Transitioning to low-carbon economies under the 2030 Agenda: minimizing trade-offs and enhancing co-benefits of climate action for the SDGs

Supplementary Material: Literature review on the impacts of climate-change mitigation measures on the SDGs

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The sections below present impacts of climate change mitigation measures on specific SDG targets, as identified through literature review. This material includes only direct (first order) impacts and covers relevant SDGs. The language used here suggests whether the impacts are context dependent or independent, through wording such as “could/can/might/may” and “would/do(es)”, respectively. For a visual representation of these impacts and their categorisation based on the scoring method developed in this paper, we recommend consulting the supplementary material in Excel format.

SDG1 – No poverty

Energy is an essential enabling element to a large number of human activities. For this reason, energy unaffordability was defined here as one dimension of poverty (SDG 1.2). Increase in energy prices due to energy (CO_2) taxes would lead to a rise in energy poverty among economically vulnerable people if complementary attenuating measures, such as subsidies or exemptions for poor households, are not implemented (Cameron et al., 2016; Hirth & Ueckerdt, 2013). Furthermore, energy price increase can also be the result of use of more expensive energy technologies or of a higher demand for electricity, for instance, through electrification of the transport systems. However, an electrification of the transport sector may protect the poor from volatile oil prices. While nuclear energy and renewables are competitive with some types of fossil fuels (especially gas) in a few countries, this is not the case everywhere and measures such as feed-in tariffs are still necessary to keep the prices low for the public while making renewables competitive with fossil fuel energy sources. Moreover, waste-to-energy tends to be more expensive than other sources of electricity and heat in most situations (U.S. Department of Energy, 2019). Nevertheless, some renewables have reached price parity and are at times even cheaper than fossil fuels in some countries (Borenstein, 2012; Evans et al., 2009; Hirth & Ueckerdt, 2013; NEA, 2018; Ouyang & Lin, 2014). Moreover, (bioenergy) carbon capture and storage ((BE)CCS) used with power plants would always lead to higher energy costs as the carbon capture and storage system itself requires energy to operate, hence, increasing the energy consumption of the plant (Rubin et al., 2015). Nevertheless, for BECCS this additional required energy could be considered productive as it leads to a carbon sink (negative emissions) rather than just GHG emissions avoidance. On the demand side, upfront costs of energy efficiency improvements would most likely be over-compensated by lower energy needs in the long-run and would lead to lower energy prices. This would decrease energy poverty. For instance, observed rebound-effects (i.e. increased consumption) after improvements in energy efficiency could be an indication that there was a higher need for energy previous to the price decrease and that it was not affordable (assuming that the effect is not a result of energy waste alone) (Cayla & Osso, 2013; Greening et al., 2000; Herring & Roy, 2007; Sorrell, 2007; Ürge-Vorsatz & Tirado Herrero, 2012; Winkler et al., 2002).

While energy unaffordability is an indicator of poverty, the lack of access to energy deprives people of this basic service altogether (SDG 1.4). In that regard, off-grid renewable sources can facilitate coverage of electricity in remote areas (Casillas & Kammen, 2010; Pueyo et al., 2013; REN21, 2016). However, forest and ecosystems conservation and rehabilitation to increase the carbon sink potential can limit access of communities in the area to biomass for energy, as well as land and natural resources (SDG 1.4) that might be essential for their livelihoods (Charnley, 2005). If a reasonable use of resources for energy is allowed, the communities can benefit from the conservation of respective ecosystems. This is also the case for large photovoltaic (PV), concentrated solar power (CSP), hydropower and biofuel production projects that require large areas of land and, in some cases (most common for hydropower), could additionally lead to communities' displacement and related impoverishment (Dombrowsky et al., 2014; Moore et al., 2010). However, occurrence of these negative impacts depends on the existence of communities in the affected area in the first place.

