Technology Executive Committee 03 November 2020

Twenty-first meeting

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Mapping of emerging climate technologies

Background note

I. Introduction

A. Background

1. At TEC 17 (September 2018), the TEC considered a background paper on possible work of the TEC on the innovation of emerging climate technologies, including zero-emission and negative-emission technologies.[1] The background paper includes definitions and examples of emerging technologies as well as indication of possible work of the TEC and tentative corresponding timeline. TEC 17 agreed to consider undertaking further work on this issue at TEC 18, as part of its next rolling workplan, drawing on the background paper.

2. At COP24/CMA1 (December 2018), the Parties adopted the Technology Framework which, among the activities to be undertaken by the TEC and the CTCN in the area of innovation, includes promoting the development, deployment and dissemination of existing innovative technologies and accelerating the scale-up and diffusion of emerging climate technologies.[2]

3. At TEC 18 and 19 (March and September 2019), the TEC further considered this matter in the context of the discussion about its rolling workplan for 2019-2022. It agreed to *analyse key emerging climate technologies* and to produce in 2020 a *mapping of emerging technologies, including possible scope of TEC work on this matter*.[3]

B. Purpose of the note

4. This background note aims to provide information for the TEC to provide guidance on further work on key emerging climate technologies.

5. The information contained in this note is based on a brief literature review and inputs receive from members of the task force. The note provides information on:

(a) Elements and features that characterize key emerging climate technologies;

(b) Mapping of key emerging climate technologies;

(c) Examples of mappings of emerging climate technologies produced by other organizations;

(d) Elements and questions that may guide TEC’s considerations on possible further work on this matter.

C. Possible action by the Technology Executive Committee

6. The TEC will be invited to consider the background note and provide guidance on further follow-up action by the TEC on this matter, as appropriate.

[1] See https://bit.ly/3jgwyCU.
[2] Decision 15/CMA.1, Annex, paragraph 8(c).
[3] See https://bit.ly/3aKi2jH.

D. Emerging climate technologies

1. Concept of key emerging climate technologies

7. The literature review discovered two definitions that are used to describe emerging technologies. Rotolo, Hicks and Martin describe an emerging technology as:

8. "[A] relatively fast growing and radically novel technology characterized by a certain degree of coherence persisting over time and with the potential to exert a considerable impact. (…) Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous". [4]

9. Furthermore, the World Economic Forum defines emerging technologies as:[5]

(a) "Technologies which arise from new knowledge, or the innovative application of existing knowledge

(b) "Those that lead to the rapid development of new capabilities

(c) "Those that are projected to have significant systemic and long-lasting economic, social and political impacts

(d) "Those that create new opportunities for and challenges to addressing global issues

(e) "Technologies that have the potential to disrupt or create entire industries."

10. While no definition was found for an 'emerging climate technology', from the above definitions it may be concluded that an emerging climate technology is any climate technology that can also be described by one (or both) of the above definitions. Note that in the literature often the words 'emerging', 'breakthrough', 'innovative', 'disruptive', 'new', 'transformational', 'exponential', 'game-changing', and 'revolutionary' were interchangeable.

2. Mapping of key emerging climate technologies

11. A list of mapped key emerging climate technologies is provided in the Annex. The list is non-exhaustive and contains key emerging technologies as identified by the Innovation task force in sectors with potential for climate change mitigation and adaptation, such energy supply, transport and agriculture, as well as technologies relevant to multiple sectors such as carbon removal and digital technologies.

12. The list includes a short description of each technology, and, where possible, basic information on the stage in the technology development cycle, the potential use and impact for climate change mitigation and adaptation as well as potential economic, social and political impacts.

3. Examples of analysis of emerging climate technologies produced by other organizations

13. Many of the institutions whose work is relevant to climate technology (e.g. United Nations organizations, intergovernmental and international organizations, academia and research institutes, private sectors, etc.) are considering the role and potential impact of emerging technologies, including those beneficial in addressing the negative impacts of climate change.

14. Publications including mapping and analysis of emerging technologies have been already produced by several institutions on various sectors and themes (e.g. energy, digital technology, zero-emission and negative emission technologies, etc.). These publications are of different length and complexity and provide different level of analysis about the target emerging technologies, all including key messages and/or recommendation for key stakeholders.

15. To facilitate consideration on this matter, the secretariat has reviewed a sample of such publications that explore how various emerging technologies can be deployed to drive impact on climate change specifically or on a broader set of social, economic and environmental goals. These publications are briefly described in the paragraphs below.

[4] https://arxiv.org/pdf/1503.00673.pdf

[5] http://reports.weforum.org/global-agenda-council-2012/councils/emerging-technologies/

16. **"Digital with purpose: Delivering a SMARTer 2030"**, developed by the Global Enabling Sustainability Initiative and Deloitte.[6] The report explores the relationship between the development and deployment of digital technologies and the achievement of the Sustainable Development Goals (SDGs). It employs an explanatory framework of 'impact functions' to categorise example 'use cases' that illustrate this relationship across each of the 17 SDGs. For each SDG (including SDG 13: Climate action), new quantitative modelling explores the expected contribution of digital technologies to progress against a selection of priority targets, compared to business-as-usual scenario in which the adoption of digital technologies is held constant. Further quantitative analysis explores the impact of the ICT sector on SDGs.

