Energy for adaptation: connecting the Paris Agreement with the Sustainable Development Goals

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Abstract

Increased effort to cope with the rapidly emerging impacts of climate change is urgently needed. Whether adaptation bears the risk of inducing a negative feedback loop through its energy requirements has not been investigated. Here we examine the Nationally Determined Contributions submitted by world governments under the Paris Agreement with the aim of identifying the adaptation options associated with energy use and of defining energy use for adaptation. By linking the resulting options to the United Nations' Sustainable Development Goals, through the related targets and indicators, we evaluate the extent to which energy use for adaptation facilitate progress towards sustainability. Drawing from the relevant literature on vulnerability and energy, we provide new evidence on the role that energy plays in the context of adaptation, proposing a framework that connects adaptation, mitigation, and sustainable development through the lens of the energy requirements of adaptation strategies. Results highlight priority policy actions to promote climate-development synergies and indicate where quantitative system models could focus in order to integrate adaptation energy needs in future energy scenarios.

1. Introduction

The landmark climate deal adopted in 2015 at the end of the 21th UNFCCC Conference of the Parties (COP 21) confirms the need for increased efforts to cope with the impacts of climate change (UNFCCC, 2015). For the first time in the history of climate negotiations, the Paris Agreement establishes a long-term adaptation goal, elevating adaptation to the same level as mitigation and reiterating the necessity of an integrated approach to climate resilience and inclusive low-carbon development. Even if the rise in global average temperature is restricted within 2°C, impacts of climate change are inevitable (De Cian et al. 2016, Park et al. 2018). Climate change is projected to negatively affect primarily low-income countries located near the Equator (Burke et al. 2015) that have limited capacity to adapt (Field et al. 2014).

In identifying what adaptation looks like on the ground, the research community shares a broad consensus on socio-economic development being the foremost strategy to reduce vulnerability (Schelling 1992, Smit et al. 2001, McGray et al. 2007, Tol 2018). Being a key enabling component of development, energy can also facilitate adaptation, but the energy needs and implications of adaptation have not featured prominently in the literature. A recent conceptual systematic review defining energy services (Fell, 2017) sheds new light on the overlooked linkages between energy use and adaptation. Several energy services are noticeably climate sensitive and provide a critical margin of adaptation across all sectors of the economy. Space heating and cooling allow households to maintain the desired levels of thermal comfort in their living environment, alleviating climate-related damages to health (Deschenes and Greenstone, 2013, Dell et al. 2014, Barreca et al. 2016) and improving the sense of wellbeing (Shaikh et al. 2014). Cooling systems make commercial and industrial activities possible in places where already difficult climatic conditions negatively influence production levels and labour productivity (Hsiang, 2010, Park and Behrer, 2017). Industrial demand is sensitive to outdoor temperature and activities such the food cold-chain require narrow stable temperature windows (Hekkenberg et al., 2009). In the health sector cold chain disruption is also a major cause of vaccine wastes (WHO, 2013). In the transport sector, air conditioning affects vehicle efficiency and increases fuel consumption (Scott and Huang, 2007). Water and energy are closely linked, and the production or consumption of one resource requires the use of the other. Desalination, water treatment, and distribution are all highly energy-intensive processes, and the energy-intensity of the entire water chain is likely to increase over time as water resources become less accessible while treatment standards and demand rise (Rothausen and Conway 2011, Sanders and Webber 2012). Increased demand for water to deal with extreme droughts implies greater dependency on energy in both the agricultural and residential sectors. Not only water requirements for agriculture will need more energy, cooling demand for livestock will also see an increase (Scott and Huang, 2007). Adaptation can be expected to become an increasingly important driver of energy demand.

On closer inspection, many of the energy services that can contribute to reduce climate vulnerability largely overlap with the basic energy requirements necessary to ensure minimum standards for decent living (Rao and Baer, 2012) related, for example, to adequate water supply or safe and comfortable space (Rao and Min, 2017), reinforcing the mutual synergies between universal energy access objectives and adaptation. The literature has mostly emphasized the role of energy as key to sustainable development (McCollum et al. 2018) and for decent living conditions (Rao and Pachauri, 2017), stressing the urgency to decarbonize the sources used to provide those services (Clarke et al. 2014). Yet, the energy use and the greenhouse gas (GHG) emissions associated with adaptation remain underexplored (Ebinger and Vergara, 2011, Rothausen and Conway 2011).

As the scale of adaptation needs increases, the associated increase in energy could lead to more emissions and higher energy prices, with potentially negative consequences for poor households and economic competitiveness, fueling a potentially negative feedback on sustainable development. Aggregate studies suggest that by 2050 the world population could need up to 17% more energy in order to cope with a warmer climate across all sectors of the economy (De Cian and Sue Wing, 2017). But for a few exceptions (IEA, 2018), socio-economic and climate policy scenarios (Riahi et al. 2017) still do not integrate energy needs for adaptation, which going forward might become of increased prominence. Historical trends of space cooling give a sense of the potential magnitude. CO2 emissions from cooling have seen a threefold increase since 1990, for a cumulative amount equivalent to the total emissions of Japan. At present, space cooling account for 10% of total electricity demand and for the 12% of the CO2 emissions of this sector (IEA, 2018). Whether energy use for adaptation could support progress towards sustainability has not been addressed. On the one hand, the energy services that might become more widespread under the pressure of climate change, such as space cooling, food and vaccine cold-chains, support the achievement of several Sustainable Development Goals (SDGs), namely those related to ending hunger, ensuring healthy lives and decent work as well as supporting sustainable urbanization as outlined in SDGs 2, 3, 8 and 11 (SEforALL, 2018). On the other hand, if not properly managed, climate-induced energy needs can lock our societies into energy-intensive infrastructure (Hallegatte et al. 2007) making decarbonization, and hence the achievement of goal 13 on climate action, more difficult.

In this paper we investigate to what extent the adaptation plans proposed in the context of the Paris Agreement are associated with energy use, and explore the implications for sustainable development. Starting from the definition of energy for adaptation as those functions and actions that reduce climate vulnerability and influence energy use, we scrutinize the Nationally Determined Contributions (NDCs) submitted to the UNFCCC to identify the high-priority adaptation options most directly connected to energy use. After validating the resulting options within the adaptation literature, we investigate how energy for adaptation contributes to achieve the 17 SDGs. We adopt a wider notion of energy use for adaptation that goes beyond cooling and air conditions and include energy services that are climate sensitive and provide a broad range of benefits in terms of reduced vulnerability across all sectors. The remainder of the paper is organized as follows. Section 2 describes our methodology. Section 3 discusses the results. Section 4 concludes and outlines the implications of our findings for future research.

2. Methodology

2.1 NDCs reveal countries' priorities with respect to adaptation

The NDCs offer a unique opportunity that reveals national interests and preferences regarding climate action (Kehoane and Victor 2016). While explicitly asking countries about their needs in terms of energy for adaptation could be plagued by the fact that governments often avoid making their preferences clear, the bottom up nature of the contributions submitted under the Paris Agreement make it possible to understand countries' adaptation priorities and the extent to which planned actions could entail significant use of energy.

Among the 190+ national governments that submitted an INDC or a NDC, henceforth (I)NDC, to the UNFCCC, 138 of them include adaptation. Adaptation plans are predominantly proposed by emerging and developing countries, where the priority of protecting their people from dangerous climate impacts is more urgent. We analyze the 138 (I)NDC documents and identify the adaptation objectives, plans, actions that most directly affect energy use while reducing vulnerability. When NDCs were missing, the INDC documents have been considered. We examined both unconditional and conditional actions described in the (I)NDCs, paying particular attention to the context as well as to all sections (e.g. capacity buildings, technology transfer, fairness and ambition), keeping track of whether a specific option is mentioned as adaptation, mitigation, or both. A code has been assigned to the selected adaptation options based on whether they are mentioned in relation to adaptation (=1), mitigation (=2), or both (=3). Coding where in the NDC adaptation measures are mentioned makes it possible to keep track of the differentiated countries' perspective on a given option and to identify the adaptation actions that can entail co-benefits for mitigation. Options that are not clearly associated with either adaptation or mitigation objectives have been assigned the code "3". For example, Togo features conservation of rainwater and reuse of wastewater among the adaptation priorities, while Madagascar mentions it in the mitigation section because the emphasis is on biogas collection from wastewater treatment power plants. Lebanon describes the reuse of wastewater in the adaptation section, but it also acknowledges the mitigation co-benefits. Citing from its (I)NDC, "better treatment of wastewater can reduce greenhouse gas emissions whilst protecting national water resources".

