1]	limited	high	***medium***
	Health Care Provision (3.7/3.8)	Akter et al. (2017); Aranda et al. (2014); Haby et al. (2016); Watts et al. (2017)	Access to modern energy services can facilitate improved health care provision, medicine and vaccine storage, utilization of powered medical equipment, and dissemination of health-related information and education. Such services can also enable thermal comfort in homes and contribute to food preservation and	[+1]	limited	medium	***medium***
	Air Pollution (3.9)	Acheampong et al. (2017); Anenberg et al. (2013); Chaturvedi and Shukla (2014); Figueroa and Ribeiro (2013); Galvão et al. (2016); Haby et al. (2016); Haines et al. (2007); IEA (2016); Kaygusuz (2011); Lelieveld (2017); Nemet et al. (2010); Rafaj et al. (2013); Rao et al (2013); Rao et al (2016); Riahi et al. (2012); Rose et al. (2014); Schwerhoff and Sy (2017); Smith and Sagar (2014); van Vliet et al. (2012); van	Promoting most types of renewables and boosting efficiency greatly aid the achievement of targets to reduce local air pollution and improve air quality; however, the order of magnitude of the effects, both in terms of avoided emissions and monetary valuation, varies significantly between different parts of the world. Benefits would especially accrue to those living in the dense urban centers of rapidly developing countries. Utilization of biomass and biofuels might not lead to any air pollution benefits, however, depending on the control measures applied. In addition, household air quality can be significantly	[+2]	robust	high	***very high***
4 QUALITY EDUCATION	Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)	Akter et al. (2017); Collste et al. (2017); Lipscomb et al. (2013); Schwerhoff and Sy (2017); van de Walle et al. (2013)	Access to modern energy is necessary for schools to have quality lighting and thermal comfort, as well as modern information and communication technologies. Access to modern lighting and energy allows for studying after sundown and frees constraints on time management that allow for higher school	[+1]	medium	high	***medium***
	Human Capital (4.4/4.6/4.7)	ESMAP (2003); Gustavsson (2007); Khandker et al. (2009); Lutz (2017); Mihelcic et al. (2017); UNESCO (2016)	Quality education throughout a society (i.e., more and better trained teachers) raises its general level of human capital. This collection of knowledge and skills can then be drawn upon to promote sustainable development, potentially influencing the technological, financial, and political solutions that are feasible to	[+1]	robust	high	***high***
5 GENDER EQUALITY	Women's Safety and Worth (5.1/5.2/5.4)	Akter et al. (2017); Burney et al. (2017); Anenberg et al. (2013); Chowdhury (2010); Haines et al. (2017); Haves (2012); Matinga (2012); Pachauri and Rao (2013); Schwerhoff and Sy (2017)	Improved access to electric lighting can improve women's safety and girls' school enrollment. Cleaner cooking fuel and lighting access can reduce health risks and drudgery, which are disproportionately faced by women.	[+1]	medium	high	***medium***
	Opportunities for Women (5.1/5.5)	Akter et al. (2017); Burney et al. (2017); Chowdhury (2010); Clancy et al (2011); Dinkelman (2011); Haines et al. (2017); Haves (2012); Kaygusuz (2011); Kohlin et al. (2011); Pachauri and Rao (2013)	Access to modern energy services has the potential to empower women by improving their income-earning, entrepreneurial opportunities, autonomy and reducing drudgery. Participating in energy supply chains can increase women's opportunities and agency and improve business outcomes.	[+1]	medium	medium	***medium***
	Reproductive Rights of Women (5.6)	Jensen and Oster (2009)	Energy access-enabled ICT services can potentially also reduce the risk of violence against women and improve fertility outcomes.	[+1]	limited	medium	***low***