17. **"Energy technology perspectives 2020"**, developed by the International Energy Agency.[7] This edition of the energy technology perspectives (ETP) focuses exploring the opportunities and risks that surround the scaling up of clean energy technologies in the years ahead. It covers different applications of energy technology, including: electrification; carbon capture, utilisation and storage; hydrogen and hydrogen-based fuels; and bioenergy. This ETP sets out where the key technologies stand today, their potential for wider deployment to meet energy policy goals, and the opportunities for and barriers to developing selected new technologies in the coming decades. It also looks at how past experiences can help governments design more effective policies to encourage innovation from research and development to market deployment. In addition, using a system approach it looks at what governments and stakeholders need to do to accelerate the development and deployment of clean energy technologies with a particular focus on those that address multiple policy objectives.

18. **"Frontier technologies to protect the environment and tackle climate change"**, developed by the International Communication Union and a group of UN organizations including UN Environment, UNESCO, UNFCCC, UNGC, UNIDO, UN-Habitat, UN Women and UNECE.[8] The report defines frontier technologies as new, innovative and disruptive technologies. It explores the vast potential of frontier technologies to help assess, mitigate and adapt to climate change. The report collates observations from the real-world deployment of eight key emerging technologies in tackling climate change: artificial intelligence (AI), Internet of Things (IoT), 5G, clean energy technology, digital twins, robotics, Space 2.0 technologies, as well as digitalization and Big Data within cities and urban regions. It offers key observations and considerations on how further exploring the application of frontier technologies to combat climate change at the local level. The report also highlights specific literature, frameworks, standards and programmes developed by UN bodies that aim to foster successful achievement of the SDGs.

19. **"Technology outlook 2030"**, developed by DNV LG.[9] The outlook presents trends and associated technologies before describing their expected impacts on society and industries. Selected technologies are grouped into ten key technology trends and further into three categories: enabling (acceleration of digitalization, virtualization and automation across the life-cycle, and precision materials), transforming (transport and logistics, low carbon energy systems, health data, precision food and space), sustaining (ocean space and other natural ecosystems). For each trend, the outlook focusses on those technologies that have the largest expected economic and societal impact on target industries – Maritime, Oil and Gas, Energy, Healthcare and Food – in the coming decade.

20. **"Global status of CCS 2019"**, developed by the Global CCS Institute.[10] The report provides detailed information on, and analyses of, the global CCS facility pipeline, policy, CO_2 storage and the legal and regulatory environment. It estimates the potential contribution of CCS to climate change mitigation and reducing the emission gap. In addition, four regional updates and a CCS Technology section further address global development and the versatility of CCS across a variety of applications and industry sectors, including natural gas, hydrogen, power sector, bioenergy.

21. **"Agroecological approaches and other innovations for sustainable agriculture and food systems that enhance food security and nutrition"** developed by FAO.[11] The report explores the nature and potential contributions of agroecological and other innovative approaches to formulating

[6] https://gesi.org/platforms/digital-with-a-purpose-delivering-a-smarter2030
[7] https://www.iea.org/reports/energy-technology-perspectives-2020
[8] https://www.itu.int/en/action/environment-and-climate-change/Documents/frontier-technologies-to-protect-the-environment-and-tackle-climate-change.pdf
[9] https://www.dnvgl.com/to2030
[10] https://www.globalccsinstitute.com/resources/global-status-report/
[11] http://www.fao.org/3/ca5602en/ca5602en.pdf

transitions towards sustainable food systems (SFSs) that enhance food security and nutrition. It describes several innovative approaches to SFSs and clusters them in two main categories: (i) sustainable intensification of production systems and related approaches (including climate-smart agriculture, nutrition-sensitive agriculture and sustainable food value chains) that generally involve incremental transitions towards SFSs; and (ii) agroecological and related approaches (including organic agriculture, agroforestry and permaculture) that some stakeholders consider to be more transformative. The report looks at emerging innovative approaches to SFSs that integrate technical interventions, investments and enabling policies and instruments.

22. **"Reaching Zero with Renewables"**, developed by IRENA.[12] The study outlines the best available deep decarbonisation options for energy-intensive industrial sectors (i.e. iron and steel, chemicals and petrochemicals, cement and lime, aluminium) and energy-intensive freight and long-haul transport sectors (i.e. road freights, aviation and shipping). It defines a zero-emission reduction scenario, identifies key challenges and includes recommendations for industry and governments to begin the transition to zero emissions.

23. **"Innovation landscape for a renewable-powered future"**, also developed by IRENA.[13] The report maps and categorises examples of the innovations being developed and implemented globally to facilitate the large-scale integration of variable renewable power. The report aims to give decision makers a clear, easily navigable guide to the diversity of innovations currently under development, or in some cases already in use (e.g. electricity storage, electrification of end-use sectors, digital technologies, news grids, dispatchable generation), in different settings across the globe. The report is augmented by innovation briefs and online resources which permit closer examination of each innovation type.[14]

24. IRENA and IEA also regularly published briefs and focus publications which provide detailed analysis of specific technologies, including information on progress of technology development and transfer as well as recommended actions for faster adoption and diffusion.[15,16] Similar publications are regularly produced by other global organizations and initiatives, such as the World Economic Forum and Mission Innovation.[17,18]

E. Possible scope of the work of the Technology Executive Committee on this matter

25. In considering possible work of the TEC on key emerging climate technologies and taking into consideration the information provided in the sections above, the TEC may wish to consider the following guiding questions:

(a) This note identifies and describes the main elements that characterize emerging climate technologies, according to the identified literature. Is the concept of emerging climate technologies sufficiently described for the TEC to deliberate on further activities of accelerating the scale-up and diffusion of emerging climate technologies? Or should the TEC continue this work by extending the investigation from desk review to stakeholder consultation?