We define energy use for adaptation as those adaptation strategies that most directly affect energy use according to either of the following four criteria:

1) Are energy-intensive or relate to energy-intensive sectors
2) Are a precondition for access to basic energy services
3) Require access to energy in order to spread their benefits and reach targeted population
4) Can save energy directly or indirectly

These criteria clarify how energy relates to the adaptation options proposed by countries. The first criterion captures adaptation measures that involve sectors traditionally considered energy intensive (e.g. large-scale infrastructure) or that require a relatively higher amount of energy in its process compared to technologies used for similar purposes (e.g. the multi-purpose dams as an energy-intensive hydraulic infrastructure and seawater desalination as one of the most energy demanding water treatment technology). The second criterion includes those options that aim at providing or extending access to basic energy services, such as renewable energy and electrification. The third criterion refers to those services that, independently from the energy sources and consumption levels, require access to energy to improve a certain outcome or to reach targeted populations (e.g. options increasing irrigation or providing water heating as well as early warning systems, which require information and communication technology such as TV and mobile phones to reach people). The fourth criterion covers the adaptation options that can decrease the use of energy directly (e.g. thermal insulation) or indirectly, by stimulating behavioral changes or decreasing the amount of other resources, such as practices augmenting energy or water efficiency and conservation in both residential and agriculture sectors (e.g. education, efficient irrigation techniques).

On a broader perspective, these criteria allow us to group the adaptation measures into two major categories reflecting their potential impact on future energy use:

a) Potentially Energy-Increasing (E-I) options, whose diffusion will result in an increase in the use of energy, including renewable sources.
b) Potentially Energy-Saving (E-S) options, whose implementation will decrease energy demand.

The final list of options includes only those that i) are mentioned as adaptation by at least one country and ii) are found in the adaptation literature (IPCC Fifth Assessment Report, 2014, Bertule et al. 2018, Bower et al. 2018, Ebinger and Vergara 2011, UNFCCC 2017, EUEI PDF 2017). For example, decentralized renewable energy or energy efficiency are mostly proposed in the mitigation section, but several countries mention those strategies also in relation to adaptation. Moreover, their importance in coping with climate impacts is acknowledged within the adaptation literature (Scott and Huang, 2007, Ebinger and Vergara 2011).

The second step of the analysis establishes linkages between the resulting energy for adaptation options and the 17 Sustainable Development Goals (SDGs). Building on an extended review of the literature carried out by the authors in this paper (see Appendix A and online Appendix), we associate each of the energy for adaptation options identified in the first step to the SDG targets or indicators to which it contributes. We focus on synergies (i.e. positive linkages) as the objective of the analysis is to bring evidence on how specific adaptation options to climate change contribute to sustainable development. To accomplish this task, we consider also ‘grey literature’ as the topic is dominated by an intense research and reporting activity carried out by international organizations as well as non-governmental and governmental agencies. To avoid double counting, within each SDG we uniquely map each adaptation option to the most strongly related indicator or target. Goal 13 on climate change is the exception, as all options contribute to the goal by definition. Indicators and targets are not always consistent with one another. We therefore use alternatively SDG indicators or targets on a case-by-case basis, based on the strength of the linkage (see online Appendix). Because of the great variety of targets proposed in the SDG framework, in this phase we distinguish the identified options in case countries clearly specify they will be implemented using renewable energy sources.

3. Results

3.1 Evidence of energy use for adaptation in the (I)NDCs

Energy use for adaptation emerges as consisting of 20 strategies most prominently mentioned to reduce vulnerability across all sectors of the economy. Table 1 lists the adaptation strategies proposed in the (I)NDCs that meet the four criteria outlined in the previous section. Examples of how those options are described in the national documents illustrate the degree of uncertainty related to actual implementation. Examples include countries with quantitative objectives, such as Antigua and Barbuda, which plan to increase seawater desalination capacity by 50% above 2015 levels and raise to 100% the share of electricity demand in the water sector and other essential services (including health, food storage and emergency services) to be met through off-grid renewable sources. Seychelles plans to promote solar water heating among households and services, with a target of 80% by 2035. Co-generation in hotels is planned to cover 20% of hot water needs by 2035. Other countries are very specific about the technology to be used in the implementation of adaptation plans. Singapore plans to use advanced membrane technologies to treat high-grade, reclaimed water and make it safe to drink. There are then examples characterized by a higher degree of uncertainty. For example, Togo mentions the reuse of wastewater without any further details. Many among less developed countries, including Malawi, Zambia and Lebanon plan to increase the use of irrigation methods or the land area under irrigation. Depending on the efficiency of the irrigation systems implemented, these actions can lead to various levels of increase in the use of both water and energy. Among the adaptation challenges in the residential sector, Lebanon vaguely mentions the need for the national electricity infrastructure to deal with the augmented demand for cooling as air temperature will increase. Several countries refer to broad programmes such as Solar Homes (Bangladesh) or Sustainable Energy for all (Saint Lucia), which can be expected to bring benefits in terms of cleaner energy for living conditions. Swaziland and Burkina Faso explicitly consider energy efficiency for their co-benefits in terms of adaptation, whereas Uruguay aims at addressing both mitigation and adaptation through the implementation of energy-efficiency labelling in household devices such as air conditioners and refrigerators.

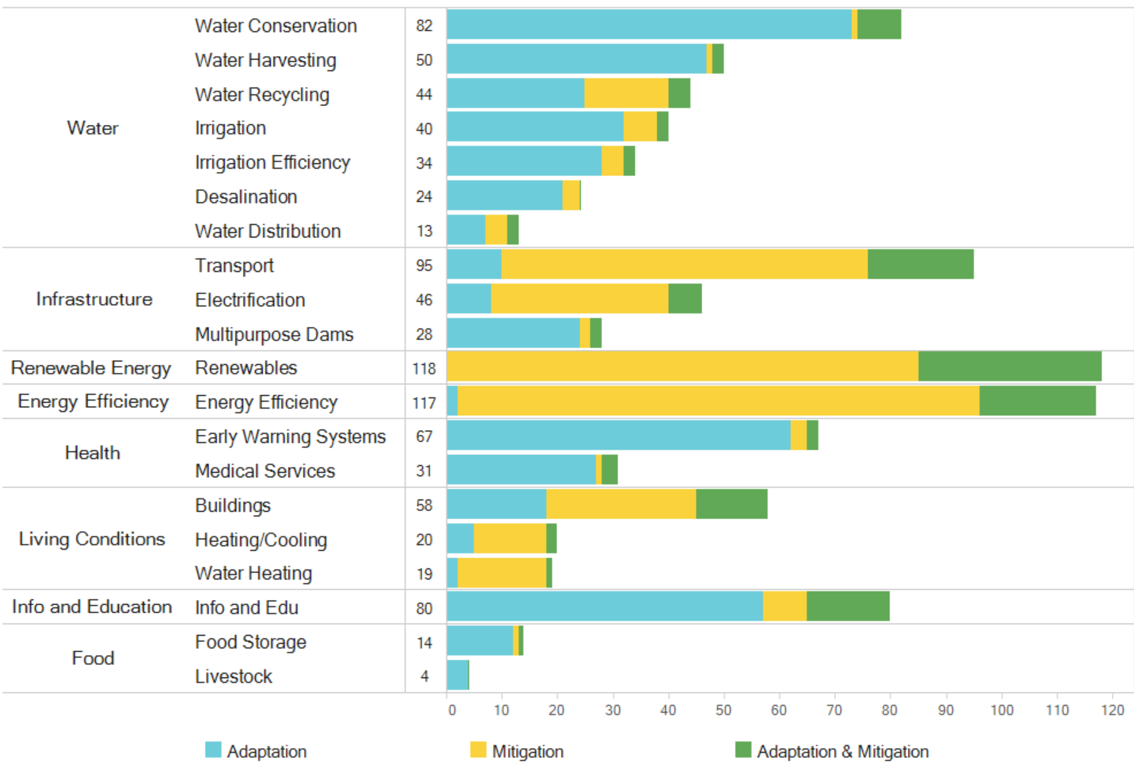
Table 1. Overview of energy use for adaptation options from the (I)NDCs. The table describes the options, summarizes the supporting adaptation literature, and illustrates examples of how those options are mentioned in the (I)NDCs.