Table 2. *Continued.*

6 CLEAN WATER AND SANITATION	Water Availability (6.1/6.2/6.4/6.5/6.6)	Acheampong et al. (2017); Byers et al. (2014); Davies et al. (2013); Dodds and Bartram (2016); Fricko et al. (2016); Fujimori et al. (2016); Giupponi and Gain (2017); Hall et al. (2017); Hanasaki et al. (2013); Hejazi et al. (2013); Hejazi et al. (2015); Hirsch et al. (2016); Liu et al (2017); Macknick et al. (2012); Miara et al. (2014); Miletto (2015); PBL (2012); Ringler et al. (2013); Schwanitz et al. (2017); Vidic et al. (2013); Yillia (2016); Zhang et al. (2018)	An up-scaling of renewables and energy efficiency will, in most instances, reinforce targets related to water access, scarcity and management, for example by lowering water demands for thermal cooling at energy production facilities ('water-for-energy') compared to less-efficient fossil energy technologies. However, bioenergy and hydropower technologies could, if not managed properly, have counteracting effects that compound existing water-related problems in a given locale. Third- and fourth-generation biofuels (e.g., algae) may have lower water impacts, since they can utilize land and water that is otherwise unsuitable for food production. Concentrated solar power tends to be installed in locations with ample sunshine, and these areas are often the same ones under water stress. In the reverse direction, today's water pumping, conveyance, and treatment	[+2]	robust	high	***very high***
		Parkinson et al. (2016); Strbac (2008); Yillia (2016)	Increased shifts toward unconventional water supply options, such as desalination, in the world's water-stressed regions will generally increase energy demand. This could either be to the benefit of renewables (if water-related infrastructure and equipment can be used for real-time demand-side power management, thus helping with integration of the intermittent sources of electricity) or could present a marked challenge to their deployment (if there are	[-1,+1]	limited	high	***medium***
	Water Quality (6.2/6.3/6.6)	Davies et al. (2013); Fricko et al. (2016); Haines et al. (2007); Miara et al. (2014); Trimmer et al. (2017); Vidic et al. (2013);	An up-scaling of renewables and energy efficiency should lead to lower levels of water pollution (chemical and thermal) than a fossil-dominant energy system. The impacts of bioenergy deployment will need to be evaluated on a case-by-case basis, however. Implementing resource recovery on household sanitation systems could improve	[+2]	medium	high	***high***
8 DECENT WORK AND ECONOMIC GROWTH	Employment Opportunities (8.2/8.3/8.5/8.6)	Akter et al. (2017); Burney et al. (2017); Bernard and Torero (2015); Chakravorty et al. (2014); Grogan and Sadanand (2013); Pueyo et al. (2013); Rao (2013); van Vuuren et al. (2015)	Provision of energy access can play a critical enabling role for new productive activities , livelihoods and employment. Reliable access to modern energy services can have an important influence on productivity and earnings.	[+1]	medium	high	***medium***
		Aether (2016); Babiker and Eckaus (2007); Bertram et al. (2015); Blyth et al. (2014); Borenstein (2012); Creutzig et al. (2013); Clarke et al. (2014); Dechezleprêtre and Sato (2014); Dinkelman (2011); Fankhauser et al. (2008); Ferroukhi et al. (2016); Frondel et al. (2010); Gohin (2008); Guivarch et al. (2011); Howells and Laitner (2005); Jackson and Senker (2011); Johnson et al. (2015); Kurth (2017)	Deploying renewables and energy-efficient technologies, when combined with other targeted monetary and fiscal policies, can help spur innovation and reinforce local, regional, and national industrial and employment objectives. Gross employment effects seem likely to be positive; however, uncertainty remains regarding the net employment effects due to several uncertainties surrounding macro-economic feedback loops playing out at the global level. Moreover, the distributional effects experienced by individual actors may vary significantly. Strategic measures may need to be taken to ensure that a large-scale switch to renewable energy minimizes any negative impacts on those	[-1,+1]	robust	low-medium	***medium***
	Innovation and Growth (8.1/8.2/8.4)	Bonan et al. (2014); Clarke et al. (2014); Figueroa and Ribeiro (2013); Jackson and Senker (2011); New Climate Economy (2014); OECD (2017); Schandl et al. (2016); Schwerhoff and Sy (2017); Shahbaz et al. (2016); York and McGee (2017)	Decarbonization of the energy system through an up-scaling of renewables and energy efficiency is consistent with sustained economic growth and resource decoupling. Long-term scenarios point towards slight consumption losses caused by a rapid and pervasive expansion of such energy solutions. Whether sustainable growth, as an overarching concept, is attainable or not is more disputed in the literature. Existing literature is also undecided as to whether or	[-1,+1]	robust	medium	***medium***