(b) Do the mapped technologies provide sufficient ground for further work of the TEC on this matter? Should the TEC expand the mapping to new technologies? Or should the TEC increase the level of information for all or a selected group of technologies, including by extending the investigation from desk review to stakeholder consultation?

(c) It is crucial for the TEC not to duplicate analysis of emerging climate technologies produced by other organizations and to make its efforts different from what already produced and attractive to different audiences. As the TEC is serving the Paris Agreement, TEC work on this topic could usefully address the potential of emerging technologies to contribute to the "transformational changes envisioned in the Paris Agreement". What are the added values of the work of the TEC activity in this area? What elements can be addressed by the TEC work that have not been covered

12 https://www.irena.org/publications/2020/Sep/Reaching-Zero-with-Renewables
13 https://www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future
14 https://www.irena.org/innovation/Toolbox
15 https://irena.org/publications
16 https://www.iea.org/fuels-and-technologies
17 https://www.weforum.org/reports
18 http://mission-innovation.net/resources/publications/

by other similar exercises? What kind of product(s) does the TEC consider to be the most useful coming out of such an exercise: tools? Road maps? Policy briefs?

Annex

List of mapped key emerging climate technologies

Technology	Sector	Short description	Stage in the technology development cycle	Potential for Mitigation	Potential for Adaptation	Potential economic, social and political impact	References
Airborne wind energy	Energy supply	Airborne wind energy (AWE) is the conversion of wind energy into electricity using autonomous tethered flying devices. Most concepts convert the pulling power of the flying devices over a winch and a generator on the ground, while others combine onboard wind turbines with a conducting tether. Advantages: - Replacing the tower of a wind turbine by a lightweight tether substantially reduces the material consumption by up to 90%; - It exploits stronger winds at higher altitudes, conditions that are usually only available offshore; - AWE allows for continuous adjustment of the harvesting altitude to the best available wind resource; - The decrease in CAPEX due to low material use, the increase in capacity factor, the easier logistics and quick set-up as well as the high power density per km2 can potentially lead to a substantial reduction of the LCOE of wind energy; - AWE systems are scalable from a few kilowatt to several megawatt, many markets and locations can be accessed like offshore repowering, floating offshore, mountainous and remote locations. Today, about 20 original equipment manufacturers are developing AWE technologies, and worldwide more than 50 research institutes, universities, industrial associations, companies along the supply chain, and utilities are involved in the sector at different levels.	RD&D. Several companies planning to commercialize their systems by 2025.	High. Not yet quantifiable	Low.	Electrification of rural areas. Avoid land use and social acceptance issues faced by other variable renewables. New employment opportunities.	https://airbornewindeurope.org/ https://www.researchgate.net/publication/324134941_Emergence_and_Economic_Dimension_of_Airborne_Wind_Energy
Floating wind systems	Energy supply	Floating offshore wind is a fast maturing technology that could harness untapped wind resources located in regions with water depths exceeding 50-60 m where traditional fixed-bottom offshore wind installations are not economically attractive. The industry is adapting various floating foundation technologies that have already been proven in the oil and gas sector, though design modifications are still required. In recent years, there have been significant developments in floating offshore wind projects including the commissioning of the world's first multi-unit installation in 2017 (30 MW Hywind in Scotland). A number of smaller demonstration projects were installed in 2018, including	Pre-commercial. Projections indicate that floating offshore wind could be deployed at the utility scale by 2024.	High. Floating turbines could unlock enough potential to meet the world's total electricity	Low	Electrification of coastal zones. Protection of marine ecosystem. Avoid land use and social acceptance issues faced by other	https://www.iea.org/reports/offshore-wind-outlook-2019 https://www.nrel.gov/news/program/2020/floating-offshore-wind-rises.html https://windeurope.org/wp-

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		Floatgen in France (2 MW) and Hibiki in Japan (3 MW). In addition, at least ten new pre-commercial scale projects in Europe are in the pipeline (WindEurope, 2017), including the 30 MW WindFloat Atlantic in Portugal and the 48 MW Kincardine in Scotland. Equinor also received approval in 2019 to build a 200 MW project off the coast of the Canary Islands which is expected to be the world's largest when it begins operations in the mid-2020s. These pre-commercial and commercial-scale projects should help to establish more firmly the costs of floating foundations. Similar undertakings are under assessment for offshore substations.		demand 11 times over in 2040		variable renewables. New employment opportunities.	content/uploads/files/policy/position-papers/Floating-offshore-wind-energy-a-policy-blueprint-for-Europe.pdf https://www.irena.org/publications/2016/Oct/Innovation-Outlook-Offshore-Wind
Floating photovoltaic systems	Energy supply	The electrical configuration of a floating PV (FPV) system is similar to that of a land-based PV system, except the PV arrays and often the inverters float on water. FPV systems can be installed on a wide variety of water bodies such as industrial ponds, hydropower reservoirs, agricultural ponds as well as other types of man-made water bodies like flood control reservoirs. All these applications are mainly inland freshwater bodies. However, FPV systems can also be built offshore or near-shore. Demand for floating PV is expanding, especially on islands (and other land-constrained countries), because the cost of water surface is generally lower than the cost of land. The ecosystem of floating photovoltaic (FPV) power is similar to that of other PV applications, with the addition of suppliers of float systems. Because off-shore applications are still limited to date, suppliers in this segment have not reached the threshold of 5 MWp of installed capacity. However, this could change in the near future. FPV deployment is expected to be cost-competitive under many circumstances and therefore not to require financial support. Nevertheless, initial projects may require some form of support to overcome barriers associated with the industry's relatively limited experience with this technology. FPV could double the existing installed capacity of solar PV but without the land acquisition that is required for ground-mounted installations.	Commercial. As of the end of September 2018 the global cumulative installed capacity of floating PV plants was 1.1 GW. The world's top ten plants are located in Asia, namely China, Japan and the Republic of Korea.	High. Estimated total capacity potential between 404 and 4,044 GWp depending on % of water surface used (from 1% to 10%).	Low.	Water saving due to reduced evaporation from reservoirs. Improvements in water quality, through decreased algae growth. Utilization of stranded production sites (e.g. flooded mines). New employment opportunities.	https://openknowledge.worldbank.org/bitstream/handle/10986/31880/Floating-Solar-Market-Report.pdf?sequence=1&isAllowed=y https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Nov/IRENA_Future_of_Solar_PV_2019.pdf