SDG2 – Zero hunger

Policies supporting biofuel production can lead to competition between climate-change mitigation and food security targets (SDG 2.1) by reducing the surface area or increasing the price of land available for agriculture (Finco & Doppler, 2010; Hasegawa et al., 2015, 2018; Lotze-Campen et al., 2014; Lundberg et al., 2015; Rogelj et al., 2018; Smith et al., 2013; Van der Horst & Vermeylen, 2011). Similarly, forest and nature protection can also reduce available land for food production and limit access of vulnerable communities to land and natural resources (SDGs 2.1 and 2.3) (Charnley, 2005; Smith et al., 2010), but communities may benefit if access is allowed. Furthermore, taxes on CO_2 emissions from agriculture would increase food prices (absent subsidies) and limit food affordability.

On the positive side, climate policies that support the use of biofuels and low-emissions agriculture facilitate the introduction of new technologies, infrastructure and knowledge for efficient and sustainable food production (SDG 2.3) (Smith et al., 2014). Examples of such methods and technologies include no-tillage agriculture, which reduces GHG emissions, water evaporation and loss of soil nutrients; optimized water and fertilizer delivery, which reduces GHG emissions, run-off, land-use extent for the same quantity of food, soil erosion and desertification; and direct seeding of rice, which substantially reduces GHG emissions caused by crop water immersion, and water and energy use, and improves soil quality through less soil compaction (World Economic Forum, 2011). These agricultural practices substantially reduce production costs and required labour, leading to an increased income for farmers (SDG 2.3) and productivity per labour input (SDGs T2.3 and T2.4) for both small- and large-scale farmers (World Economic Forum, 2011). Mixing agricultural and livestock practices can also increase productivity while reducing emissions and demand for land (Bogdanski, 2012; Thornton, 2010). On the downside, this increase in efficiency could reduce agricultural jobs (SDG T2.3). However, emerging bioenergy use can open access to untapped markets and, if adequately implemented, increase small-holder farmers income and jobs (Berndes et al., 2016; Brüntrup et al., 2016; Gohin, 2008) (SDG T2.3).

Agricultural practices for climate-change mitigation make food production systems more sustainable, can help improve ecosystems and soil quality (SDG T2.4) and could consequently increase resilience to changes in climate (Smith et al., 2014; World Economic Forum, 2011). Nonetheless, poorly managed bioenergy monocultures can have the opposite effect by decreasing soil quality, water availability and biodiversity, and hence, weakening ecosystem resilience (Bonsch et al., 2016; Davis et al., 2013; Dias de Oliveira et al., 2005; Finco & Doppler, 2010; von Blottnitz & Curran, 2007). Finally, from a behavioural perspective, decreased food waste and lower consumption of livestock combined with cultivation of food crops instead of feed can increase food availability (Lamb et al., 2016; Tilman & Clark, 2014). The use of more efficient cookstoves that last longer can also enhance food security (Berrueta et al., 2017).

SDG3 – Good health and well-being

A broad spectrum of air pollutants is produced through combustion of fossil fuels and other activities that jointly lead to GHG and other polluting emissions. Hence, tackling GHG emissions directly lowers air pollution (especially NO_x and SO_x but also volatile organic compounds, carbon monoxide, black carbon, particulate matter and organic carbon) (Braspenning Radu et al., 2016). Furthermore, climate-change mitigation measures reduce water and soil pollution from leakage during fossil-fuel extraction, transport, production and use, and from livestock and intensive use of nutrients (Atilgan & Azapagic, 2015; McMichael et al., 2007) (SDGs 3.4, as sources of non-communicable diseases, and SDG 3.9). Examples of GHG emissions measures with positive impacts on air, water and soil pollution are energy-efficiency improvements, use of renewable sources, cleaner transportation, reduction in material and energy demand, reduction in agricultural burning practices and improved cooking stoves, when the assumed business as usual implies the use of fossil fuels (Anenberg et al., 2012, 2013; Creutzig et al., 2012; Haines et al., 2007; Haines & Dora, 2012; International Energy Agency, 2016; von Blottnitz & Curran, 2007; West et al., 2013; Woodcock et al., 2009). A reduced demand for meat would lower the risk of zoonotic pathogens (SDG 3.3) (Klous et al., 2016). Moreover, in countries where meat consumption is high, a lower demand would offer numerous health benefits. Nevertheless, this measure could be problematic in developing countries where the population may not be able to obtain the needed daily nutrients from vegetal sources (Garnett, 2011).