Table 2. *Continued.*

	Strong Financial Institutions (8.10)	Bhattacharyya (2013); DB Climate Change Advisors (2011); Muench et al. (2016); Schmidt (2014); Schwerhoff and Sy (2017); WBGU (2012)	To support clean energy and energy efficiency efforts, strengthened financial institutions in developing country communities are necessary for providing capital, credit, and insurance to local entrepreneurs attempting to enact change.	[+2]	robust	high	***high***
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Inclusive and Sustainable Industrialization	Bertram et al. (2015); Fankhauser et al. (2008); Guivarch et al. (2011); Johnson et al. (2015)	A rapid up-scaling of renewable energies could necessitate the early retirement of fossil energy infrastructure (e.g., power plants, refineries, pipelines) on a large-scale. The implications of this could in some cases be negative, unless targeted	[0,-1]	medium	high	***medium-high***
	Infrastructure renewal (9.1/9.3/9.4/9.5)	Bhattacharyya et al. (2016); Goldthau (2014); Haines et al. (2017); Meltzer (2016); Reza et al. (2011); Riahi et al. (2012)	Financial and technical support can play a critical role in promoting the development of the renewable energy industry and more energy-efficient infrastructure. This includes targeted policy incentives (e.g., subsidies, R&D support) and spending on scientific research to encourage technological	[+2]	robust	high	***high***
			Transitioning to a more renewably-based energy system that is highly energy efficient is well alighed with the goal of upgrading energy infrastructure and making the energy industry more sustainable. Upgrades to fossil energy infrastructure can help improve resource-use efficiency (e.g., reducing leaks from natural gas pipelines and fugitive emissions from coal, oil and gas extraction). In the reverse direction, infrastructure upgrades in other parts of the economy, such as modernized telecommunication networks and 'green buildings' can create the conditions for a successful expansion of renewable energy and energy	[+1]	medium	medium	***medium***
10 REDUCED INEQUALITIES	Empowerment and Inclusion (10.1/10.2/10.3/10.4)	Akter et al. (2017); Burney et al. (2017); Dinkelman (2011); Figueroa and Ribeiro (2013); Pachauri et al. (2012); Pueyo et al. (2013)	Energy efficiency measures and the provision of energy access can free up resources (e.g., financial, time savings) that can then be put towards other productive uses (e.g., educational and employment opportunities), especially for women and children in poor, rural areas. Public transit, ride/car-sharing, and	[+1]	robust	medium	***medium***
		Cameron et al. (2016); Casillas and Kammen (2012); Fay et al. (2015); Hallegate et al. (2016); Hirth and Ueckerdt (2013); Jakob and Steckel (2014); Schwerhoff et al. (2017)	The distributional costs of new energy policies (e.g., supporting renewables and energy efficiency) are dependent on instrument design. If costs fall disproportionately on the poor, then this could work against the promotion of social, economic and political equality for all. At the same time, through their impact on asset prices and therefore on wealth, policies geared toward	[-1,+1]	robust	high	***high***
		Cass et al. (2010); Cumbers (2012); Kunze and Becker (2015); Walker and Devine-Wright (2008)	Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing	[+1]	medium	medium	***medium***
		Cayla and Osso (2013)	The impacts of energy efficiency measures and policies on inequality can be both positive (if they reduce energy costs) or negative (if mandatory standards increase the need for purchasing more expensive equipment and appliances).	[-1,+1]	limited	low	***low***
11 SUSTAINABLE CITIES AND COMMUNITIES	Housing and Transport (11.1/11.2)	Bhattacharya et al. (2016); Haines et al. (2017); Kahn Ribeiro et al. (2012); UN (2016c)	Ensuring access to basic housing services implies that households have access to modern energy forms.	[+3]	robust	high	***very high***
			Efficient transportation technologies powered by renewably-based energy carriers will be a key building block of any sustainable transport system.	[+2]	robust	high	***very high***
	Urban Environmental Sustainability (11.3/11.6)	Ahmad and Puppim de Oliveira (2016); Bongardt et al. (2013); Creutzig et al. (2012); Figueroa and Ribeiro (2013); Grubler and Fisk (2012); Kahn Ribeiro et al. (2012); Raji et al. (2015); Riahi et al. (2012)	Renewable energy technologies and energy-efficient urban infrastructure solutions (e.g., public transit, densification) can also promote urban environmental sustainability by improving air quality and reducing noise.	[+2]	robust	high	***very high***

Table 2. *Continued.*

12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Natural Resource Protection (12.2/12.3/12.4/12.5)	Ali et al. (2017); Banerjee et al. (2012); Bhattacharyya et al. (2016); Cameron et al. (2016); Carmona et al. (2017); Gutowski et al. (2017); Ham and Lee (2017); Riahi et al. (2012); Schandl et al. (2016); Schwanitz et al. (2014)	Renewable energy and energy efficiency slow the depletion of several types of natural resources, namely coal, oil, natural gas, and uranium. Advanced technologies and infrastructure will, however, still require vast amounts of minerals, including both common commodities and critial rare earth elements. Supplies of these minerals face long-term limitations, and it will take time before recycling activities can contribute at a massive scale. Increasing recycling rates offers a means to improve the energy efficiency of materials production and use and consequently to reduce the impacts of mining and extraction, raw goods conversion, and waste incineration and landfilling. Waste-to-energy technologies can generate useful energy (electricity, heating/cooling) from disposables that are not suitable for recycling. The phasing-out of fossil fuel subsidies encourages less wasteful energy	[+2]	robust	high	***very high***
	Sustainable Practices and Lifestyles (12.6/12.7/12.8)	CDP (2015); European Climate Foundation (2014); Khan et al. (2015); New Climate Economy (2015); Stefan and Paul (2008)	Sustainable practices adopted by public and private bodies in their operations (e.g., for goods procurement, supply chain management, and accounting) create an enabling environment in which renewable energy and energy efficiency	[+1]	robust	high	***high***
13 CLIMATE ACTION	Climate Strategies and Education (13.2/13.3)	IPCC (2011); Jennings (2009); Schreurs (2008)	Better integrating climate change measures into national planning and improving education, awareness, and capacity on climate issues will go a long way in furthering international targets for renewables and energy efficiency.	[+2]	robust	high	***high***
	Global Warming (*)	Anenberg et al. (2013); Cherian (2015); Gambhir et al. (2017); Kriegler et al. (2013); Kriegler et al. (2014); PBL (2012); Riahi et al. (2015); Riahi et al. (2017); Rogelj et al. (2013); Tavoni et al. (2013); van Vuuren et al. (2015)	Meeting the renewable energy and energy efficiency targets of SDG7 is a necessary, but not entirely sufficient, condition for long-term temperature stabilization below 2 °C. For the latter to be achieved with high probability, an up-scaling of efforts beyond 2030 will be needed. Providing universal access to modern energy services by 2030 is fully consistent with the Paris Agreement, as reaching this target will have only a minor effect on global carbon emissions. *[*Note: The 2030 Agenda text describing SDG13 does not specifically mention a long-term temperature goal, but it does refer to the UNFCCC process, and the*	[0,+2]	robust	high	***very high***
14 LIFE BELOW WATER	Marine Protection (14.1/14.2/14.4/14.5)	Inger et al. (2009); WBGU (2013)	Depending on the local context and prevailing regulations, ocean-based energy installations could either induce spatial competition with other marine activities, such as tourism, shipping, resources exploitation, and marine and coastal habitats and protected areas, or provide further grounds for protecting those	[-1,+1]	limited	high	***medium***
	Ocean Acidification (14.3)	Caldeira and Wicket (2003); Feely et al. (2009); Gruber (2011); Le Quére et al. (2009); The Royal Society (2005); WBGU (2013)	Deployment of renewable energy and improvements in energy efficiency globally can reduce carbon dioxide emissions, and this, in turn, will slow rates of ocean acidification.	[+2]	robust	high	***high***
	Marine Economies (14.7)	Buck and Krause (2012); Michler-Cieluch et al. (2009); WBGU (2013)	Ocean-based energy from renewable sources (e.g., offshore wind farms, wave and tidal power) are potentially significant energy resource bases for island countries and countries situated along coastlines. Multi-use platforms combining renewable energy generation, aqua-culture, transport services and leisure	[+1]	limited	high	***low***