Technology	Sector	Short description	Stage in the technology development cycle	Potential for Mitigation	Potential for Adaptation	Potential economic, social and political impact	References
Wave power systems	Energy supply	Wave energy converters capture the energy contained in ocean waves and use it to generate electricity. There are three main categories: - oscillating water columns that use trapped air pockets in a water column to drive a turbine; - oscillating body converters that are floating or submerged devices using the wave motion (up/down, forwards/backwards, side to side) to generate electricity; and - overtopping converters that use reservoirs to create a head and subsequently drive turbines. Due to the limited commercial experience, the estimates for levelized cost of electricity (LCOE) of wave energy technologies in 10 MW demonstration projects is in the range of EUR 330-630 /MWh. However, there is considerable scope for economies of scale and learning, with the projected LCOE for wave energy in 2030 estimated to be between EUR 113-226/MWh if deployment levels of more than 2 GW are achieved. The wave regimes vary substantially across the different regions, resulting in a wide variety of technologies. Consequently, there is a lack of industrial cohesion and limited supply chains for the variety of components required. For both planning and technology development purposes, synergies with other offshore industries would be advantageous to the wave energy industry. Similarly, there are opportunities to create more dedicated infrastructures – including ports and transmission grids – to support the installation and operation and maintenance of wave energy converters. More than 100 pilot and demonstration projects exist throughout the world, but only a handful of technologies are close to commercialization. The next step on the road to commercialization is the demonstration of wave energy farms in the range of 10 megawatts (MW). Many activities are also around ocean energy powering small scale devices for other end use sectors such as ocean observatory, underwater vehicle charging, devices in oil and gas platforms.	Demonstration.	High. With 2% of the world's 800 000 kilometre (km) of coastline exceeding a wave power density of 30 kilowatt per meter (kW/m), the estimated global technical potential is about 500 gigawatt electrical energy (GWe) based on a conversion efficiency of 40%.	Low.	Reduction of reliability on fossil fuel import for small islands states. Job and economic development in coastal areas.	https://www.irena.org/documentdownloads/publications/wave-energy_v4_web.pdf https://www.oceanenergy-europe.eu/wp-content/uploads/2019/04/ETIP-Ocean-Integrated-Strategy-2019-LR.pdf

Technology	Sector	Short description	Stage in the technology development cycle	Potential for Mitigation	Potential for Adaptation	Potential economic, social and political impact	References
Bioenergy with carbon capture and storage (BECCS)	Carbon removal	BECCS involves the utilisation of biomass as an energy source and the capture and permanent storage of CO2 produced during the conversion of biomass to energy. BECCS can include a variety of industries, biomass feedstocks and methods of energy conversion. In all instances, the atmospheric CO2 absorbed by plants and trees as they grow, and the CO2 released in the production of bioenergy is captured before it reaches the atmosphere and stored in geological formations deep underground on very long-time scales. Negative emissions are possible if the CO2 stored is greater than the CO2 emitted during biomass production, transport, conversation and utilisation. BECCS is applied in two overarching methods according to the utilisation of the biomass: - combustion (directly uses biomass as a fuel source to produce heat for use in electricity generation or industrial applications); and - conversion (conversion of biomass through either digestion or fermentation to produce gaseous or liquid fuels). Presently, BECCS applications tend to involve the capture of fermentation CO_2 from ethanol plants. Fermentation CO_2 is high purity and typically only requires dehydration before it can be compressed for transport and storage. This makes it a very low-cost CO_2 source for capture. Waste to Energy (WtE) plants are another area of growth potential for BECCS. If a WtE plant is able to capture and store a higher proportion of its CO_2 than its fossil-fuel based CO_2 production (i.e. plastics) then the plant's overall emissions will become negative. This will make the plant a net reducer of atmospheric GHGs, a source of useful heat and power, and a way to reduce the burden on limited landfill space.	Demonstration. Currently, five facilities around the world are actively using BECCS technologies. Collectively, these facilities are capturing approximately 1.5 million tonnes per year (Mtpa) of CO2.	High. It depends on climate mitigation scenarios. The most widely used average for BECCS contribution in the literature is 3.3 gigatonne per annum (Gtpa) CO2 in 2100 derived from the IPCC's last full Climate Change Assessment Report in 2014.	Low	Need to ensure social and political acceptance of CCS due to geological CO_2 storage. Just job transition for communities reliant on emissions intense industries. New employment opportunities.	https://www.globalccsinstitute.com/resources/publications-reports-research/bioenergy-and-carbon-capture-and-storage/ https://www.ipcc.ch/sr15/ https://www.ipcc.ch/srccl/
Direct air capture (DAC) with carbon capture and storage	Carbon removal	Direct Air Capture (DAC) is a modular technology that can capture CO2 directly from the atmosphere using chemicals that bind or stick to it. CO2 can then be stored or repurposed into CO2 re-use applications, such as manufacture of construction aggregates, plastics and synthetic fuels. There are two promising groups of DAC technologies: - Large infrastructural DAC using water solutions containing hydroxides to extract CO2 from the air. It requires high temperatures (greater than 800°C) for regeneration, which tends to be provided by burning natural gas. - A modular technology based on amine materials bonded to a porous solid support. The process operates at 85°-120°C requiring far less heat energy. There is potential for future cost reductions through mass production.	Demonstration.	High. It depends on climate mitigation scenarios. Two pilot facilities in USA have each a capacity to remove 3,000-4,000 tonnes of CO2 per	Low.	Need to ensure social acceptance, when coupled with geological CO_2 storage. Substantially more expensive than CO2 capture from more concentrated point sources.	https://www.globalccsinstitute.com/wp-content/uploads/2020/06/JF_ICEF_DAC_Roadmap-20181207-1.pdf