However, measures with potentially negative impacts on air, soil, and water are bioenergy, (BE)CCS, nuclear, gas and geothermal energy sources. The use of bioenergy leads to air pollution, but the net impact on air quality depends on the fuel quality and on the fossil fuel source replaced. Furthermore, bioenergy production might increase the use of fertilizers and consequent emissions to soil and water (Dias de Oliveira et al., 2005). While (BE)CCS reduces SO_x and particulate matter, the technology requires additional energy to be operated and this leads to an increase in NO_x and NH_3 (European Environment Agency, 2011). Furthermore, (BE)CCS and nuclear energy pose a risk of CO_2 and radioactive material leakage, respectively, to air, soil, and water, with potentially catastrophic consequences in the case of nuclear energy (IPCC, 2014). However, outside these very rare events, coal leads to even higher radiation exposure per unit of electricity produced for both the public and workers as compared to nuclear energy (UNSCEAR, 2016; IPCC, 2014; Markandya and Wilkinson, 2007).

The use of renewable energy resources and electric transportation might raise concerns on the increase in pollutants such as cadmium for solar PVs and lithium for batteries, and requires appropriate toxic material management. However, fossil fuel extraction, processing and use lead to substantial emissions of a wide variety of toxic compounds, for instance, mercury and lead (Atilgan & Azapagic, 2015; Duan & Tan, 2013; Pirrone et al., 2010). Some methods of gas extraction, such as fracking, lead to soil and water pollution by injection of water and chemicals into the ground. However, other gas extraction methods might have lower impacts than coal mining and avoid transport-related oil spills (Atilgan & Azapagic, 2015; IPCC, 2014; Jaramillo et al., 2007; Markandya & Wilkinson, 2007). Geothermal energy can lead to emissions of hydrogen sulphide (H_2S) and ammonia (NH_3) to air and to discharge of thermal and polluted water with dissolved chemicals such as sodium chloride (NaCl), boron (B), arsenic (As) and mercury (Hg). CO_2 and CH_4 are also emitted to air (Kristmannsdóttir & Ármannsson, 2003).

Road traffic accidents can be reduced through transport-related climate-change mitigation measures, such as improved urban planning and infrastructure investments to reduce traffic congestion, and modal share switch to increased use of public transport (Creutzig et al., 2012; Haines & Dora, 2012; Pridmore et al., 2017) (SDG 3.6). However, an increased use of silent electric vehicles can negatively affect road safety, if warning sounds are not implemented (IPCC, 2014), while the increased use of bicycles poses an additional accident risk when it is not paired with adequate infrastructure (SDG 3.6). Finally, lower levels of noise and modal switches to active travel modes are likely to have a positive influence on mental and physical health of citizens (Saunders et al., 2013; Woodcock et al., 2009). On the contrary, placement of wind turbines close to households can affect residents through noise and intermittent shadows (Evans et al., 2009). A reduction in meat consumption in areas where consumption is high can also have positive effects on health, reducing risks of non-communicable diseases (Bustamante et al., 2014) (SDG3.4). In energy deprived households, improvements in energy efficiency may increase warmth and reduce humidity, helping to reduce a series of health risks, such as cardiovascular and respiratory illnesses (Huebner et al., 2013; Zhao et al., 2017).

SDG4 – Quality education

Information and education measures for GHG emissions reduction include environmental product labels, information campaigns and specialized training. These promote sustainable development and sustainable lifestyles, raising public awareness of environmental issues (SDG 4.7). Moreover, education and vocational training directly contribute to the increase in number of people with vocational skills (SDG 4.3, 4.4 and 4.5).

SDG5 – Gender equality

Measures that support energy efficiency in buildings and more effective cookstoves would particularly benefit women, who tend to spend a disproportionate amount of time at home in most communities (Berrueta et al., 2017). Moreover, as women tend to play an important role in agricultural activities, special attention needs to be given to ensure that regulations in this sector do not overburden women. In particular, agricultural taxes may affect women farmer's income and food availability, but increased productivity could have a positive effect (Jost et al., 2016; Terry, 2009). Similarly, women's reliance on local ecosystem resources for food and wood puts them in a vulnerable situation when conservation measures restrict access, but they can benefit from inclusive ecosystem conservation measures (Katila et al., 2017; Larson et al., 2015).

