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Technology and Climate Change

Sustainability Industry Report

The Al-Attiyah Foundation

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There is general recognition that technological breakthroughs will play a key role in climate change mitigation and adaptation. New technologies are required to expand the scope of low-carbon energy, facilitate atmospheric carbon removal, tackle hard-to-abate sectors, and deal with the unavoidable impacts.

What are some of the promising technologies in the medium to long-term? What policy instruments are needed to fast track the development of necessary technologies for combating climate change?

SUSTAINABILITY REPORT

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current sustainability topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available on the Foundation's website.

- Global investments to date in climate change technology have given more attention to mitigation in preference to adaptation. Technological innovation and R&D are more focussed on mitigation in the energy sector than in others (such as agriculture), while adaptation takes a backseat.
- There are few estimates for how much adaptation technologies can contribute to the Paris Agreement goals and lack proper and detailed assessment in comparison to emissions pathways for mitigation technologies.
- Adaptation strategies that target "baked in" climate impacts can highlight the benefits to human welfare, thereby generating support for climate action plans (CAPs) and national adaptation plans (NAPs) and bolstering policy objectives of reducing global emissions.
- The US Green New Deal and the EU Green Deal are examples of such policy approaches that link adaptation benefits with mitigation objectives to increase overall mitigation action.
- Focussing effectively requires separating techno-optimist goals that cannot be achieved from those that can. The achievable goals can then be divided into those which require more research and pilots, and those which are ready for full-scale commercial deployment to bring down costs. Some technologies may be broadly compatible with existing systems; others require wider infrastructural or even socio-economic change.
- Robust policy and the transfer of knowledge between existing networks (communities and cities, or cross-border) can enable the diffusion of climate technologies at scale, bringing down costs; and facilitate the localisation of raw materials for technology manufacture, which can be particularly beneficial in developing precious metals-free and/or rare earth elements-free climate technologies.
- Policies that highlight the valuable integration of mitigation and adaptation technologies employ spatial theory and landscape approaches to guide climate action.
- The oil and gas industry is the perfect example of a sector at the crossroads of both climate change mitigation and adaptation technologies. It can be the harbinger of various socio-economic benefits to communities at operation sites through a number of adaptation technologies that can also support mitigation.

The perceived wisdom for how to approach climate targets has changed several times over the past three decades[i]. From initial ideas of climate stabilisation, suggested approaches have focussed on a percentage-based cut in CO_2 emissions; atmospheric CO_2 concentrations; carbon budgets; and today's dominant framing of temperature rise limits (though these depend on greenhouse gas concentrations, with a somewhat uncertain relationship)[ii].

Across all these approaches technology has been recognised as an essential enabler of climate action. Alongside this reframing, a simultaneous improvement in technological (and scientific) representation of mitigating and adapting to climate change has also taken place, be it through enhanced modelling power, data, and capacities; or better technological innovation.

Climate change technologies received a major impetus in 2010 in the form of post-financial crisis stimulus packages in the US and EU that encouraged a shift to greener technologies (although they had been gaining in global attention since the 1970s when modern renewables appeared on the scene, and when carbon pricing and CCS emerged in Norway in the 1990s). Around the same time the UNFCCC[iii] established a Technology Mechanism to guide and support the global development and transfer of technologies for mitigating and adapting to climate change[iv].

This was followed by a Technology Framework established under the Paris Agreement with the aim of guiding the linework of the Technology Mechanism in supporting international, national, and subnational institutions to achieve the Agreement's mitigation and adaptation targets[vi] .

The Framework stresses the importance of both mitigation and adaptation for achieving a 1.5°C warming limit target – however, global investments to date have given more attention to mitigation activities in preference to adaptation. This has also been the case with technologies. Technological innovation and R&D are more focussed on mitigation in the energy sector than in others (such as agriculture), while adaptation takes a backseat.

While the number of patented inventions in overall climate technology innovation has increased steadily over the past three decades, it does not correspond to a proportional rise in innovation for climate adaptation in absolute terms. For example, the share of pure adaptation inventions (when considering the total number of patented inventions) in 2020 is nearly the same as in 1999[vii].