Sector	Adaptation Option	Description and Supporting Literature	Examples from (I)NDCs
Water	Desalination	Removing salt from sea or brackish water can increase water supply (Bertule et al. 2018, Barnett and O'Neill, 2010). Renewable-based technologies have a growing potential for this type of energy-intensive water treatment (IRENA, 2012).	SINGAPORE: Expand desalination capacity to meet up to 80% of its water demand in 2060. ANTIGUA&BARBUDA: Increase seawater desalination capacity by 50% above 2015 levels by 2050. TUNISIA: Install mini seawater desalination plants using renewable energies in the tourist sector.
	Irrigation	Expanding equipped but not irrigated land as well as developing new irrigation projects (Ebinger and Vergara 2011, Bouwer et al. 2018) can reduce crop vulnerability. Large-scale deployment of solar pumps can support renewable-based irrigation (IRENA, 2016).	ZAMBIA: Introduce water technologies for irrigation. MALAWI: Increase irrigation at smallholder level and increase the land area under irrigation. UGANDA: Expand the use of off-grid solar systems to support value addition and irrigation.
	Water distribution	Expanding or improving water supply and distribution, including water pumping can increase water supply and reduce losses. Given the high energy-intensity of this option, the use of renewable energy reduces the risk of maladaptation (Bouwer et al. 2018, Sanders and Webber, 2012).	ANTIGUA&BARBUDA: 100% of electricity demand in the water sector through off-grid renewable sources. UGANDA: Extend electricity or expand use of off-grid solar system to support water supply. GAMBIA: Use of renewable energy for lifting water from wells and boreholes.
	Water conservation & improved efficiency	Implementing i) agricultural practices that reduce water requirements; ii) institutional changes that favor water-saving behaviors (e.g. water metering, changes in water charging and trade); iii) improved water resource management and efficiency in industry and distribution (Bouwer et al. 2018, Bertule et al. 2018) can reduce water needs, while keeping the same services.	JORDAN: Introduce water metering. IRAQ: Water use efficiency in distribution network and water consumption meters. SWAZILAND: Reduce vulnerability to the impacts of climate change through integrated water resource management.
	Water recycling and reuse	Implementing technologies to collect, reuse, and treat wastewater can increase water supply for non-drinkable uses, such as irrigation and industrial usages, as well as for domestic use (Bouwer et al. 2018, Bertule et al. 2018).	TOGO: Reuse of wastewater. SINGAPORE: Use advanced membrane technologies to purify reclaimed, treated water, making water safe to drink. SWAZILAND: Water recycling and reuse.
	Water harvesting and groundwater recharge	Collecting and storing rainwater, artificially recharging groundwater aquifers, as well as implementing large-scale or small-scale water reservoirs on farmland can increase water supply and storage (Bertule et al. 2018, Bouwer et al. 2018).	JORDAN: Maintenance of old Romanian wells for water harvesting purposes and establishment of new wells in the rural area. MOROCCO: Artificial replenishment of groundwater tables. LEBANON: Artificial recharge of groundwater aquifers and increasing surface storage.
	Efficiency in irrigation	Implementing water saving irrigation techniques (e.g. modern pressurized irrigation systems, micro-irrigation, wetting and drying practice) can reduce water and energy demand while keeping agricultural productivity (Bertule et al. 2018, Bouwer et al. 2018).	CHINA: Develop water-saving agricultural irrigation. JORDAN: Introduce water saving technologies such as drip, micro-spray, and night irrigation. TOGO: Build and/or improve reservoirs for micro-irrigation and livestock watering in rural areas throughout all regions.
Living Conditions	Heating/cooling	Expanding space heating and cooling can increase resilience of the built environment (Revi et al. 2014, Ebinger and Vergara 2011, Hallegatte et al. 2014). Renewable-based heating and cooling have a large potential in several countries (IRENA, 2015).	JORDAN: Expand the use of solar cooling in commercial and industrial facilities. MOLDOVA: Research on technologies and practices that save cooling energy and reduce electrical peak load. LESOTHO: Diffuse the use of efficient biomass space heating stoves.
	Water heating	Expanding water heating can increase resilience of the built environment (Scott and Huang, 2007). Solar water heating has a large potential in many countries (Ebinger and Vergara 2011, IRENA, 2015).	BANGLADESH: Expand Solar Homes Programme. URUGUAY: Use of solar collectors for domestic hot water in large users, industrial and residential users. SEYCHELLES: Promote the use of solar water heating and cogeneration for hot water in hotels.
	Building standards	Implementing building codes, upgrading informal settlements, and retrofitting existing housing stock can reduce vulnerability of settlements and support mitigation (Ebinger and Vergara 2011, Hallegatte et al. 2014, Revi et al. 2014).	MALAWI: Develop and implement climate related building codes to account for climate change. ANTIGUA&BARBUDA: By 2020, update the Building Code to meet projected impacts of climate change. URUGUAY: Green Seal Certification to achieve a more resilient performance of buildings, through appropriate design and materials.

Food	Livestock	Expanding heating and cooling services can increase the resilience of livestock and mitigate their vulnerability to water scarcity, drought, and extreme events (Scott and Huang, 2007).	MEXICO: Strengthen thermal comfort for livestock. JORDAN: Promote renewable energy in agricultural and food production for cooling and heating purposes (poultry production). MOLDOVA: Improve ventilation and air conditioning systems in livestock farms.
	Food storage	Building and upgrading storage facilities and processes can reduce post-harvest losses happening during the storage phase (Abass et al. 2014, Kumar and Kalita, 2017).	ETHIOPIA: Implement methods that prevent deterioration of food and feed in storage facilities. UGANDA: Expand post-harvest handling and storage. GAMBIA: Post harvest and food processing and preservation techniques.
Health	Medical services	Improving hospital and infrastructure for medical services, expanding network of health centers can increase the supply of the essential health services needed to reduce vulnerability of the health sector (Noble et al. 2014).	MALAWI: Construct more health centers in order to improve access to health facilities within a walking distance. SUDAN: Improve community sanitation and medical services, including capacities for diagnosis and treatment. SUD SUDAN: Public health systems strengthened by building hospitals.
	Early warning systems	Developing early warning systems can prevent human and economic losses in case of extreme events. Benefits can significantly exceed the costs, resulting in potentially large health benefits at low cost (Bouwer et al. 2018, Denton et al. 2014).	JORDAN: EWS to protect health from the potential impacts of climate change. MALDIVES: Develop appropriate early warning systems. BAHAMAS: Ensure that national emergency management plans also include heat stress
Infrastructure	Multi-purpose dams	Implementing dams that include more than one function can accommodate multiple adaptation needs, such as energy, water storage, and flood control (Bertule et al. 2018, Bouwer et al. 2018).	MALAWI: Construct storage dams for hydropower generation. CENTRAL AFRICAN REPUBLIC: Develop hydroelectric installations (including micro-dams). JORDAN: Dams for storing floodwaters during the wet winter seasons and releasing water during the summer seasons.
	Rural electrification	Extending rural electrification can enable adaptation and mitigate climate vulnerability (EUEI PDF, 2017, Murphy and Corbyn 2013). If based on a diversified network of energy sources, it can reduce the vulnerability of energy supply (Ebinger and Vergara, 2011).	BANGLADESH: Key areas to address adverse impacts of climate change include Increased Rural Electrification. SAINT LUCIA: Sustainable energy for all initiative. UGANDA: Extend electricity to the rural areas.
	Transport	Improving the resilience of public transportation systems can reduce the vulnerability of urban centers, which are highly dependent on transport for daily functioning (Revi et al. 2014). Improvements in vehicles and transport efficiency can compensate for the increased use of air conditioning (Scott and Huang, 2007, Ebinger and Vergara 2011).	SINGAPORE: Constant review and revision of design codes, regulations and policies to account for new information and the latest climate projections. BAHRAIN: Improve public transport efficiency, reduce personal vehicle use. MOLDOVA: Promote the use of heat-tolerant streets and highways landscape protection.
Energy Efficiency	Energy efficiency	Implementing energy efficiency programs can reduce the vulnerability of the energy system, with mitigation co-benefits. If less energy is required for an identical service, power outages will cause less damage and thus encourage climate resilience (Scott and Huang, 2007, Ebinger and Vergara 2011).	MALAWI: Promote the use of energy efficient light bulbs. SWAZILAND: Reduced vulnerability to climate change through energy efficiency. BURKINA FASO: Promote energy efficiency in urban and rural households.
Renewable Energy	Renewable energy	Differentiating the sources of energy supply by relying on a wider range of renewable sources can reduce the vulnerability of the energy sector (Ebinger & Vergara 2011, Denton et al. 2014). For example, micro grids and decentralized energy solutions are low-carbon and create a more resilient power system (EUEI PDF, 2017).	ETHIOPIA: Expand electric power generation from geothermal, wind and solar sources to minimize the adverse effects of droughts on hydroelectricity. EGYPT: Increased use of renewable energy may provide several opportunities, including reduced local environmental and health impacts. BURKINA FASO: Diversification of energy sources (solar, wind, biogas).
Information & Education	Information and education	Education, awareness and capacity building can enhance adaptive capacity and support development (Denton et al. 2014). Climate services are an important component of the adaptation agenda (Tall et al. 2018).	KENYA: Enhance education, training, public awareness, participation and access to information on climate change adaptation across public and private sectors. Enhance climate information services. MALDIVES: Improve climate data collection, management and forecasting. Education, training and public awareness remain a key priority.