SDG6 – Clean water and sanitation

Water-use efficiency can be improved through climate-change mitigation policies, such as the elimination of water intensive power plants (e.g. coal-fired power plants), improvements in energy production and use efficiency, and water efficient agriculture, such as precision agriculture and direct seeding of rice (see examples in SDG2), helping to avoid water-use conflicts (Byers et al., 2014; Chuang et al., 2009; Fricko et al., 2016; Fujimori et al., 2017; Kyle et al., 2013; Reidinger, 1974; Rio Carrillo & Frei, 2009; Spang et al., 2014; World Economic Forum, 2011) (SDGs 6.1 and 6.4). However, measures supporting bioenergy (Bonsch et al., 2016; Fingerman et al., 2011; Mouratiadou et al., 2016; Wu et al., 2009), concentrated solar power (CSP), nuclear (Byers et al., 2014; Chuang et al., 2009; Spang et al., 2014), geothermal (Rybach, 2003; Shortall et al., 2015) and hydro-energy (T. Abbasi & Abbasi, 2011; Kelly-Richards et al., 2017; Premalatha et al., 2014; Zhang et al., 2015) could increase or decrease water use and the access of communities to these resources, depending on the water consumption of the fossil fuel energy options replaced.

Moreover, the above-mentioned measures would positively or negatively affect thermal (except hydropower) and non-thermal water pollution, depending on the energy source they replace (Spang et al., 2014) (SDG 6.3). In that regard, energy efficiency and switching to alternative technologies for cooling (e.g. air-cooling) and electricity production (solar PV and wind) would reduce thermal and non-thermal water pollution (Byers et al., 2014; Fricko et al., 2016; Raptis et al., 2016) (SDG 6.3). Nonetheless, the increase in energy demand at power plants with CCS installed would lead to an increase in energy-related water use and thermal pollution (SDGs 6.1, 6.3 and 6.4). In industrial settings, carbon capture and utilisation (CCU) could be optimized to reduce water demand (Brandl et al., 2017). On the demand side, electric transportation could lead to an increase in water use and thermal pollution if provided electricity comes from water-intensive sources (King & Webber, 2007) (SDGs 6.1, 6.3 and 6.4). Non-thermal water pollution impacts are discussed under SDG3.

Altogether, aforementioned positive impacts as well as protection and restoration of forest areas, peat lands and other ecosystems for climate-mitigation purposes, help preserve fresh water bodies and avoid water quality issues, such as eutrophication (Eory et al., 2017; Smith et al., 2013) (SDG 6.6). Similarly, in the case of reforestation, original water ecosystems could be restored (Dooley & Kartha, 2018)). Nevertheless, water use for forest plantations can lead to water stress (Kibria, 2015; Lamb et al., 2016). Therefore, in-depth environmental impact assessments need to be undertaken for bioenergy, CSP and nuclear (SDG 6.6) and with particular attention in the case of hydro-energy, tidal and wave energy (SDG 6.6) to ensure water ecosystem impacts are not increased as compared to the replaced fossil fuel energy option (see also SDG15). For instance, in the case of hydro-energy natural areas are inundated to make space for the water reservoirs and the original route of the river might be diverted, leaving some communities without water resources. Furthermore, dams lead to sediment deposition and interfere with freshwater wildlife (T. Abbasi & Abbasi, 2011; Kelly-Richards et al., 2017; Premalatha et al., 2014; Zhang et al., 2015). Similarly, tidal energy may lead to sediment redistribution and affect marine life. However, if appropriately implemented, negative impacts can be minimized and certain benefits can be achieved in support of ocean biodiversity (Gill, 2005; Inger et al., 2009; Neill et al., 2012). In contrast, fossil fuel burning releases nitrogen oxides and sulfur oxides which make water bodies acidic. This is also an issue in the case of biomass and biofuel burning.