Figure 1 Innovation for climate change mitigation and adaptation as a share of total patented innovation[vii]

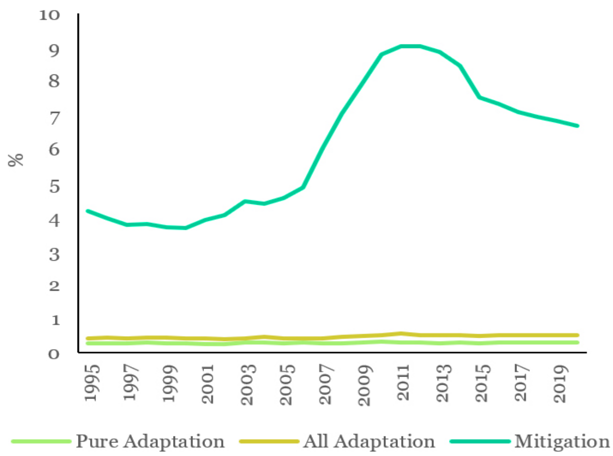


Figure 2 Innovation for climate change adaptation as a share of total patented innovation[viii]

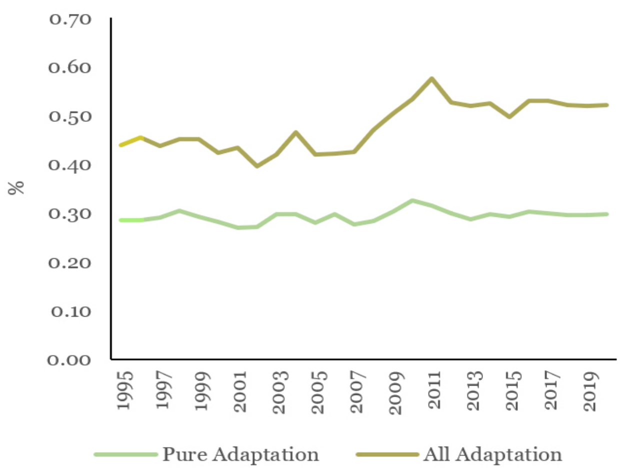


Figure 3 Climate change mitigation and adaptation technology patents in all OECD countries (1990=100)[x]

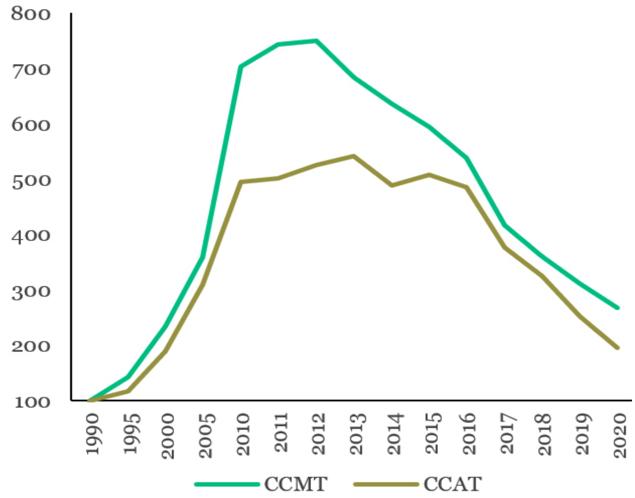


Figure 1 and Figure 2 show the shares of climate change mitigation and adaptation innovation in total patented innovation each year from 1995-2020. Climate change adaptation innovation is considerably lower than the share of climate change mitigation patents over the same period, but maintains a constant rate, particularly for pure adaptation[ix].

This is discouraging because technological progress does not crowd out other forms of innovation. The growing relevance of climate adaptation technologies has seemingly not led to an increase in the proportion of global innovation efforts to develop patented technologies in that field.