Technology	Sector	Short description	Stage in the technology development cycle	Potential for Mitigation	Potential for Adaptation	Potential economic, social and political impact	References
		Compared to other forms of negative emissions (carbon dioxide removal i.e. trees), DAC facilities require little land. There are however, concerns about its requirement for large amounts of water and energy to extract low concentration CO2 from the atmosphere. Some estimates capture cost at USD 500-700 per tonne of CO2 stored, that can be brought down to approximately USD 100 per tonne of CO2 stored.		year.		Issue of land and construction material availability due to plant size.	
Green hydrogen	Transport Industry Energy supply	Demand for pure hydrogen is around 70 Mt per year, mostly for oil refining and chemical production. This hydrogen currently is produced from natural gas and coal, and associated CO2 emissions are significant. (SMR) is the most common way of producing hydrogen. Developing low-carbon hydrogen production routes is critical for hydrogen to aid in clean energy transitions. The most established technology options for producing hydrogen from renewable energy sources are: - Coupling SMR with CCUS; and - Generating hydrogen through water electrolysis using renewable energy. Three main electrolyser technologies are used or being developed today: alkaline (ALK) and proton exchange membrane (PEM) electrolysers and solid oxide electrolyser cell (SOEC). Less mature pathways are biomass gasification and pyrolysis, thermochemical water splitting, photocatalysis, supercritical water gasification of biomass, and combined dark fermentation and anaerobic digestion. Hydrogen can help further deployment of renewable energy in hard-to-electrify sectors: transport (fuel cell electric vehicles), industry (chemical plants, refineries, iron and steel) and those relying on existing gas grids, such as buildings and power. Key hydrogen technologies are maturing. Scale-up can yield the necessary technology cost reductions. A policy and regulatory framework to encourage the appropriate private investment is critical.	Commercial (ALK and PEM electrolysis, and SMR). Demonstration (SOEC) Applied research / prototype (Biomass gasification and pyrolysis, thermochemical water splitting, photocatalysis, supercritical water gasification of biomass, combined dark fermentation and anaerobic digestions)	High. 18 % of global final energy demand could be met by hydrogen, equal to about 78EJ. The corresponding abatement potential represents 6 gigatonnes of CO_2 annually.	Low.	Decarbonization of emission intensive sectors. Improvement of air quality and outdoor pollution. Versatility, possibility of use in a wide range of applications. Need for demonstration of the safety case for new applications, especially in the domestic and industrial sectors	https://www.irena.org/publications/2019/Sep/Hydrogen-A-renewable-energy-perspective https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power https://www.iea.org/reports/hydrogen https://www.iea.org/reports/the-future-of-hydrogen

Technology	Sector	Short description	Stage in the technology development cycle	Potential for Mitigation	Potential for Adaptation	Potential economic, social and political impact	References
Next generation batteries	Energy supply Transport	Global battery demand is expected to grow by 25% annually to reach 2,600 GWh in 2030. Batteries play an increasingly important role in three areas: 1) decarbonizing transport through electrification; 2) enabling the shift from fossil fuel to renewable power generation as a dispatchable source of electricity; and 3) helping to provide access to electricity to off-grid communities. This means batteries can fundamentally reduce GHG emissions in the transport and power sectors, which currently comprise roughly 40% of global GHG emissions and contribute to the UN SDGs. Lithium-ion technologies are the fastest growing form of battery on the worldwide market, with the potential to dominate the market in the short term. Yet, they struggle to hold a full charge for longer than four hours and their storage capacity noticeably reduces over time. Numerous opportunities exist to tackle a range of environmental pressures currently exerted by batteries, these include: - Using non-toxic, abundant materials (e.g.: lithium-sulphur, lithium-air, sodium-ion); - Increasing energy density (or energy storage capacity); - Powering battery plants with clean sources of energy; - Extending battery lifespan; - Improving charging efficiency (‘roundtrip efficiency’); and Enabling ease of recycling and re-use at end-of-life by embracing ‘design for disassembly’ principles. The sustainable expansion of the battery value chain offers many environmental, social and economic benefits. It will, however, not be achieved without an active shift from the current development trajectory. This requires coordinated, immediate actions by companies, investors and policymakers, in consultation with all stakeholders.	R&D.	High. (0.4 GtCO2 emissions reduction in transport and contribute to enable renewables as a reliable source of energy to displace carbon-based energy production, which will avoid 2.2 GtCO2 emissions – together roughly 30% of required emission reductions in these sectors until 2030)	Low.	Increased access to electricity in off-grid remote areas. Environmental benefits due to more efficient use of raw materials, reduced impacts of pollutants on human health and nature. New job opportunities in key industries (manufacturing, automotive, energy, digital technology). Reduction of social issue due to metal mining (e.g. cobalt).	http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf https://ec.europa.eu/environment/integration/research/newsalert/pdf/towards_the_battery_of_the_future_FB20_en.pdf https://www.rechargenews.com/transition/seven-emerging-technologies-that-will-be-vital-for-fighting-climate-change/2-1-727169 https://battery2030.eu/digitalAssets/816/c_816048-l_1-k_roadmap-27-march.pdf