7 AFFORDABLE AND CLEAN ENERGY

SDG7 – Affordable and clean energy

Climate-change mitigation and SDG7 are strongly interlinked. Firstly, tackling GHG emissions implies increasing the share of low- and zero-carbon energy technologies, such as renewables (SDG 7.2). A second approach to address climate change is to substantially increase energy efficiency and lower energy demand in all sectors (SDG 7.3). Furthermore, both energy-efficiency improvements and renewable energy share increase could lead to more reliable energy systems (energy security) by reducing dependence on limited natural resources, with especially positive effects in countries with high energy imports (Bollen et al., 2010; Cherp et al., 2013; IEA, 2005; McCollum et al., 2013, 2014) (SDG 7.1). However, high reliance on intermittent energy sources and an increased dependency on electricity as final form of energy across sectors (given increase in, for instance, electric vehicles and electric cookstoves and heaters) could affect the reliability of the energy system (Guivarch & Monjon, 2015; Hung et al., 2016) (SDG 7.1). The increase in diversity of (clean) energy sources and related infrastructure investments would enhance access to modern energy services (here we defined all low-carbon energy sources as modern) (SDG 7.1), but energy affordability may be affected (SDG 7.1), as indicated under SDG1. Finally, renewable energy sources, are more easily introduced in remote areas, enabling broader electricity access (SDG 7.1) as shown under SDG1. However, if forest protection limits communities access to biomass asa source of energy, this could affect both energy access and the level of renewable energy consumed. Finally, reducing food waste and improving agricultural and livestock productivity would reduce energy demand (Kummu et al., 2012; Schader et al., 2015).

SDG8 – Economic growth and employment

Avoiding high reliance on fossil-fuel industries that are based on finite resources, would prevent possible future economic disruption caused by resource shortage and price volatility, and as such facilitate a sustained economic growth (SDGs 8.1 and 8.3). In that sense, a switch to non-bioenergy CCS technologies, gas and nuclear energy could hamper economic growth in the long run (Fankhauser et al., 2008; Ferroukhi et al., 2016; IPCC, 2014). Sustained economic growth could be enhanced through a switch to renewable energy sources and a decrease in energy demand. Although the costs of mitigation could slow economic growth in the short-term, low-carbon investments are likely to have positive economic effects in the long-term (Fankhauser et al., 2008; Ferroukhi et al., 2016; IPCC, 2014; The New Climate Economy, 2018). Moreover, sustained economic growth can also be stimulated by an increase in economic productivity (SDG 8.2) and resource efficiency (SDG 8.4) and some climate-change mitigation measures specifically focus on efficiency in production and consumption, such as industrial energy and material use efficiency. However, (BE)CCS increases the use of resources as additional energy is required to run the technology itself, although this additional energy could be considered productive in BECCS by expanding the carbon sink potential. A comparison of economic productivity between fossil fuel and nuclear and renewables is not suitable given the very different types of limited resources and respective impacts. However, low-carbon transition measures more generally contribute to a sustainable economic growth through a decoupling from resource use and related environmental degradation (SDG 8.4) (see impacts described under SDG 3 and SDG 15). However, adequate environmental assessments need to be conducted to ensure potential risks are avoided.

Forest protection and development projects can generate additional income through enabled economic activities such as pollination and tourism (Katila et al., 2017). Moreover, as tree plantations have a higher rate of timber production, afforestation and reforestation projects can stimulate the economy through timber markets (Kibria, 2015). In general, afforestation and reforestation projects would also create new jobs, even if the timber is not sold.

Technological and infrastructure upgrading (SDG 8.2) for improved productivity, reduced waste and low-carbon energy production are stimulated by climate-mitigation measures across all sectors (Bhattacharya et al., 2016; Mattauch et al., 2015). This demand for new technologies and infrastructure would stimulate economic diversification and innovation (SDGs 8.2 and 8.3) for countries that produce related equipment, including BECCS, although fossil fuel CCS, nuclear and gas could lead to lock-in effects into finite resources and limit capitalization on related investments (Bertram et al., 2015; IPCC, 2014).