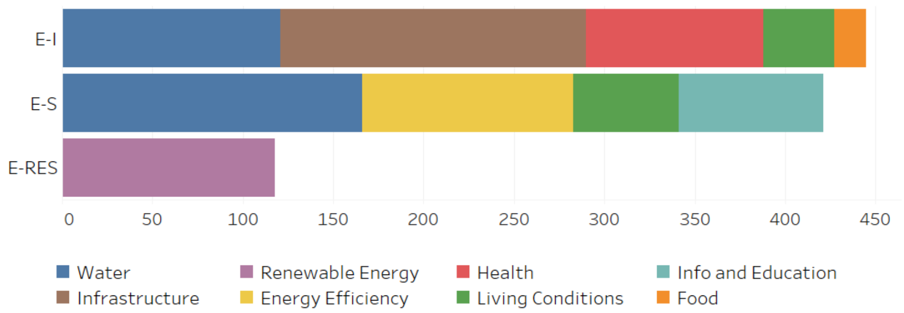
Overall, the energy-related adaptation options emerging from the (I)NDC plans can be grouped into 8 major sectors: water, infrastructure, renewable energy, energy efficiency, health, living conditions, information and education, and food (Figure 1 and online Appendix). About one third of the 988 energy for adaptation measures totally identified across 138 countries are related to the water supply sector, followed by infrastructure, which includes the provision of basic public services like electricity and transport. Renewable energy sources and energy efficiency measures, each accounting for 12% of total options, play a critical role as key solutions bridging mitigation and adaptation needs. Health services are often mentioned (10% of total number of options) as a sector that urgently needs to be extended and improved to adequately respond to extreme wheatear events and potential climate change implications for human wellbeing. A similar share (10%) of adaptation actions contributes to ensure adequate life and working conditions (space heating and cooling, water heating, building codes). Enhanced information and education represent 8% of total identified measures. A smaller share (4%) of adaptation actions requires energy services that contribute to the protection of vulnerable livestock (e.g. thermal comfort for livestock) and food supply (food storage). As expected, options related to infrastructure, renewables and energy efficiency are mostly mentioned in relation to mitigation (yellow color in Figure 1), but they are sometimes perceived as having the potential to bring about several co- benefits in terms of reduced vulnerability and improved resilience (Table 1). For example, decentralized energy systems based on diverse sources of energy - which are being accounted for in the renewable energy category - might be more flexible and less prone to power outages. To the extent that renewables help to enrich the portfolio of energy sources, they contribute to adaptation (Ebinger and Vergara 2011).

Figure 1. Frequency of energy for adaptation options in the (I)NDCs. Colour scale shows whether options are mentioned as adaptation (blue), mitigation (yellow), or both (green). Numbers indicate the frequency of each of the 20 options shown in the bar chart.



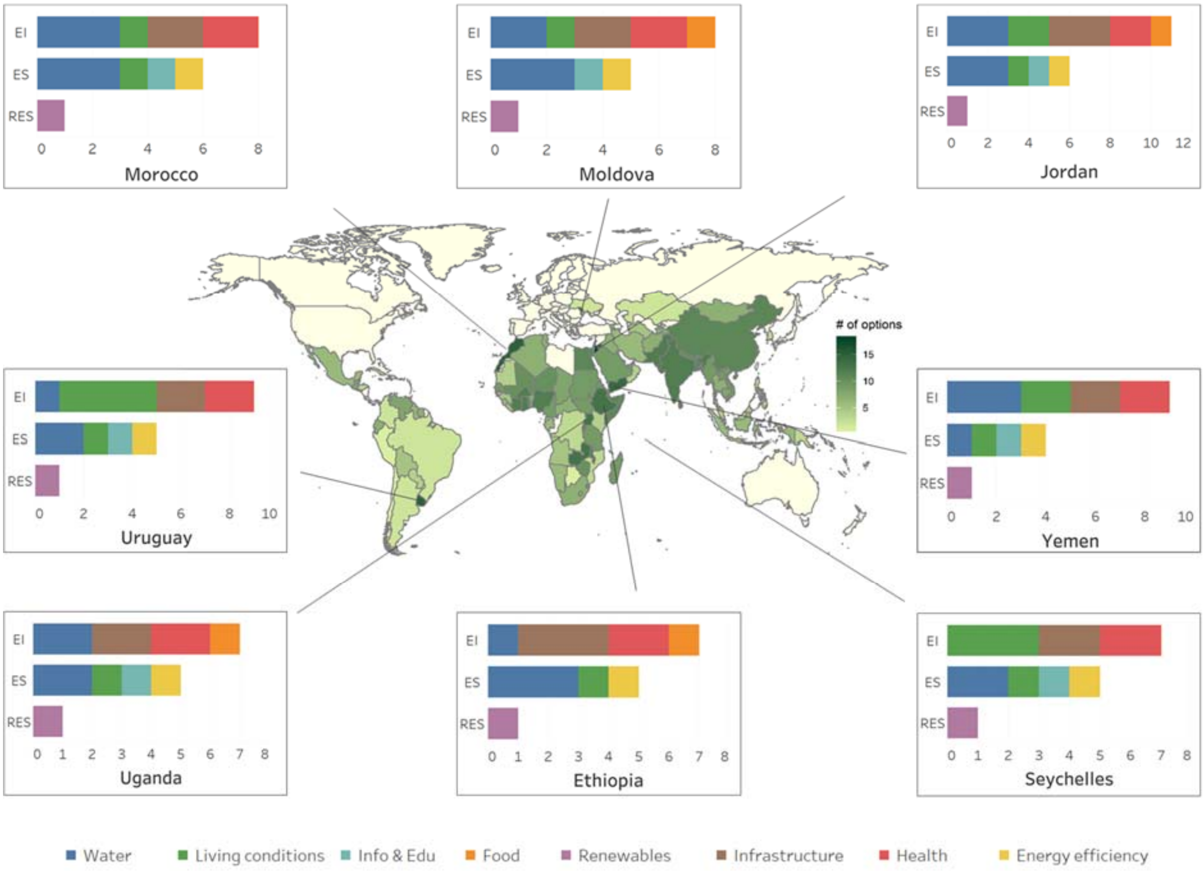
Of the 20 energy-related, adaptation options identified, 6 have a higher potential to save energy (water conservation & improved efficiency, water harvesting and groundwater recharge, efficiency in irrigation, building standards, energy efficiency, information and education) while the remaining 14 can be considered energy-increasing (desalination, irrigation, water distribution, water recycling and reuse, heating/cooling, water heating, livestock, food storage, medical services, rural electrification, multi-purpose dams, transport, renewable energy, early warning systems). Potentially energy-saving options, which account for 43% of total measures identified, can be viewed as adaptation options with mitigation co-benefits. On the contrary, the energy-increasing adaptation options may imply potential trade-offs between mitigation and adaptation objectives, if the energy source does not come from renewable energy. The distribution of sectors along these categories (Figure 2) shows that the highest energy saving potential, excluding measures directly addressing energy efficiency, is within the water and living condition sectors, where, potentially energy saving options represent more than 50% of the adaptation strategies proposed by countries. Among the options that can indirectly deliver energy saving behaviour we included also information and education activities. All the other sectors suggest a careful evaluation of the energy sources to be used, in order not to foster maladaptation.