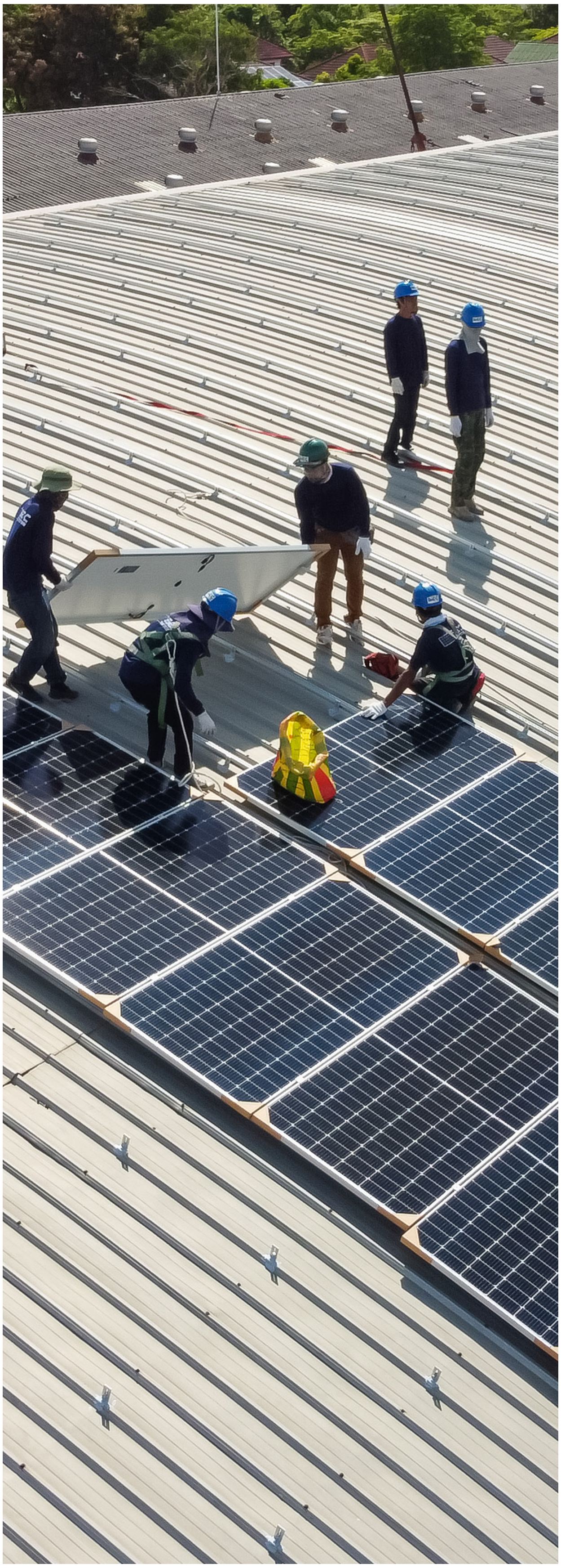
Figure 3 shows technology patents for climate change mitigation and adaptation in all OECD countries till 2020. Although patents for climate change mitigation technologies (CCMTs) remain higher than those for climate change adaptation technologies (CCATs), the gap has narrowed in recent years due to a decline in innovation for mitigation technologies after peaking in the early 2010s.

Major reasons attributed to this decline include the increasing maturity of CCMTs, contributing to a lower propensity to patent. For example, many of the more recent developments that have brought down solar PV costs are likely to be related to improved "know how" in exploiting the innovations from previous years. However, there is less evidence of a drop for some advanced forms of CCMTs, including fuel cell and hydrogen applications for transport[xi].

Another reason is that CCMTs are converging with other fields, including CCATs and digitalisation. This is most apparent in the energy and building sectors, where the rate of penetration of digital (ICT) technologies in CCMTs is extremely high, reducing the number of "pure mitigation" technology patents.

Also of note is that the narrowing of the CCMT-CCAT gap in Figure 3 reflects how most modern-day CCATs include elements of both adaptation and mitigation. For example, recent innovations in most hard infrastructure-based adaptation technologies – such as power plants, road networks, water systems and the like – that have multidecadal shelf lives, can include mitigation co-elements, such as carbon capture, usage of scrap steel, sustainable wood or cement clinker substitutes, biomass-based fuels for operations power, and hybrid construction equipment[xii].