Table 2. *Continued.*

15 LIFE ON LAND	Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15	Bailis et al. (2015); Bazilian et al (2011); Karekezi et al. (2012); Schwerhoff and Sy (2017); Winter et al. (2015)	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.	[+2]	medium	high	***high***
		Hirsch et al. (2016); Kline et al. (2015); Mueller et al. (2015); Phumee et al. (2017); Smith et al. (2010); Smith et al. (2014); van Vuuren et al. (2015); Whitmee et al. (2015); Yillia (2016)	Protecting terrestrial and inland freshwater ecosystems, sustainably managing forests, halting deforestation, preventing biodiversity loss and controlling invasive alien species could potentially clash with renewable energy expansion, if that would mean constraining large-scale utilization of bioenergy or hydropower. On the other hand, prevention of soil degradation is critical for bioenergy production. In the reverse direction, access to modern energy could mean less disturbance of local biodiversity for fuel collection. Good governance, cross-jurisdictional coordination, and sound implementation	[-1,+1]	medium	medium	***medium***
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Institutional Capacity and Accountability (16.1/16.3/16.5/16.6/16 .7/16.8)	Acemoglu (2009); Acemoglu et al. (2014); ICSU, ISSC (2015); Tabellini (2010)	Institutions that are effective, accountable, and transparent are needed at all levels of government (local to national to international) for providing energy access, promoting modern renewables, and boosting efficiency. Strengthening the participation of developing countries in international institutions (e.g., international energy agencies, United Nations organizations, World Trade Organization, regional development banks and beyond) will be	[+2]	medium	medium	***medium***

Figure 2. Nature of the interactions between SDG7 (Energy) and the non-energy SDGs. The relationships may be either positive (left panel) or negative (right panel) to differing degrees. See table 1 for definitions pertaining to each score from +3 (positive) to –3 (negative) in integer increments. The absence of a colored wedge in either the left or right panels indicates a lack of positive or negative interactions, respectively; if wedges are absent in both panels for a given SDG, this indicates a score of 0 ('consistent'). Only one positive or negative score is shown per SDG; in instances where multiple interactions are present at the underlying target level (positive and negative treated separately), the individual score with the greatest magnitude is shown. Note that, while not illustrated by this figure, some SDG linkages may involve more than simple two-way interactions (e.g. the energy-water-land 'nexus'). As described in the text, no scoring is done for the 'means of implementation' goal, SDG17.

the underlying target level (positive and negative treated separately), the individual score with the greatest magnitude is shown.) In other words, efforts to ensure access to modern energy forms for the world's poorest and to deploy renewables rapidly and accelerate the pace of energy efficiency improvements in all countries should, more often than not, be to the benefit of the broader sustainable development agenda—vis-à-vis a world in which vast inequalities in energy access remain and where energy supply, conversion and demand activities are inefficient and fossil-dependent. There are instances, however, where dis-benefits, or trade-offs, could emerge.

To take an example, substituting coal and natural gas in electricity generation with solar, wind and most other renewables (though perhaps not biomass), and subsequently using that electricity to power end-use processes in the transport, buildings, and industrial sectors will help to improve the air quality of cities throughout the world (SDG3). Cleaner air, in turn, means healthier populations that can more productively contribute to the economy. The literature is robust in this area (i.e. relatively expansive with numerous high-quality studies), and scientific agreement is high regarding the positive impacts. We therefore assign a 'very high' level of confidence to the nature of this interaction and give it a score of [+2] ('reinforcing') (see table 2). Taking another example, if an expansion of renewables leads to large-scale bioenergy production globally, then there is a risk of competition with land for food production (SDG2) and water for multiple uses (SDG6). Increased food prices could potentially result in such a scenario, which would be to the detriment of the poor worldwide. The literature in this area is, at present, less consistent: while there is agreement about the potentially negative impacts (and the need for policy packages that minimize or avoid these impacts), there is also contradicting evidence in specific contexts. Therefore, more research appears to be needed. We therefore assign a 'medium' level of confidence to the nature of this interaction and give it a score of [−1, +1] ('constraining' to 'enabling').