Figure 2. Frequency of energy for adaptation options by type of potential impact on energy use, Energy-Saving (E-S) and Energy-Increasing (E-I). Renewable energy is shown separately (E-RES).



The 138 countries that include adaptation plans are predominantly emerging or developing countries (Figure 3) though no pattern is identified between latitude and number of options. A rich list of energy-related adaptation options can be found in countries ranging from Middle East and North Africa such as Jordan (18 options) and Morocco (15 options), to South America, with Uruguay (15 options), and Eastern European countries such as the Republic of Moldova (14). With respect to the potential impact on energy use, all countries with the largest number of options rely predominantly on energy-increasing options, with the exception of the water sector where energy-saving options prevail (but in Yemen). Uruguay, Seychelles, Yemen and Jordan have a relatively higher share of potentially energy-increasing strategies in the Living Conditions sector mostly due to heating/cooling and water heating.

Figure 3. Geographic distribution of energy for adaptation options. Countries in light yellow do not include adaptation options in the (I)NDCs. Barcharts shows the frequency of energy for adaptation options by type, Energy-Saving (E-S) and Energy-Increasing (E-I) in the top eight countries.



3.2 Evidence of how adaptation contributes to sustainable development

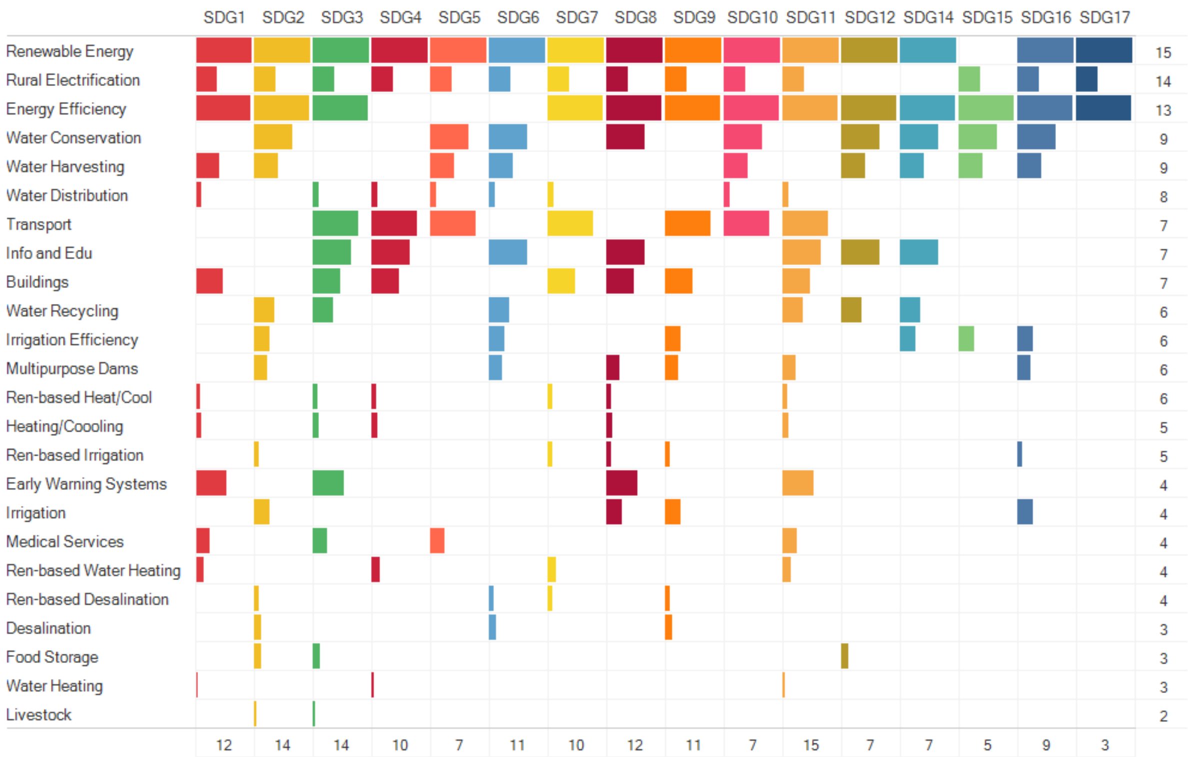
The energy-related adaptation options summarized in Table 1 are all connected to at least one SDG (Figure 4). Based on the extensive review of the literature summarized in Table A1 and in the online Appendix, the options that support the highest number of goals include renewable energy (contributing to 15 SDGs out of 17), rural electrification (showing potential synergies with 14 SDGs), and energy efficiency (relating to 13 SDGs). Water conservation and water harvesting follow, with 9 linkages each. As an enabling condition of sustainable development, increased use of modern, efficient and clean energy sources plays a critical role in the realization of most SDGs, especially those most directly related to basic needs (e.g. education, health, food, water, gender equality) or economic growth and productivity (e.g. poverty alleviation, inequality, employment), reinforcing the findings of recent studies linking energy and the SDGs (McCollum et al. 2018).

Concerning the energy implications of the five adaptation options that most strongly support sustainable development, expanding renewables and rural electrification are both energy-increasing, whereas energy efficiency, water conservation, and water harvesting are energy-saving. Although in several cases, the expansion of rural electrification is based on renewable sources of energy (e.g. India mentions program that aims at electrification of rural areas based on a decentralized renewable energy system), fossil fuels are still mentioned in some (I)NDCs (e.g. Bangladesh mentions Gas exploration and reservoir management to ensure energy security and guarantee low carbon development).

Looking at the SDGs that would benefit the most from the implementation of the adaptation options highlighted, SDG 11 (Inclusive, safe, resilient and sustainable cities and human settlements) shows the greatest number of linkages with 15 (62% of all options) energy-related adaptation options supporting the achievement of this goal, followed by SDG3 (Healthy lives and well-being for all) and SDG2 (Zero hunger), with 14 (54% of all options) options each. SDG11 (Making cities and human settlements more sustainable and resilient) is supported primarily by adaptation solutions related to the infrastructure sector, including renewable energy, low-carbon and climate-proof transport systems, as explicitly required by most of the targets and indicators included in the goal. SDG2 (Ending hunger and achieving food security) shows strong connections not only with the adaptation actions directly addressing the vulnerability of the food sector but also with a high number of options related to the water and energy sectors. Access to more efficient and cleaner energy technologies as well as practices that increase water supply and efficiency are key to sustain food productivity and reduce post-harvest losses (Karekezi et al. 2012, FAO 2016, Abass et al. 2014, Kumar and Kalita, 2017). A greater heterogeneity characterizes the options that support SDG3 (Promoting healthy lives and well-being for all), highlighting how options across all the sectors shown in Figure 1 contribute to the six targets in which the goal is articulated. Ensuring universal health will indeed benefit from medical services enhanced to protect vulnerable people from climate risks, increased food security and water quality, improved residential conditions due to building standards, deployment of cleaner and efficient appliances as well as from educational campaigns targeting climate-sensitive diseases. Recent studies (Cedeño-Laurent et al. 2018) highlight how building characteristics in the broad sense (from resilience affecting the sense of security to water quality, indoor pollution, thermal comfort, disinfection systems) indirectly and directly influence mental health and well-being. Numerous linkages also emerge with those goals involving sectors explicitly requiring the implementation or expansion of the energy for adaptation options, such as SDG7 (Affordable and clean energy), supported by 10 options (42%), SDG6 (Clean water and sanitation), supported by 11 options (45%) that increase clean and efficient water supply. Table A1 describes in detail the mechanisms that give rise to the highlighted synergies for all options and all SDGs.