The net effect of climate-change mitigation on employment probably differs across countries as jobs created in renewables and energy-efficiency sectors may or may not account for all lost jobs in the fossil-fuel industry (in the same country) and workers may not easily switch between sectors (SDGs 8.5). Nonetheless, studies show that, provided sufficient support for job transition, climate-change mitigation would not pose a threat to current employment rates and would likely have a positive impact on job numbers (Babiker & Eckaus, 2007; Fankhauser et al., 2008; Ferroukhi et al., 2016; GEA, 2012; ILO, 2010; IPCC, 2014; Kerr et al., 2016; Tirado Herrero et al., 2011; UKERC, 2014). Furthermore, the transition to a low-carbon economy would likely create many decent jobs (SDGs 8.3 and 8.8) in energy efficiency, urban planning and renewables industries (Höhne et al., 2015; ILO, 2010) and lead to more safe and secure working environments through infrastructure upgrading across sectors and a reduction in occupational accidents related to fossil-fuel extraction and transportation (Markandya & Wilkinson, 2007; Steinsvåg et al., 2008; Sumner & Layde, 2009). Vocational training for skills relevant to a low-carbon transition can support the creation of new (decent and safe) jobs where there is demand (Apeaning & Thollander, 2013; Healy & Barry, 2017; Louie & Pearce, 2016). Support for (BE)CCS, nuclear and hydro-energy poses a risk of work-related accidents in the absence of adequate safety measures, such as high levels of CO_2 inhalation, nuclear material leakage and landslide, respectively. However, the risk for nuclear catastrophic events is low. There have been two catastrophic events at nuclear power plants in the past (Chernobyl in 1986 and Fukushima in 2011). In the case of the Fukushima Daiichi accident the doses to the public are generally low or very low and no discernible increased incidence of radiation-related health effects are expected (UNSCEAR, 2013). The Chernobyl accident resulted in the deaths of 28 power plant employees and fireman from acute radiation syndrome and also in excess thyroid cancers among the public (6000 as of 2006) with a small number of fatalities (15 as of 2005). Nonetheless, current reactor designs have improved in safety and an emergency this severe is not considered possible for running nuclear power plants (IAEA, 2016).

SDG9 – Infrastructure and industrialization

As indicated under SDG8, a low-carbon transition broadly requires investment in reliable, clean, efficient and sustainable infrastructure, retrofitting or closure of old inefficient industries and power plants and infrastructure upgrading (SDGs 9.1, 9.4 and 9.5), as well as a reduction in material and energy demand (SDG 9.4). Such developments would facilitate sustainable industrialization (SDG 9.2) and stimulate innovation and economic diversification (SDG 9.5), as shown under SDG8. However, except for fossil fuel CCS and agricultural measures, climate change mitigation measures take a toll on existing fossil fuel industries, reducing demand for fossil fuels and in some cases, leading to premature closure of fossil fuel power plants. As indicated under SDG8, if policies that facilitate a smooth low-carbon transition are not implemented, climate mitigation measures can lead to negative economic and employment impacts in countries with significant fossil fuel resources and high employment in the sector and would limit inclusive industrialisation (SDG 9.2) (Johnson et al., 2015; McGlade & Ekins, 2015). Similar trade-offs may also be seen in the livestock industry as a result of increased costs and reduced demand (Eory et al., 2017) and in the energy and agricultural industries, provided energy (GHG) and agricultural GHG taxes.

SDG10 – Reducing inequality

Most impacts presented under SDG 1 and SDG 2 are also directly related to SDG 10, in particular with regard to economic improvements for the bottom 40% of the population based on income (SDG 10.1). Measures that affect access to (affordable) basic services and resources or that have impacts in the area of agriculture would disproportionately target the poor as these are more likely to be dependent on those services and resources and to have their incomes affected by changes in prices, costs or access. On a different note, from a participatory perspective, small-scale renewable energy plants can be developed in a way that benefits individuals and communities, hence, increasing inclusiveness in decision-making and benefits sharing of energy production (Kunze & Becker, 2015; Mccollum et al., 2018).