Context-dependencies and the nature of SDG interactions

To be sure, the nature of a given SDG interaction cannot always be universally defined: linkages are often context-dependent and case-specific, as they hinge on where, when and how the pursuit of targets occurs. Thus, when assessing interactions for the purposes of policy implementation, it is important to clearly articulate such dependencies, where they exist. We have done this in several places in table 2. Considerations of time, geography, governance, technology, and directionality are particularly important in this regard (Nilsson *et al* 2016):

- *Time* || Certain interactions play out in real time, whereas the impacts of others materialize only after significant time lags (e.g. energy infrastructure is long-lived; a unit of carbon released today will still have a global warming effect many decades from now).
- *Geography* || Policies enacted in one location may result in major impacts between different SDGs, but in another location have very little, or no, impact, due to unique geographical conditions and resource endowments (e.g. air quality improvements brought

about by renewables and energy efficiency are likely to accrue mainly to those living in the dense urban centers of rapidly developing and transition countries).

- *Governance* || How a policy is implemented (by which instruments and through which institutions) is a determining factor in its ultimate effect (e.g. without proper safeguards in place, policies supporting renewables and energy efficiency could fall disproportionately on the poor, and this could impair the fight to eliminate poverty).
- *Technology* || There may be a real trade-off between SDGs due to technological limitations; but when advanced technologies are deployed, the trade-offs may be suppressed, if not eliminated (e.g. the widespread deployment of electric vehicles could allow for growth in private mobility for the foreseeable future, but with lower impacts on human health, local ecosystems, and the global climate; replacing fossil fuels with biofuels in vehicles would not always achieve the same results).
- *Directionality* || The interaction between two SDGs can be (i) unidirectional or bidirectional and (ii) symmetrical or asymmetrical (e.g. the relationship between large-scale utilization of bioenergy on the one hand and food security and the protection of terrestrial ecosystems on the other; see below for an elaboration of this dimension).

Among these dependencies, the concept of directionality is often forgotten in more general discussions of 'synergies and trade-offs', or at least it is not always articulated in an explicit way. A few extra words of clarification are therefore warranted here. Many of interactions between the SDG7 (energy) targets and those of the other SDGs are either uni-directional (i.e. an impact of SDG7 on the others, or vice-versa) or they are bi-directional (simultaneously impacting one another, though often not in complete symmetry). An example of the former is energy access provision (Target 7.1), which the literature suggests is a necessary (but not sufficient) condition for delivering the types of services fundamental to escaping the poverty trap: education (SDG4), employment (SDG8), and quality healthcare (SDG3). Yet, in the reverse direction provision of those distinct services by some other means (e.g. programs that transport disadvantaged individuals to more affluent communities where those services can be obtained) does not guarantee that energy access will be achieved in the communities where it is most needed. An example of the latter relationship (bi-directional) is the large-scale utilization of renewable bioenergy (Target 7.2), which (potentially) can have negative effects on food production, and thus the goal of ending hunger (SDG2), while in the reverse direction ending hunger and protecting terrestrial ecosystems (SDG15) may impose limits to how much cropland is available for bioenergy production altogether.

Insights relevant for the scientific community

Based on our reading of the relevant literature, the energy-related interactions among certain SDG dimensions are relatively well understood, at least compared to others (see rightmost column of table 2). For these, we are able to conclude with 'high' or 'very high' confidence how those interactions are likely to play out in the future in various contexts. More specifically, there appears to be considerable agreement within the existing scientific evidence base that ensuring universal energy access to the poor, deploying most types of renewables at scale and/or boosting energy efficiency efforts will have positive impacts on—or, conversely, will be aided by—the targets for achieving poverty alleviation (SDG1), better human health (SDG3), greater water availability and quality (SDG6), enhanced sustainability of cities (SDG11), natural resources protection (SDG12), reduced climate change (SDG13), and strong and just institutions (SDG16). On the other hand, we find lower agreement in the literature for—and therefore assign lower levels of confidence to—the energy-related interactions among the other SDGs. For instance, it is not entirely clear how a transition from a fossil- to a renewable-based energy system globally will affect the labor markets of individual countries and regions (SDG8) or will impact local-scale marine economies (SDG14). (These impacts depend on where exactly factories and infrastructure are sited.) And to be sure, even for the SDGs where fewer knowledge gaps exist, there may be sub-dimensions where additional research would be important. For example, the overall impact of 'active travel modes' (walking and cycling) is in need of further study, in order to understand the role that good governance (in the form of quality infrastructure provision) can play in ensuring that this city-level energy efficiency strategy does more to improve people's health than to put them at greater risk of road traffic accidents (SDG3). This highlights the complexities inherent in the SDGs: to truly appreciate them, one must dive down to the target level.