Whereas some options that most contribute to sustainable development are widely proposed across (I)NDCs, such as energy efficiency and renewable energy, other options which also have a high potential with respect to contributing to development, namely renewable-based water distribution, water conservation or water harvesting, are less frequently mentioned. By synthesizing the synergies between SDGs and the preferred adaptation options found in the NDCs, Figure 4 provides some guidance in terms of priorities for implementing the SDGs through adaptation projects. The first five options have pervasive implications for sustainable development, and indeed are mentioned in most countries, as highlighted by the width of the bar. Yet, only a few countries mention options such as water distribution, irrigation efficiency, heating and cooling, which indeed show a thin bar, even though they support a number of important SDGs (1, 3, 4, 8, 11).

Figure 4. Contribution of energy for adaptation options to the SDGs. Coloured bars for each option-SDG combination indicate a positive contribution of the option to the SDG. The size of the bar is proportional to the number of countries mentioning the option in the (I)NDC. Figures at the bottom summarize the numbers of options supporting each Goal. Figures on the right summarize the numbers of Goals supported by each option. All options, by definition, contribute to the climate action Goal 13 (not shown).



4. Conclusion

The (I)NDCs submitted under the Paris Agreement provide a unique wealth of information regarding adaptation priorities and plans across a large number of countries. In this paper we show how these documents provide a novel opportunity to investigate the energy needs of adaptation, as well as the implications for sustainable development, two topics that has received low recognition in the literature.

The climate actions described in the (I)NDCs reveal that several adaptation options consistently mentioned across different countries are associated with energy use either because they are energy-intensive or relate to energy-intensive sectors (e.g. dams, desalination), because they represent a precondition for access to basic energy services (e.g. rural electrification), because they require access to energy in order to spread their benefits and reach targeted population (e.g. early warning systems), or because they have the potential to save energy (e.g. energy efficiency, irrigation efficiency).

Our analysis identifies 20 energy for adaptation options, 6 of them (accounting for 43% of the total observed measures across all countries) leading to future potential energy savings, while the other 14 options are more likely to increase energy use. However, the majority of countries (65%) plan to rely on renewable sources when mentioning particularly energy-intensive options such as irrigation, desalination, water distribution, space heating and cooling, water heating, but still the risk of maladaptation remains, along other dimensions mentioned by Barnett and O'Neill (2010). Although renewable-based options would not exhibit the risk of increasing GHG emissions, other dimensions of maladaptive risk related to distributional implications, high opportunity costs, private adaptation, and path dependency still apply to some of the options identified. Forms of reactive adaptation such as the installation of air conditioning, often in response to urgency, has lower cost in the short-run compared to proactive strategies such as upgrading new and existing buildings, which require higher costs in the short-run, but have larger pay-offs in the long-term, especially in the context of achieving multiple sustainable goals. Failure to integrate heating and cooling needs into the planning process brings a high risk of lock-in in sub-optimal energy-intensive infrastructure (Hallegatte et al 2007).

Energy use for adaptation has a strong potential to support development, especially regarding the dimensions articulated by SDG 11 (Inclusive, safe, resilient and sustainable cities and human settlements), SDG2 (Zero hunger), and SDG3 (Healthy lives and well-being for all). What are the possible leverages that could push the undocumented energy for adaptation options having widespread development co-benefits (such as renewable-based water distribution) requires further research on policy adoption and implementation.

From a policy viewpoint, the framework proposed highlights adaptation actions with potential co-benefits for mitigation and sustainable development, offering guidance for the NDC's assessment as well as for designing the mechanisms aimed at promoting mitigation and adaptation while supporting sustainable development in the context of the Paris Agreement. Yet, our analysis only elucidates the potential direction adaptation could take, should countries actually implement the options described, within the bounds of uncertainty that varies across countries. Future research is warranted to understand policy adoption decisions and how those vary across climatic conditions, institutional, and socio-economic settings.

Quantifying the energy requirements of the adaptation options identified in this article, accounting for the great heterogeneity across space and technology (Sanders and Webber 2012), would provide valuable input for climate policy scenario analysis. Model-based analysis integrating energy for adaptation options and mitigation (van Ruijven et al. 2012, Pachauri 2014, Hasegawa et al.2014), is needed to substantiate how the global macroeconomic and environmental implications of adaptation could interact with mitigation in the transition towards sustainability. Such research would complement the expanding literature in climate policy and SDGs, which however is focusing on mitigation (McCollum et al. 2018a).

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Appendix A

Table A1 summarizes the linkages between energy for adaptation options from the (I)NDCs and the SDGs, along with the supporting literature that substantiates the connections. The database quantifying the number of options contributing to each goal that has been used to generate Figure 4 in the main paper is available online (**online_appendix.xls**), along with the database counting the occurrence of the energy use for adaptation options in the (I)NDCs by country.

Table A1. Linkages between energy use for adaptation in the (I)NDCs and SDGs, and supporting literature.

	Goals and targets (from the 2030 Agenda for Sustainable Development)	**Energy for Adaptation options identified in the Nationally Determined Contributions**	**Linkages explained**
Goal 1.	**End poverty in all its forms everywhere**		
	1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance	Rural electrification (RE), (Ren-based) Heating/cooling, (Ren-based) Water heating, (Ren-based) Water distribution (RWD), Water harvesting	Access to basic services is fundamental to human development. Rural electricity is recognized to be a key enabling factor for poverty reduction (McCollum et al. 2018). According to Rao and Min (2017), modern heating/cooling equipment, minimum and accessible water supply are among the basic comfort elements that ensure Decent Living Standards. Rural electrification can have positive socio-economic impacts (Estache 2010).
	1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	Medical services, Early warning systems (EWS), Building standards (BS), Energy efficiency (EE), Renewable energy (RES)	Development of EWS is a key adaptation response to prevent human and economic losses in case of extreme events. Improved public medical services as well as housing and living conditions help reduce the vulnerability and exposure of the poor to climate-related shocks and disasters (UNFCCC 2007). Energy efficiency measures reduce energy expenditure and thus contribute to reducing exposure and alleviating poverty (Gomez-Paredes et al. 2013). Efficient use of resources, renewable energy and access to modern energy can free up resources (both finance and time) that can otherwise be used in other productive activities (e.g., educational and employment opportunities) (Karekezi et al. 2012, McCollum 2018).
Goal 2.	**End hunger, achieve food security and improved nutrition and promote sustainable agriculture**		
	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round	Food storage (FS), Rural electrification, Renewable energy, Energy efficiency	Food storage and primary processing infrastructure can help reducing post-harvest losses, for example through improved electric-powered preservation (e.g. drying and smoking) and chilling/freezing. Overall, access to more efficient, cleaner and more affordable energy options is an effective tool for combating extreme hunger by increasing food productivity and reducing post-harvest losses (Karekezi et al. 2012, FAO, 2016). Along with food security, food storage contributes to increase safe and nutritious food access by all people (Grubler et al. 2018, Karekezi et al. 2012).