SDG11 – Sustainable cities and communities

Energy efficiency improvements in buildings require high upfront investments that may lead to a short-term increase in housing costs and limit affordability (SDG 11.1), if not subsidised (Cayla & Osso, 2013). However, the resulting energy savings, improved thermal insulation and other benefits related to such upgrading would increase the availability of adequate and safe housing (SDG 11.1) (Ürge-Vorsatz & Tirado Herrero, 2012; Winkler et al., 2002). In addition to housing adequacy, energy access and affordability are key elements in the provision of basic services to communities (SDG 11.1) and may be affected by climate change mitigation measures, as described under SDGs 1 and 7. More energy efficient industries could provide waste heat, waste water and electricity to cities, making them more sustainable (Karner et al., 2016).

Transport-related GHG emissions per person kilometre can be reduced, for instance, by improving planning and infrastructure, by stimulating the use of public transport, cycling and walking, or by tackling fuel efficiency and emissions intensity through use of electric vehicles or biofuels. These measures improve transport sustainability and can expand access to public transport (SDG 11.2) (Bhattacharya et al., 2016; Creutzig et al., 2015; United Nations Secretary-General's High-level Advisory Group on Sustainable Transport, 2016). Furthermore, as indicated under SDG3, transport-related climate-change mitigation measures can lead to road safety (SDG 11.2), provided adequate investments in cycling infrastructure and signalling of electric vehicles in low-speed areas.

Cities compactness, energy efficiency and the use of renewables would improve sustainability of human settlements (SDG 11.3) (IPCC, 2014), reduce the environmental impacts of cities (SDG 11.4, see also SDG 15) and improve urban air quality (SDG 11.6). Although the resulting waste from decommissioning of wind turbines (Martínez et al., 2009), and from running power plants and CCS would require additional waste management (SDG 11.6), replacement of coal would reduce radioactive fly and bottom ash waste (Baba, 2002). Moreover, organic municipal waste could be addressed through management of related methane emissions (waste-to-energy systems) (Ayalon et al., 2001; Bogner et al., 2008).

SDG12 – Sustainable consumption and production

Measures for climate-change mitigation addressing consumers through climate-change awareness campaigns, education programs and product-performance labels enhance awareness of sustainable development and related lifestyles (also under SDG4) (SDG 12.8). GHG emissions audits, reporting and monitoring, regulations, fiscal/financial incentives and voluntary agreements are measures that encourage GHG emissions reduction in companies, and hence, improve their sustainability (SDGs 12.2 and 12.6). Similarly, public procurement regulations to support acquisition of low-carbon services and products ensure increased sustainability (SDG 12.7).

Material and energy efficiency, limited resources (e.g. fossil fuels) depletion deceleration, and management of natural resources (e.g. forests), are essential outcomes of GHG emissions reduction measures (SDG 12.2), as shown under SDGs 8 and 9. Nevertheless, replacement of fossil fuels with other energy sources and expansion of EVs can lead to increased demand for rare earth minerals, such as lithium, cobalt, neodymium, palladium, platinum, gallium, dysprosium and other (Buchert et al., 2011). Furthermore, a related outcome of energy and resource efficiency measures is waste reduction (SDG 12.5) that also applies to food waste to address methane emissions (SDG 12.3), as shown under SDG 11, and to waste-to-energy systems. Finally, as shown under SDG3, actions to reduce GHG emissions have a direct impact on air, water and soil pollutants (SDG 12.4).

SDG13 – Climate action

SDG13 concerning climate change covers two major aspects: adaptation and mitigation. As this study focuses on the impacts of climate-change mitigation measures (mainly covered in SDG13.2) on other SDGs, direct synergies and trade-offs with climate change adaptation (SDG13.1 and SDG13.2) are also relevant. For instance, managing, conserving and restoring forests and nature areas to increase carbon sinks also improve adaptation of natural and human habitats (Griscom et al., 2017; Verchot et al., 2007) (SDGs 13.1 and 13.2). Similarly, mitigation practices in agriculture likely lead to more resilient food production systems, although trade-offs could also occur, if biofuels are not sustainably grown, for instance (shown under soil quality in SDG 3) (Aguilera et al., 2013; Smith & Olesen, 2010). Finally, the use of hydropower implies the creation of water reserves which may support adaptation to periods of water scarcity (IPCC, 2014).