The rise and fall in innovation in CCMTs has previously been linked to oil price fluctuations[xiii], which partially explains how the corresponding dip in innovation in CCATs (including those that facilitate both adaptation and mitigation) in OECD countries could have been susceptible to the extreme oil and energy price volatility of 2020/2021.

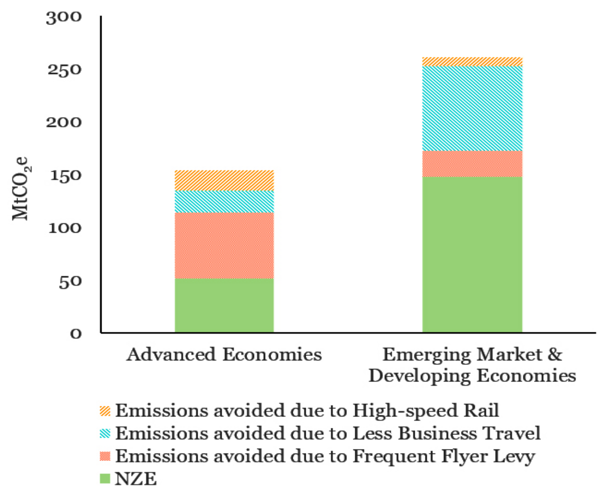


Estimates for how much adaptation technologies can contribute to the Paris Agreement goals are few and lack proper and detailed assessment in comparison to emissions pathways for mitigation technologies.

The IEA estimates in its Net Zero Emissions by 2050 scenario (NZE 2050) that by 2030, "behavioural changes" such as replacing car trips with walking, cycling or public transport, or foregoing long-haul flights, can provide ~9% of the total emissions reductions compared to its Stated Policies Scenario (STEPS)[xiv].

Behavioural changes are also important for climate change adaptation, although these have been studied far less. Cognitive and affective factors, as well as social and cultural factors, are known to motivate or inhibit adaptation behaviour[xv].

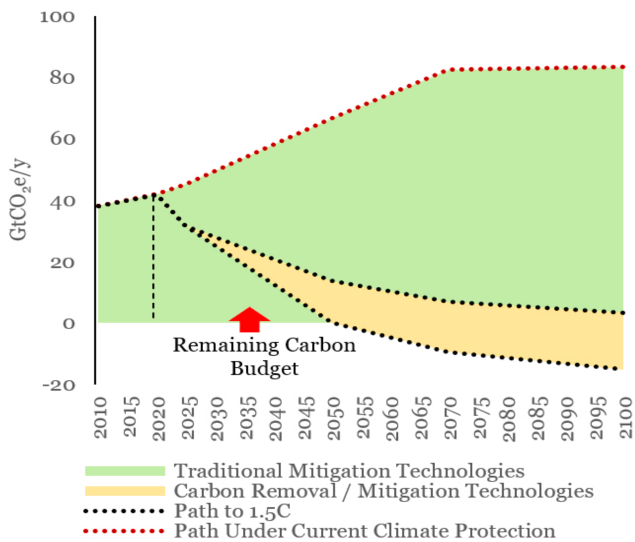
Figure 4 Emissions reduction due to behavioural changes – a form of soft adaptation – in the IEA's NZE Scenario[xvi]



According to the US-based NPO GHG Management Institute, climate action to achieve the Paris Agreement's 1.5°C limit in global temperature rise will be insufficient if, through adaptation, it does not address the "baked in" impacts of accumulated past emissions[xvii], but does not provide an estimate for how much the gap to 1.5°C could actually be narrowed through CCATs.

This is why overall estimates of global climate action efforts in meeting international climate targets and treaties are overwhelmingly based on the impact of mitigation technologies, although it is now recognised that successful adaptation measures can also help countries advance their mitigation goals.

Figure 5 Global emissions reduction pathways for a 1.5°C pathway are overwhelmingly reliant on mitigation technologies[xviii]



For example, adaptation strategies that target "baked in" climate impacts can highlight the resulting benefits to human welfare, thereby generating necessary support for CAPs and NAPs, and bolstering international (and national) policy objectives of reducing global emissions by 45% by 2030 to remain aligned with a 1.5°C pathway.