	2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment	Desalination, Irrigation, Water recycling and reuse, Multipurpose dams, Livestock	Improved irrigation and modern irrigation technologies help increase agricultural productivity (Duflo and Pande 2007) and therefore enhance food security (Karekezi et al. 2012). The use of safely treated wastewater has become a means of increasing water availability for irrigation (WWAP 2017). Practices to keep an adequate thermal comfort for livestock reduce the losses in meat and milk production due to animals' vulnerability to increased heat stress and acclimation (FAO, 2016).
	2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	(Ren-based) Desalination, (Ren-based) Irrigation, Water conservation, Water harvesting, Irrigation efficiency	Clean energy technologies (e.g. wind and solar pumps) and water saving practices can improve the irrigation benefits and therefore contribute to increasing sustainable food production (Karekezi et al. 2012). Water efficient practices (e.g. supplemental irrigation, water harvesting or shallow groundwater resources) are important for increasing water productivity in rainfed agriculture and reduce the carbon footprint of the agricultural sector (FAO, 2016).
Goal 3.	**Ensure healthy lives and promote well-being for all at all ages**		
	3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under5 mortality to at least as low as 25 per 1,000 live births	Food storage (FS), Livestock	Undernutrition contributes to the severity of a range of diseases, and is responsible for nearly half of total under-five deaths (UNICEF, 2015). By supporting food security and reducing undernutrition (Karekezi et al. 2012), food storage techniques contribute to preventing children mortality.
	3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases	(Ren-based) Heating/Cooling, Medical services, Building standards (BS), Information and education	Adaptive measures to reduce health risk and diffusion of vector borne disease due to climate change include the implementation and enforcement of health care interventions (e.g. vaccination programmes) and educational campaigns as well as the improved quality of residential conditions and health infrastructure (e.g. building insulation, cooling of health care facilities) (Smit et al. 2001, Smith et al. 2014).
	3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being	Building standards, Food storage	Emergency preparedness is considered an essential feature of modern buildings. When one's sense of security is threatened, their bodies elicit a cascade of biological fight-or-flight responses that alter their physical and psychological functioning (Cedeño-Laurent et al. 2018).
	3.6 By 2020, halve the number of global deaths and injuries from road traffic accidents	Transport (TS)	Experiences in Europe, Latin America, and India show that well-planned and designed sustainable transport measures can play a significant role in improving road safety, as a benefit from restricted private car traffic and the promotion of more energy-efficient modes, such as public transport, cycling, and walking (Duduta et al. 2013).
	3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	Rural electrification, Energy efficiency, Renewable energy, Building standards	Switching from traditional cooking methods and fuels to modern, cleaner and more efficient stoves or electricity reduce air pollution (Grubler et al. 2018) and associated mortality and illnesses (Smith et al. 2014). Buildings characteristics affect health through several channels (water quality, indoor pollution, thermal comfort, Cedeño-Laurent et al. 2018).
		Water recycling and reuse, (Ren-based) Water distribution, Renewable energy	Appropriate wastewater collection and treatment helps protect the water quality while significantly reducing the number of people exposed to water-related diseases (WWAP 2017). Expanding or improving water supply and distribution, including water pumping through renewable energy, help ensuring access to safe water (Karekezi et al. 2012). Water quality in buildings as well as disinfection systems affect health (Cedeño-Laurent et al. 2018). Overall, modern forms of energy are proved to play an important role in improving access to safe water and sanitation (Karekezi et al. 2012).

	3.d Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks	Early warning systems	EWSs integrate adaptation with sustainable development and the Sendai Framework for Disaster Risk Reduction (UNFCCC 2017).
Goal 4.	**Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all**		
	4.1 By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes	Rural electrification, Renewable energy	Access to modern forms of energy improves the quality and availability of educational services and increases the likelihood that children will attend and complete schooling (e.g reducing the time that women and girls spend carrying fuel). In addition, rural electrification helps retain good teachers in rural areas, thus contributing to enhancing the quality of rural education (Karekezi et al. 2012).
	4.5 By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations	Transport, (Ren-based) Water distribution	As women are more dependent on public transport than men, sustainable and accessible transport planning plays a crucial role in broadening women's access to health and education services, employment, improving the exchange of information, and promoting social cohesion (UN 2008). Women spend far more time than men fetching water that, in the presence of renewable water distribution systems, can otherwise be spent in pursuit of education (Karekezi et al. 2012).
	4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development	Information and education (I&E)	Explicitly mentioned in the SD goal and target (UNGA, 2015).
	4.a Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all	Rural electrification + (Ren-based) Heating/cooling, (Ren-based) Water heating, (Ren-based) Water distribution + Building codes	Access to electricity and drinking water are explicitly mentioned in the SD target (UNGA, 2015). Access to air conditioning positively affects children cognitive functions during heatwaves (Cedeño-Laurent et al. 2018a).
Goal 5.	**Achieve gender equality and empower all women and girls**		
	5.2 Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation	Rural electrification	Rural electrification can play an important role in eliminating violence against women, as it leads to lower acceptance of intimate partner violence (IPV). It is especially access and higher exposure to information via TV sets that causes the difference in IPV acceptance (Sievert, 2015).
		(Ren-based) Water distribution, Water harvesting, Water conservation	Women and young girls often go out to collect fuel, fodder and water for homes and, particularly in conflict or post conflict situations, this can present a threat to their security (Huyer, 2016).
	5.4 Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate	(Ren-based) Water distribution, Renewable energy, Transport	The lack of access to improved water supply places a disproportionate burden on women and girls who tend to be the primary collectors of water for the family (UNDP 2018). Access to efficient cook stoves and modern forms of energy help alleviating the burden placed on women and children in fuel collection (Karekezi et al. 2012). The burden of women's housework reduces as a result of improved public transport access (ADB 2015).
	5.5 Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life	Transport standards, Rural electrification	Poor access to transport limits women's capacity to extend their economic enterprises, thereby reducing household income and overall national productivity (Duchène 2011). Access to modern energy services has the potential to empower women by improving their income-earning, entrepreneurial opportunities,

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			autonomy and reducing drudgery (McCollum, 2018). Rural electrification increases female employment (Estache 2010).
	5.6 Ensure universal access to sexual and reproductive health and reproductive rights as agreed in accordance with the Programme of Action of the International Conference on Population and Development and the Beijing Platform for Action and the outcome documents of their review conferences	Rural electrification, Medical services	Women's reproductive health is seen as benefiting from electrification, as women with access to TV, are more informed on many health messages, including reproductive health and contraceptive methods, prevention of sexually transmitted diseases, and health checks for breast cancer and colon cancer (Cecelski 2003).
	5.b Enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women	Rural electrification	Rural electrification facilitates access to technology. Electrification helps foster "connective" applications such as radio, television, information, cell phone (Jacobson 2007).
Goal 6.	**Ensure availability and sustainable management of water and sanitation for all**		
	6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	(Ren-based) Desalination, (Ren-based) Water distribution	Desalination contributes to alleviating fresh water scarcity problems and increasing the supply of drinking water (Bertule et al. 2018). Expanding or improving water supply and distribution, including water pumping through renewable energy helps ensuring access to safe water (Karekezi et al. 2012).
	6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Rural electrification, Renewable energy	Modern forms of energy are proved to play an important role in improving access to safe water and sanitation (solar water disinfection, Karekezi et al. 2012).
	6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	Water recycling and reuse	Explicitly mentioned in the SD goal and/or target. Appropriate wastewater collection and treatment helps protect the water quality while significantly reducing the number of people exposed to water-related diseases (WWAP, 2017)
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	Water conservation, Irrigation efficiency, Information and Education	Water efficiency and demand management practices include a variety of measures that include improving use efficiency through improved technologies (e.g. increased efficiency in irrigated agriculture, water metering) but also awareness raising and education campaigns (Bertule et al. 2018).
		Multipurpose dams, Water harvesting	Rainwater harvesting and groundwater recharge as well as multipurpose dams help address water scarcity through water augmentation and storage (Bertule et al. 2018).
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	All water quality/efficiency/harvesting/storage options	
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Water Conservation	
Goal 7.	**Ensure access to affordable, reliable, sustainable and modern energy for all**		
	7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	Rural electrification	Explicitly mentioned in the SD goal and target (UNGA, 2015).

	7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	(Ren-based) Desalination, (Ren-based) Irrigation, (Ren-based) Water distribution, (Ren-based) Heating/cooling, (Ren-based) Water heating, Renewable energy	Explicitly mentioned in the SD goal and target (UNGA, 2015).
	7.3 By 2030, double the global rate of improvement in energy efficiency	Energy efficiency, Building standards, Transport systems/standards	Explicitly mentioned in the SD goal and target (UNGA, 2015).
Goal 8.	**Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**		
	8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labor-intensive sectors	Irrigation, (Ren-based) Irrigation, Renewable energy, Multi-purpose dams	Irrigation stimulates agricultural productivity and economic growth. Dam-based irrigation can have negative effects where dams are placed, but they can have positive impacts on poverty and wages in downstream villages (Dulflo and Pande 2007).
	8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services	Rural electrification, Information and education	Cleaner energy options can enhance working conditions and open opportunities to generate livelihoods, increase the number of jobs, and provide decent work. Access to affordable energy options from gaseous and liquid fuels and electricity can assist enterprise development (Karekezi et al. 2012). The digital revolution facilitates access to information and can have positive impacts on economic growth, but it needs to come along with good institutions and human capital (WDR 2016).
	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead	Rural electrification, Energy efficiency, Water conservation, Building standards	Energy efficiency and water conservation have the potential to improve global resource efficiency. Building rating systems (RSs) have initially been developed to promote the reduction of energy and water use and waste (Cedeño-Laurent et al. 2018).
	8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment	(Ren-based) Heating/Cooling	Investments in heating and cooling equipment represent an option for firms to adapt to the negative impact that temperature shocks may have on workers (Park and Behrer, 2017).
Goal 9.	**Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**		
	9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all	Rural electrification, (Ren-based) Desalination, Multipurpose dams, Irrigation, (Ren-based) Irrigation, Irrigation Efficiency, Transport	According to the UN's definition, infrastructure includes transport, irrigation, energy and information and communication technology (UNGA 2015). Here are considered options that support this infrastructure resilience and deployment.
		Transport	Explicitly mentioned in the SD goal and target (UNGA, 2015).
	9.2 Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries	Rural electrification, Renewable energy, Energy efficiency	Rural electrification contributes to industrial development and GDP increase (Rud 2012, Estache 2010). Diversification of energy sources and energy efficiency can help reduce energy costs (Ebinger and Vergara 2010).
	9.3 Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets	Rural electrification, Renewable energy	