There are several reasons why uncertainty remains for some of the interactions highlighted in table 2. First, the context-dependencies listed previously often make it difficult to draw generalizable conclusions about interactions that may ultimately depend on locally-specific factors. An example would be the impact of energy access provision on creating employment and educational opportunities for women (SDG5, SDG10): the effect could certainly be positive, but much depends on how rigid the cultural norms are within the prevailing society. Second, appropriate scientific tools are less mature for studying some SDG dimensions, namely tools that are of the quantitative ilk. For instance, as far as we are aware, no energy systems or integrated assessment models capture the feedback effects between educational attainment and renewables, efficiency and energy access in an endogenous way[12].

Filling the knowledge gaps delineated here demands that scientists from different disciplines share knowledge and collaborate on a heretofore unprecedented scale. The expertise of energy researchers from a wide variety of fields must be leveraged for this purpose (Anadon *et al* 2016, Gallagher *et al* 2016), including, but not limited to social scientists (sociologists, anthropologists, demographers, human geographers, political scientists, economists, urban planners, and experts in education, law and communications); natural scientists (biologists, hydrologists, oceanographers, atmospheric chemists, and experts in climate, health and agricultural studies); engineers (across the spectrum); and integrated systems modelers, to name just a few. If those collaborations can be realized, and if they turn out to be fruitful, then the evidence base on energy-related SDG interactions could grow quickly. With any luck, it should then be possible to conduct an even deeper exploration of these interactions within a few years' time, perhaps as part of a full-scale 'SDG interactions assessment', not dissimilar to the national and global climate change assessment reports that are regularly produced by various bodies (e.g. IPCC 2014, APCC 2014, USGCRP 2017). Such an assessment could include systematic reviews of the relevant literature combined with open calls for inputs by both scientists and policy makers (i.e. both internal and external expert elicitations), as well as a series of workshops and meetings for both invited experts/stakeholders and the core team of lead authors. A key feature of such a report would of course be the translation of scientific insights for policy-relevant decision making. Perhaps a useful starting point for this kind of exercise would be the 2019 edition of the *Global Sustainable Development Report* published by the United Nations (UN-GSDR 2017). Alternatively, given that an assessment of this sort would be a massive undertaking that could span years (as with the IPCC assessments), one could also imagine smaller reports conducted over shorter time intervals that partition the SDGs into clusters (see also Boas *et al* 2016). The *economic-social-environmental* framing could be utilized for this purpose, or perhaps even the thematic groupings the UN's High-level Political Forum is already making use of in its clustered reviews of the SDGs (sustainabledevelopment.un.org/hlpf). Regionally-focused sustainable development reports offer another possibility for informing the discourse at a sub-global level; the GSDR could then synthesize these findings globally (Boas *et al* 2016). Moreover, deeper collaboration between research communities could also give scientists a stronger voice in the SDG process, which has moved from goal-setting to implementation and follow-up. These latter phases demand the building of integrative, multi-dimensional assessment systems geared toward evaluating the outcomes, interactions and impacts of the various measures put in place across the spectrum of SDGs (Griggs *et al* 2014, Kline *et al* 2015).

Insights relevant for policy-making

The overarching take-away from our literature review summarized in table 2 is that the three targets of SDG7 (Energy) are, in one way or another, linked to those underpinning each of the other SDGs. One conclusion then, from a practical perspective, is that policy-makers must take action toward creating the enabling environments necessary for interdisciplinary research to flourish. A variety of methods from diverse disciplines (from qualitative case studies and socio-anthropological field work all the way to quantitative empirical analyses on 'big data' as well as integrated modeling) can be sought when assessing the multi-dimensional outcomes and impacts of proposed instruments, projects and plans (i.e. the means of policy implementation). Interdisciplinary science must provide the analytical backbone for such assessments. Moreover, having identified numerous interactions, it is clear that the 'silo approach' to policy-making, as traditionally applied in countries the world over, is no longer suitable as a mechanism for effecting systemic change. A paradigm shift to policy and institutional frameworks that take an integrated, holistic perspective is long overdue (Griggs *et al* 2014, Cherian 2015, Bartram and Dodds 2016, Boas *et al* 2016). For this to happen effectively, 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 (Boas *et al* 2016, Gallagher *et al* 2016, Keairns *et al* 2016, Stafford-Smith *et al* 2017). Integrated planning institutions within countries could play an important role here, bridging the knowledge and plans of seemingly disparate government ministries that have for decades been tasked with handling policy objectives in a more isolated way[13]. An alternative strategy, should joint action fail for whatever reason in a given jurisdiction, is for the strongest institution among the group to adopt a nexus perspective and then act semi-unilaterally with all interests in mind (Gallagher *et al* 2016). In terms of global governance, Boas *et al* (2016) suggest that the UN's High-level Political Forum (HLPF) is well-positioned to play a critical 'orchestrating' role that brings 'different regional

[12] The shared socioeconomic pathways took a step in this direction (KC and Lutz 2017), in terms of projecting the effects of education on population growth, and thus future energy demands. More could be done, though.