The other two targets of SDG13 are also affected by climate mitigation action. All climate change mitigation measures lead to an increase in domestic climate action and integration of climate concerns in national policies (SDG 13.2). Lastly, awareness raising and capacity building through campaigns and trainings are one type of climate action (SDG 13.3).

SDG14 – Life under water

As water bodies around the globe are closely interrelated with oceans, thermal and non-thermal pollution impacts identified under SDG6 would also apply to ocean pollution, even when power plants are not located along the coast (SDG 14.1). However, the economies of countries near marine areas may be stimulated by the use of renewable energy installations, such as off-shore wind turbines and wave and tidal energy conversion, if adequately managed to avoid impacts on ecosystems services (SDG 14.7) (Gilmartin & Allan, 2015; Michler-Cieluch et al., 2009). Conservation of mangrove forests for climate mitigation in themselves support targets of SDG14 (SDG 14.2 and 14.5) and enhance tourism and fish stocks (Joffre et al., 2015; Kibria, 2015; Primavera, 2006; Truong & Do, 2018).

SDG15 – Life on land

As shown under SDG3, most climate-change mitigation measures decrease air pollution and avoid deposition and leakage of pollutants to soil and water bodies. Furthermore, conservation, restoration and sustainable management of the world's ecosystems, such as wetlands, forests, pastures and agricultural land are important climate-change mitigation measures (SDGs 15.1, 15.2, 15.4, 15.5)

(Griscom et al., 2017; Smith et al., 2013; Swart, 2003; van Zeijts et al., 2017). In addition to protecting and restoring natural areas, adopting sustainable agriculture (e.g. lower use of pesticides and nutrients) (Smith et al., 2013) could expand natural habitats and increase biodiversity (IPCC, 2014) (SDGs 15.4, 15.5).

Furthermore, sustainable agricultural practices to reduce GHG emissions, such as no-tillage and direct seeding, prevent soil degradation and desertification (Smith et al., 2013) (SDG 15.3). Nonetheless, not all agricultural practices are beneficial to ecosystems. For example, large scale monocultures of biofuels can lead to deforestation and reduce habitats and biodiversity (Bonsch et al., 2016; Davis et al., 2013; Dias de Oliveira et al., 2005; Finco & Doppler, 2010; von Blottnitz & Curran, 2007). An integration of crops and livestock can reduce environmental impacts, support soil quality and enhance biological diversity as compared to monocultures (Lemaire et al., 2014; Viaud et al., 2018).

Other forms of renewable energy production could also lead to biodiversity trade-offs. For instance, hydropower and tidal/wave energy may substantially change natural habitats and ecosystems (SDGs 15.4 and 15.5) (Gill, 2005; Inger et al., 2009; IPCC, 2014; Neill et al., 2012). Wind turbines could also have significant impact on the bird populations in the vicinity (Schippers et al., 2020). However, in-depth local environmental assessments are necessary to determine net impacts compared to replaced fossil fuels (Athanas & McCormick, 2013; Rybach, 2003; Shortall et al., 2015; Sliz-Szkliniarz, 2013) (SDGs 15.1, 15.4 and 15.5). Rooftop solar PV and wind are likely to be the most benign of energy sources and would likely have a positive overall impact on ecosystems (S. A. Abbasi & Abbasi, 2000). Improved efficiency of cookstoves and heating with biomass can reduce deforestation for timber (Gebreegziabher et al., 2017; Mehetre et al., 2017; ver Beek et al., 2020). On the contrary, fossil fuel CCS would increase demand for fossil fuels and related trade-offs (but will reduce some air pollutants). Finally, CCS, BECCS and nuclear pose risks of CO_2, nutrients and radioactive leakage, as previously discussed, but such risks are likely minor compared to potential negative impacts of fossil-fuel use and related upstream activities (see also SDG 3).

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