Technology	Sector	Short description	Stage in the technology development cycle	Potential for Mitigation	Potential for Adaptation	Potential economic, social and political impact	References
Thermal energy storage	Energy supply	Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are used particularly in buildings and industrial processes. TES is becoming particularly important for electricity storage in combination with concentrating solar power (CSP) plants where solar heat can be stored for electricity production when sunlight is not available. There are three kinds of TES systems, namely: 1) sensible heat storage that is based on storing thermal energy by heating or cooling a liquid or solid storage medium (e.g. water, sand, molten salts, rocks), with water being the cheapest option; 2) latent heat storage using phase change materials or PCMs (e.g. from a solid state into a liquid state); and 3) thermo-chemical storage (TCS) using chemical reactions to store and release thermal energy. Sensible heat storage is relatively inexpensive compared to PCM and TCS systems and is applicable to domestic systems, district heating and industrial needs. However, in general sensible heat storage requires large volumes because of its low energy density (i.e. three and five times lower than that of PCM and TCS systems, respectively). Thermal energy storage systems can be either centralised or distributed systems. Centralised applications can be used in district heating or cooling systems, large industrial plants, combined heat and power plants, or in renewable power plants (e.g. CSP plants). Distributed systems are mostly applied in domestic or commercial buildings to capture solar energy for water and space heating or cooling. In both cases, TES systems may reduce energy demand at peak times. Support for research and development (R&D) of new storage materials, as well as policy measures and investment incentives for TES integration in buildings, industrial applications and variable renewable power generation is essential to foster its deployment.	Commercial (TES systems, PCM systems in building) RD&D. (PCM systems for industry and CSP, TCS systems).	High. Not yet quantifiable, varying depending on system and application.	Low.		https://www.irena.org/publications/2013/Jan/Thermal-energy-storage https://www.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Compact-Thermal-Storage-Position-Paper.pdf

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Blockchain - Distributed ledger technologies (DLT)	Digital technology	Blockchain technology, or more generally Distributed Ledger Technology (DLT), introduces new and innovative form of decentralized database that enables a secure exchange and storage of data and digital assets, primarily designed for peer-to-peer transaction platforms. Blockchain holds the most potential to accelerate climate action in three main areas based on the unique needs of the Paris Agreement: 1. Next-generation registries and tracking systems: - Interoperability of emission reduction registries with other databases, such as for example GHG inventories; that would also help avoidance of double counting of emission reduction; - Linking of carbon pricing mechanisms and markets; 2. Digitizing Measuring, Reporting and Verification (MRV): - Increased access to existing data sets and aggregation of data; - Real time monitoring of key issues; 3. Decentralized access to clean energy and finance: - Help to mobilize corporate demand and respective finance; - Smart contract, where consumers are transformed into active participants in the market, able to buy and sell their electricity directly. Despite a very fast development of blockchain and related technologies by start-ups but also by many large corporations, many governments and regulation struggle to keep pace with the technical developments. This underscores the need to inform and engage policymakers in co-shaping the future systems of blockchain based credits and value transfer.	RD&D.	Not yet quantifiable.	Not yet quantifiable.	Increased speed, transparency and traceability of transactions and services in multiple contexts (e.g. commodity trading, decentralised energy generation, etc.). Improved security and trust of digital identities. Easier access to online services (e.g. baking services) for larger groups of global population. More secure, verifiable, transparent, and immutable registries (e.g. land registries, carbon credit registries, etc.)	https://www.irena.org/publications/2019/Sep/Blockchain https://www.undp.org/content/undp/en/home/librarypage/corporate/the-future-is-decentralised.html https://www.climateledger.org/resources/CLI_Report-2019-State-and-Trends.pdf https://www.climateledger.org/resources/CLI_Report-January19.pdf https://gesi.org/platforms/digital-with-a-purpose-delivering-a-smarter2030
Precision agriculture	Agriculture	Precision agriculture, or precision farming, aims to improve the accuracy and control in farm management to increase environmental performance and yields, while reducing inputs and costs. Precision agriculture leverages information technology and a wide array of technologies, divided into three main categories: - Guidance systems (i.e., hard- and software that guide tractors and implements over a field), which include all forms of automatic steering/guidance for tractors and self-propelled agricultural machinery, such as driver assistance, machine guidance, controlled	Varying from RD&D to commercialization depending on type of technology.	Significant. Not yet quantifiable.	High.	Increase yields and farmers' income. Better working conditions. Increased animal welfare.	https://www.dnvgl.com/to2030/technology/precision-agriculture.html http://www.fao.org/3/I8429EN/i8429en.pdf https://www.europarl.