[13] These are some of the motivations behind, for example, Colombia's 'Integrating Approach' [communitascoalition.org/pdf/Integrating_Approach_7OCT2013.pdf] and Ethiopia's 'Climate-Resilient Green Economy vision' (www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf).

organisations, states and UN organisations together to create synergies between separate terrains of work', but that for this to work well, the HLPF needs to be given an effective mandate by national governments. Accounting for country-to-country inter-linkages (whether synergies or trade-offs) can also be supported by transnational partnerships that aid in the sharing of knowledge and best-practices, such as the Champions 12.3, Open 2030 Project, and the Cap-Net UNDP initiatives (Boas *et al* 2016, Gallagher *et al* 2016). In short, there are numerous ways that policy knowledge can be synthesized across government jurisdictions and knowledge domains. Yet, failing these major pushes toward policy integration, the silo approach could persist indefinitely, and this would not serve the SDGs well, as the possibilities for achieving them would then be seriously compromised.

Integrated, holistic thinking on policy may also serve as a strong motivator for action along individual SDG dimensions. On the one hand, for instance, improving air quality and bettering human health (SDG3) are major concerns of local policy-makers in India and China. Thus, a better appreciation for how energy-focused climate change mitigation actions (SDG13) impact air pollutant emissions might ultimately incentivize even stronger energy-climate policies than if climate change were the only concern (see also Deng *et al* (2017)). Put differently, countries might consider ratcheting up their internationally-agreed carbon reduction pledges—their Nationally Determined Contributions (NDCs)—based on national/local concerns. Given that pledged actions to date are far too lenient for keeping global temperatures well below 2 °C over the long term (Rogelj *et al* 2016), having this added incentive to reduce carbon emissions would not be particularly bad. Incidentally, the Chinese government already seems to realize this, with respect to the air quality improvements they aim to achieve as a result of their policies for phasing out fossil energy (Buckley 2013). Meanwhile, the Indian government is targeting energy access policies as a means to improve the health of the rural poor (Smith 2016). To be sure, energy solutions along one SDG dimension could also impose risks of trade-offs, as highlighted in table 2. Government-supported strategies and measures should therefore strive to minimize, or avoid, such negative interactions between SDGs, while ensuring that where positive ones exist, they materialize as frequently and quickly as possible and their full potential is tapped.

What is more, because of their broad influence and active support to developing countries throughout the world, the international donor community along with non-governmental organizations have a potentially large role to play in helping countries shape policies that cut across sectors, disciplines and geographies. In fact, the *2030 Agenda for Sustainable Development* has called on these entities to do exactly that. Many regional and national institutions, both large and small, have begun using the *2030 Agenda* as the focus of their actions for the next decades. A few examples are summarized below; they have been selected because of their large impact and influence in policy-making throughout the world.

- The European Union is one of the most well-funded and influential donors. In its *New European Consensus on Development* (EU, 2017), the emphasis is not only on ensuring coherence and consistency across the various development efforts by all of its agencies but also on adopting a "Framework for Action" that is focused on supporting development strategies that 'factor in the SDGs and their interlinkages'.
- Soon after the endorsement of the SDGs, the World Bank outlined its strategy in a similar document, *The World Bank Group Support for the 2030 Agenda for Sustainable Development* (World Bank, 2015), which puts an emphasis on helping countries adopt 'integrated multi-sectoral multi-stakeholder solutions that address the inter-connectedness of many development challenges'.
- The United Nations Development Programme (UNDP), in its leadership role within the UN Development Group, has committed to supporting countries integrate the SDGs into their national development plans and policies through their work in some 170 developing countries. Their focus is on ensuring integrated solutions targeted at a few key areas including poverty alleviation, democratic governance and peacebuilding, climate change and disaster risk, and economic inequality.
- Non-governmental organizations are formulating newly revised strategies in support of the SDGs. The business community provides one great example. Major convening organizations include, for instance, the Global Compact, World Business Council for Sustainable Development (WBCSD), and World Economic Forum (WEF). In its *CEO Guide to the Sustainable Development Goals*, the WBCSD argues that the SDGs provide an excellent framework through which businesses can contribute to the new development agenda by way of sustainable business solutions. One of the main points of the *CEO Guide* is the need for collaboration and cooperation across business sectors. Another representative NGO example is the International Union for Conservation of Nature (IUCN), which highlights that the challenges referred to in the *2030 Agenda* cannot be solved in isolation and that work addressing interlinkages is the critical to addressing these challenges.

Discussion and concluding remarks

With the arrival of the UN's *2030 Agenda*, the notion of integrated and holistic thinking has entered into the global policy discourse in a highly visible way.

Moving toward action now requires a surge of support from the scientific community, in order to ensure that a greater recognition of SDG interactions actually does drive policy practitioners toward socially desirable development pathways.