	9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	Building standards + Energy efficiency, Rural electrification	Mentioned in the SD goal and target (UNGA, 2015).
	9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020	Rural electrification	Solar electrification helps foster connective applications such as radio, television, information, cell phone (Jacobson 2007).
Goal 10.	**Reduce inequality within and among countries**		
	10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average	Energy efficiency, Renewable energy, Rural electrification, (Ren-based) Water distribution, Water conservation, Water harvesting	Efficient use of resources, renewable energy and access to modern energy can free up resources (both finance and time) that can be used for other productive activities (e.g., educational and employment opportunities) (Karekezi et al. 2012; McCollum 2018).
	10.2 By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status	Renewable energy	Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities (McCollum 2018).
	10.3 Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard	Renewable energy, Transport	Sustainable public transport options play a crucial role in broadening access to basic services and job opportunities as well as promoting social cohesion (UN 2008). Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities (McCollum, 2018).
Goal 11.	**Make cities and human settlements inclusive, safe, resilient and sustainable**		
	11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	(Ren-based) Heating/cooling, (Ren-Based) Water heating, Rural electrification, Building standards, (Ren-based) Water distribution	Safe and basic housing services imply access to modern forms of energy, durable and resilient homes which, at the community level, require infrastructure such as electricity and water distribution (Cedeño-Laurent et al. 2018). According to Rao and Min (2017) modern heating/cooling equipment, minimum and accessible water supply are among the basic comfort elements that ensure Decent Living Standards.
	11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons	Transport	Explicitly mentioned in the SD goal and target. Urban centers rely on transport for their daily functioning. A resilient public transportation system is essential to ensure access to goods and services, as well as employment, production, and livelihoods opportunities, and is critical for effective disaster response (Revi et al. 2014).
	11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	Building Standards	
	11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	Medical services	Direct economic costs include non-market impacts on health - morbidity and mortality. Improved hospital and infrastructure for medical services, as well as a more extended network of health centers contribute to resilience, by allowing a quicker and more effective making response in case of emergency (Hallegatte 2015).
		Multipurpose dams	Multipurpose dams can contribute to flood control, reducing water-related disasters (Bouwer et al. 2018).

	11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	Transport Systems + Water Recycling and reuse, Energy efficiency, Renewable energy + Rural electrification	The climate imperatives to deploy more efficient technologies and to reduce reliance on energy from fuel combustion - including electrification of end-uses - have co-benefits in terms of reduced pollution. Policies that stimulate energy efficiency reduce local air pollutants (WEO 2017, OECD 2016). Regulatory regimes, in particular vehicle standards regimes, contribute to reduce the health impact of road transport pollution (OECD 2014).
	11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels	Early warning systems, Information and education	EWS, I&E are key strategies to address disaster risk, and belong to those strategies that contribute to the Senday Framework. Examples of knowledge sharing activities and implementation of early warning system, and how they contribute to risk reduction, are described in UNFCCC (2017).
Goal 12.	**Ensure sustainable consumption and production patterns**		
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	Water conservation, Water harvesting, Energy efficiency, Renewable energy	Renewable and energy efficiency can reduce pressure on natural resources, as access to modern forms of energy means less disturbance for local biodiversity and lower reliance on wood and other natural resources (e.g. forest). Recycling activities - including wastewater treatment and reuse - contribute to reducing pressure on natural resources such as fresh water (McCollum et al. 2018).
	12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses	Food storage	During the crop transition from farm to consumer, crops undergo several operations - harvesting, threshing, cleaning, drying, storage, processing and transportation. Storage plays a vital role in the food supply chain, and several studies reported that maximum losses happen during this operation. (WB 2011, Abass et al. 2014, Kumar and Kalita 2017).
	12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	Water recycling and reuse	Appropriate wastewater collection and treatment helps protect the water quality while significantly reducing the number of people exposed to water-related diseases (WWAP, 2017).
	12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	Information and education	Explicitly mentioned in the SD target (UNGA 2015).
Goal 14.	**Conserve and sustainably use the oceans, seas and marine resources for sustainable development**		
	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	Water conservation, Water recycling and reuse, Water harvesting, Irrigation efficiency Information and education	Measures that restrict overuse and pollution of water at its source, or improve water treatment capacity, contribute to the reduction of water bodies' pollution. Improving farmer knowledge on sustainable agricultural practices helps avoid nutrient excess dosages, and therefore leakage (Bertule et al. 2018). Overall, awareness-raising campaigns are an effective way of reducing marine debris (Willis et al. 2017).
	14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans	Water Conservation	

	14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels	Renewable energy, Energy efficiency	Emission reduction induced by the deployment of renewable energy and energy efficiency practices reduces global emissions and slow down ocean acidification rates (McCollum et al. 2018, Grubler et al. 2018).
Goal 15.	**Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**		
	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	Rural electrification, Energy efficiency	Access to modern energy services and energy efficiency reduce the need to rely on firewood taken from forests and hence contribute to halting deforestation (Grubler et al. 2018, McCollum et al. 2018, Karekezi et al. 2012).
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	Water harvesting including groundwater recharge, Water conservation & improved water use efficiency (including water metering), Irrigation efficiency	Water harvesting, water conservation, and improved efficiency are all options that contribute to reduce water needs. Measures aimed at improving water use efficiency can also lead to benefits in terms of improved soil moisture retention capacity (Bouwer et al. 2018). Irrigation efficiency can also be improved through altering farming practices and conservation tillage that help improve soil moisture conservation (Bertule et al. 2018).
Goal 16.	**Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels**		
	16.1 Significantly reduce all forms of violence and related death rates everywhere	Water conservation, Water harvesting, Multi-purpose dams, irrigation, (Ren-based) Irrigation, Irrigation efficiency	Water availability, and therefore all options that increase water supply, as well as agriculture dependency (agriculture output as a share of GDP) increase the likelihood of occurrence of hydro-political interactions defined as either conflicts or cooperation (Farinosi et al. 2018).
		Rural electrification	At the community level, access to electricity can have benefits for education, health and water supply. Street lighting, which increases safety, is also a benefit of electricity access at the community level (van Ruijven et al. 2012).
	16.5 Substantially reduce corruption and bribery in all their forms	Renewable energy, Energy efficiency	Renewable energy, by reducing reliance on oil and oil rent, can contribute to reducing the corruption associated with oil-rent-seeking activities. The empirical evidence suggests that non-oil natural resources, which management is more apparent to the public, are less prone to corruption (Okada and Samreth 2017).
Goal 17.	**Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development Finance**		
	17.7 Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favorable terms, including on concessional and preferential terms, as mutually agreed	Renewable energy, Energy efficiency	Evidence from CDM projects shows the significant potential of technology transfer associated with renewable energy sources such as solar and wind power and measures to improve energy efficiency at the household level or in services (Dechezlepretre et al. 2008).
	17.8 Fully operationalize the technology bank and science, technology and innovation capacity-building mechanism for least developed countries by 2017 and enhance the use of enabling technology, in particular information and communications technology	Rural electrification	10% of world electricity consumption is dedicated to ICTs and one cannot access the internet without electricity. Expanding access to energy and to the Internet can be done concurrently. Studies show that solar electrification plays an important role in fostering "connective" applications such as radio, television, information, cell phone (Jacobson 2007).

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