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		traffic farming; - Recording technologies (i.e., sensors mounted on ground-based stations, rolling, airborne or satellite platforms, and gathering spatial information), which include soil mapping, soil moisture mapping, canopy mapping, yield mapping, etc.; and - Reacting technologies (i.e., implements, hard- and software that together can vary the placement of agricultural inputs in the field), which include technologies such as variable rate irrigation and weeding and variable rate application of seeds, fertiliser and pesticides. The rising population's huge demand for food, in combination with changing weather conditions induced by climate change and governmental initiatives towards adopting modern environmentally friendly agricultural processes, are expected to drive the precision agriculture market globally. The largest impact will be seen in countries with developed economies and large farmlands, notably in Europe and in the US. Little or no impact is expected to be seen in developing countries where about two-thirds of the 475 million farm households are smaller than 2 hectares. All categories of PATs (guidance, recording, and reacting) contribute to the reduction of GHG emissions due to their interconnections and it is difficult to separate them according to importance.				Reduced environmental pressure on soil and natural resources.	europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN.pdf https://www.mdpi.com/2071-1050/9/8/1339/pdf
Cellular agriculture	Agriculture	Cellular agriculture is the emerging field of producing animal products from cell culture, rather than animals. This field builds on advances in biotechnology, and currently informs food science of protein-containing products such as milk and eggs, as well as tissue-based foods such as meat and fish. Other commonly used terms include clean, in vitro, lab-grown, or synthetic meat. Reducing the environmental impacts of meat production, and particularly GHG emissions, is generally highlighted as a significant potential advantage of cultured meat. When compared to other industries, animal-based products have a larger environmental footprint compared to plant-based products in terms of soil and water demand, and greenhouse gas (GHG) emission, with the beef industry imparting the heaviest environmental impact. Livestock sector is estimated to be responsible for 14.5% of GHG emissions and taps 30% of Earth's terrain and 8% of the global freshwater. With an expected doubling of the global demand for meat by 2050, traditional meat production systems cannot be considered sustainable.Models suggest that the scale of cattle production required for high levels of beef consumption would result in significant global warming, but it is not yet clear whether cultured meat production would provide a more climatically sustainable alternative. The climate impacts of cultured meat is associated to the energy consumed for its	RD&D.	Not yet quantifiable.	Not yet quantifiable.	Consumer reluctance to replace conventional with cultured meat. Overcoming of some ethical problems associated with livestock production. Reduced environmental pressure on soil and natural resources.	https://www.frontiersin.org/articles/10.3389/fsufs.2019.00005/full https://www.researchgate.net/publication/279514998_Meat_Alternatives_Life_Cycle_Assessment_of_Most_Known_Meat_Substitutes

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		production; cultured meat is not prima facie climatically superior to cattle; its relative impact instead depends on the availability of decarbonized energy generation and the specific environmental footprints of the production systems. Consumer acceptance and confidence in in vitro produced cultured meat might be a significant impediment that hinders the marketing process.					
Electric road systems	Transport	Electric road system (ERS) is defined as a system that provides dynamic electric vehicle charging through either conductive or inductive (wireless) means for various types of vehicles on roads and highways. Dynamic on-road charging also enables the use of electric powered Heavy Goods Vehicles (HGVs) which is currently not feasible with statically charged battery technology (although vehicle manufacturers are working on this). There are a number of different types of ERS technology being developed and trialled, all of which will require the participation of the road infrastructure owners for deployment. Currently available ERS may be split into three categories: - inductive (wireless), which uses a magnetic field to provide the energy with a magnetic field generator installed in the roadway and a receiver installed under the vehicle; - conductive rail installed in the road to provide the needed energy; and - conductive overhead, which uses conductive wire lines above the vehicle to provide the energy and a power receiver installed on top of the vehicle. The three conceivable energy supply systems are all still in the development phase, and the various solutions have different levels of maturity. In general, the overhead line concept is currently the most mature technology and system prototype demonstrations have occurred in an operational environment, particularly for long-haul trucks transportation. Concerns arise over the impact of any type of system that is integrated	R&D.	High. Not yet quantifiable. (It is estimated a >7 million t of CO_2 savings per year if 30% of truck traffic on German highways is electrified and supplied with renewables).	Not quantifiable.	Reduced air pollution as well as reduced noise in urban environments. Safety issues due to exposed rail solutions and magnetic fields from inductive solutions.	http://www.diva-portal.org/smash/get/diva2:1301679/FULLTEXT01.pdf https://www.mobility.siemens.com/global/en/portfolio/road/ehighway.html https://www.trafikverket.se/contentassets/2d8f4da1602a497b82ab6368e93baa6a/piarc_elvag.pdf

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		into the pavement structure, regarding durability, future maintenance and safety. Robust assessments of system specific strengths and weaknesses, and credible validations of infrastructure costs estimates need further studies and advanced demonstrations in operational environments.					
Artificial intelligence and machine-learning	Digital technology	Artificial Intelligence (AI) and machine learning (ML), like most technology, have the potential to help in the fight against climate change. They can make systems more efficient (e.g. prevent electricity loss during transmission), enable remote sensing and automatic monitoring (e.g. pinpoint deforestation, gather data on buildings, and track personal energy use), provide fast approximations to time-intensive simulations (e.g. climate models and energy scheduling models), and has the potential to lead to the development of interpretable or causal models (e.g. for understanding weather patterns, informing policy makers, and planning for disasters). UN Environment has identified six major categories where artificial intelligence can contribute to climate action: 1. Automated dection and monitoring (emissions; RE potential; climate-related hazards); 2. Risk assessments and impact modelling (security, species/ecosystem distribution; insurance) 3. Predictive analytics, forecasting and scenarios for decision-support (solar/clouds; temperature; agriculture; water; air quality); 4. Optimization of energy and materials use (Smart cities, agriculture, electrical grids/load management; product design; supply chains on carbon intensity; oil and gas reserve); 5. Consumer awareness and behavior nudging (calculation of carbon footprint; peak load periods);	RD&D.	High. (Estimates project a GHG emissions reduction worldwide by 4 per cent, equivalent to the 2030 annual emissions of Australia, Canada and Japan combined)	High.	Improved monitoring of changes in ecosystems and biodiversity. Better design and maintenance of infrastructures (e.g. buildings, roads, power lines, etc.). More precise forecast systems and faster disaster and response.	https://www.climatechange.ai/ https://arxiv.org/pdf/1906.05433.pdf https://www.itu.int/en/action/environment-and-climate-change/Documents/frontier-technologies-to-protect-the-environment-and-tackle-climate-change.pdf