Providing such support remains a challenge, however. The act of synthesizing adequate scientific evidence for advising policy is both aided and hampered by, firstly, the recent explosion of accessible scientific information and, secondly, the sheer breadth of the SDG agenda, which spans a diverse array of scientific communities and disciplines (Le Blanc 2015, ICSU 2017, Minx *et al* 2017a). In these times of 'big literature', where it becomes impossible for researchers to comprehensively track and keep up with all the progress in their field at all times, the application of systematic review methodologies alongside 'big data' applications for research synthesis has become crucial for avoiding major selection biases in assessment exercises (Minx *et al* 2017a, 2017b, Nunez-Mir *et al* 2016). What is more, the availability of systematic reviews—like that performed in the current paper—will become a pre-condition for those conducting even more comprehensive scientific assessments on the SDGs going forward, such as the UN's 2019 *Global Sustainable Development Report*, currently being written (UN-GSDR 2017), which aims to simultaneously address *all* sustainable goal development goals and their interactions. As long as comprehensive and credible reviews are available across the full swath of SDG dimensions, this task remains manageable.

Though, while achieving 'systematicity' in reviews can be very powerful, one lesson learned from our analysis is that a literature assessment based entirely on systematic queries in databases of academic papers is not sufficient on its own. Systematic queries offer a complement to expert assessment just as much as expert assessment complements systematic queries. This is especially true when reviewing a body of literature as broad as the SDGs. Computer algorithms cannot *a priori* decide how to prioritize certain papers over others; on top of that, a complete reliance on searching academic databases risks missing seminal studies in the gray literature, the IPCC assessments and the Global Energy Assessment being cases in point. Only expert elicitation would be able to effectively capture the latter.

As noted above, the large number of dimensions covered by the SDGs poses an especially acute challenge for scientific assessments. Meaningful policy advice requires rigorous evaluation of policy alternatives (Edenhofer and Minx 2014, Edenhofer and Kowarsch 2015), and this becomes an increasingly intractable exercise as the dimensions rise and the relevant universe of data points expands (Kowarsch *et al* 2017). Dealing with competing normative viewpoints also becomes highly challenging. This difficulty materializes in particular when synergies and trade-offs between different SDGs are considered, as we illustrate here in this manuscript. So while Kowarsch *et al* (2017) suggest, for pragmatic reasons, to reduce dimensionality in scientific assessments, we recognize that this may not always be possible, depending on the scope of the assessment. One overarching insight from our experience in this study is that there is an urgent need for an open discussion on the limits to scientifically derived policy advice in relation to the scope of policy frameworks assessed.

In the current paper, we focus specifically on reviewing the sustainable development literature with links to energy. The scope of the assessment is therefore quite large. More specifically, we report on a two-stage, large-scale review of the relevant evidence base (results summarized in table 2), which we conducted to better our understanding of how key energy-related interactions between SDGs might play out throughout the world over the coming decades. Our review starts from the deep and complementary knowledge possessed by a diverse team of experts and is then complemented by a systematic literature search and selection procedure. Based on the nature and strength of the interactions we identified from this sizeable set of evidence, as well as our collective evaluation of the confidence that can currently be ascribed to each of those interactions, we arrive at several conclusions relevant for both the scientific and policy-making communities. These are summarized here.

First, our analysis indicates that positive interactions between SDG7 (Energy) and the other SDGs clearly outweigh the negative ones, both in number and magnitude (figure 2).

Second, in order to fill knowledge gaps in critical areas, we argue that there is an urgent need for scientists from different disciplines to share knowledge and collaborate even more than they already do today. This could lead to, indeed even require, new data, updated scientific tools, and fresh, interdisciplinary perspectives that support original analyses (Anadon *et al* 2016, Gallagher *et al* 2016). According to our analysis of the literature, an improved understanding is especially needed for how achievement of the SDG7 (Energy) targets interact with SDG2 (Zero Hunger), SDG4 (Quality Education), SDG5 (Gender Equality), SDG8 (Decent Work and Economic Growth), SDG9 (Industry, Innovation and Infrastructure), SDG10 (Reduced Inequalities), SDG14 (Life below Water), and SDG15 (Life on Land).

Third, policymakers must do more than simply acknowledge the mere existence of SDG interactions; they also need to mobilize additional resources and implement new laws and planning and evaluation methodologies. With respect to energy policy in particular, the choice of policy instrument and design needs to be made carefully, so that the effects on other sustainability dimensions are as intended (e.g. renewable energy policies should not be allowed to drive up energy prices for the poor unless redistributional fuel price support mechanisms are simultaneously put in place). Moreover, wider efforts to promote policy coherence and integrated assessments are required to address potential policy spillovers across sectors, sustainability domains, and geographic and temporal boundaries (Griggs *et al* 2014, Cherian 2015, Bartram and Dodds 2016, Boas *et al* 2016). Policy-makers would thus do well to ensure that their particular country's institutions engage in inclusive practices that cut across government bodies during all phases of policy planning, implementation, monitoring and assessment. Institutional reforms that usher out last century's favored governing model, the siloed approach, are for these reasons needed more than ever. In our opinion, energy is a logical place to start on this path, given how deeply woven it is into the fabric of the Sustainable Development Goals. 'Doing energy right' is fundamental to the success of the *2030 Agenda*; furthermore, energy scientists have a major role to play in offering guidance to the discourse.

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ORCID iDs

David L McCollum https://orcid.org/0000-0003-1293-0179
Joeri Rogelj https://orcid.org/0000-0003-2056-9061
Jan C Minx https://orcid.org/0000-0002-2862-0178

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