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		6. Quality control (Fake news/fake data; hackers and gaming the system). It has been estimated, for instance, that 'using AI for environmental applications could boost the global economy by up to USD 5.2 trillion in 2030, a 4.4 per cent increase on the business-as-usual scenario. ML and AI will require large amounts of computing power . Decarbonization of the energy system to ensure that AI and ML can fulfil their sustainability potential is a crucial factor. Studies are showing that typical current ML processes can 'emit more than 626 000 pounds of carbon dioxide equivalent (CO2e) – nearly five times the lifetime emissions of the average American car (and this includes manufacture of the car itself.					
Clean steel production	Industry	While the energy intensity of steel has gradually fallen since 2009, expanding production from 2009 to 2014 raised total energy demand and CO2 emissions. Short-term CO2 emissions reductions could come largely from energy efficiency improvements and increased scrap collection to enable more scrap-based production. Longer-term reductions would require the adoption of new direct reduced iron (DRI) and smelt reduction technologies that facilitate the integration of low-carbon electricity (directly or through electrolytic hydrogen) and CCUS, as well as material efficiency strategies to optimise steel use. Today, a large number of promising breakthrough technology projects are ongoing in different parts of the world. Approaches differ and can be categorised as follow: - Hydrogen as a reducing agent - Avoids carbon and uses hydrogen to reduce iron ore, thereby averting the creation of CO2, and producing H2O (water) instead. - Carbon Capture and Storage (CCS) - Generates a clean and concentrated CO2 stream that can be captured and stored. The process involves retrofitting steel plants with capture technology and requires the development of transportation networks and access to storage sites. - Carbon Capture and Utilisation (CCU) - Uses the components of the co-product gases from existing processes to produce fuels or input material for the chemical industry. - Biomass as a reducing agent - Can partially substitute coal for biomass such as charcoal. - Electrolysis – Reduces iron ore using electricity. Every one of these technologies will have a role to play in cutting CO2 emissions. Governments can help by providing RD&D funding, creating a market	RD&D.	High.	Low.	Need to ensure social acceptance, when coupled with geological CO_2 storage.	https://www.iea.org/reports/iron-and-steel https://www.worldsteel.org/en/dam/jcr:0191b72f-987c-4057-a104-6c06af8fbc2b/fact%2520sheet_climate%2520mitigation_2019_vfinal.pdf https://www.worldsteel.org/en/dam/jcr:7ec64bc1-c51c-439b-84b8-94496686b8c6/Position_paper_climate_2020_vfinal.pdf

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		for near-zero-emissions steel production, adopting mandatory CO2 emissions reduction policies, expanding international cooperation and developing supporting infrastructure.					
Agroecology	Agriculture	Agroecological represents an emerging transdisciplinary field that includes all the ecological, sociocultural, technological, economic and political dimensions of food systems, from production to consumption. It embraces a set of practices (e.g. climate smart agriculture, organic agriculture, agroforestry, regenerative agriculture, permaculture, sustainable intensification, integrated water management, farmer managed seed systems, etc.) that harness, maintain and enhance biological and ecological processes in agricultural production, in order to reduce the use of inputs that include fossil fuels and agrochemicals and to create more diverse, resilient and productive agroecosystems. Agroecology combines traditional and modern scientific knowledge in innovative ways that integrate technologies in “hard” forms (e.g. new irrigation systems, drought-resistant seeds, etc.), with “soft” technologies (e.g. insurance schemes, crop rotation patterns, etc.) and ‘orgware’ (e.g. institutional arrangements). The integration of all these aspects requires site-specific assessments to identify suitable and context-specific production technologies and practices. There has been much less investment in research on agroecological approaches than on other innovative approaches, resulting in significant knowledge gaps including on: relative yields and performance of agroecological practices compared to other alternatives across contexts; how to link agroecology to public policy; the economic and social impacts of adopting agroecological approaches; the extent to which agroecological practices increase resilience in the face of climate change; and how to support transitions to agroecological food systems, including overcoming lock-ins and addressing risks that may prevent them.	RD&D.	High. Not yet quantifiable.	High.	Increased and stabilized farmers’ incomes. Protection of local agricultural, ecological and cultural heritage. Inclusiveness of women, local communities and indigenous people. Promotion of circular economy models. Reduced environmental pressure on soil and natural resources.	http://www.fao.org/3/ca5602en/ca5602en.pdf http://www.ipes-food.org/_img/upload/files/IPES-Food_FullReport_WA_EN.pdf file://programme.unfccc.int%40ssl/DavWWWRoot/drive/FTC/files/U_Technology/TEC/Task%20forces/1.%20Innovation%20(2019-2022)/2%20-%20RDD/2b%20-%20Mapping%20of%20emerging%20technologies/Literature/Agroecology/Agroecology%20Booklet_digital_links.pdf