The US Green New Deal and the EU Green Deal are examples of such policy approaches that link adaptation benefits with mitigation objectives to increase overall mitigation action[xix].

For example, the EU Green Deal's Just Transition Fund assists vulnerable populations to adapt to climate change impacts through CCATs (afforestation and vegetation to sequester carbon, an act which also reduces the risk of floods and heatwaves; residential solar-distributed grid systems to displace fossil fuel sourced-energy that can help keep the lights on when more frequent storms knock down powerlines) that garners public support for mitigation.

Fact Box 1 What are "baked in" climate impacts?[xx]

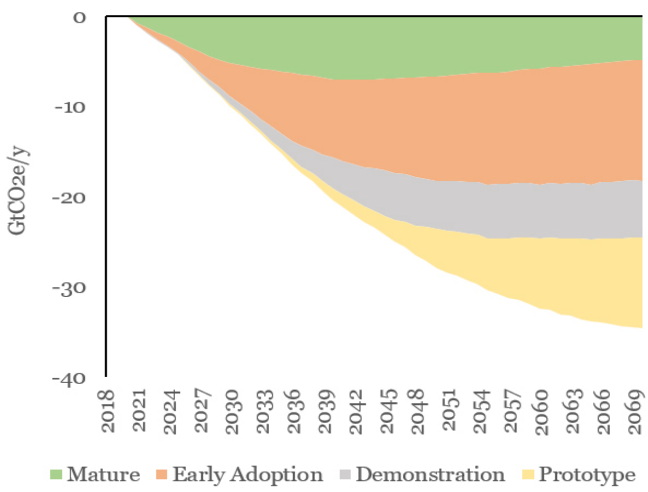
Baked in climate impacts refer to the damage already been done to date by climate change. In other words, if the world reduces CO_2 concentrations to 350 parts per million as of today, it would still have 30 years of baked in climate change related impacts to deal with.

Although there are numerous estimates for emissions reduction through mitigation, not all mitigation technologies are at a level of maturity that will yield the emissions reductions required, even at a 2°C limit pathway.

For example, nearly 25% of the cumulative CO_2 emissions reductions achieved by 2070 in the Sustainable Development Scenario (SDS, compared to STEPS) come from technologies that currently are at a large prototype or demonstration phase (see Figure 6 and Figure 7), and about 40% from technologies that have not yet been commercially deployed on a large scale[xxi].

Their contribution to emissions reductions is even higher in heavy industry and long-distance transport, where commercially available and scalable options for achieving deep emissions reductions are currently limited.

Figure 6 Readiness of technologies to meet the IEA's Sustainable Development Scenario[xxii]



According to the World Economic Forum, half of the emissions reductions needed to reach 2050 climate goals rely overwhelmingly on technologies in early development or prototype stages[xxiii]. This indicates a misalignment between mitigation technology development and subsequent commercialisation and/or maturity of said technology.

The misalignment can be ascribed to an ever-evolving scope for such technologies, including cost competitiveness; effective technological refinement; speed of scale; finance at scale; use of materials (scarce or critical); manufacturing agreements or disagreements; supply chains; and normative shifts to displace incumbents.

Table 1 What is the current scope for new climate change technologies?

Scope	Can be best attained through
Cost Competitiveness	Sustained demand for climate technologies; production efficiencies; aggressive R&D spending; tax rebates and subsidies
Innovation Refinement	Localisation; contextualisation in development; managerial and institutional refinements to deal with heterogeneity in climate
Speed of Scale	Risk guarantees (such as public guarantees); multilateral sovereign guarantee mechanisms; agreed-upon “social value of carbon”
Finance at Scale	Regulatory mandates; pledges from financial sector and large companies; revaluation of cleantech stocks
Alternative Non-Scarce Materials	3D printing; automation tech; non-noble metals, alloys, ceramics; biomaterials; recycling
Manufacturing Agreements	“Learning by doing”; economies of scale

Focussing effectively requires separating techno-optimist goals that cannot be achieved from those that can. The achievable goals can then be divided into those which require more research and pilots, and those which are ready for full-scale commercial deployment to bring down costs. Some technologies may be broadly compatible with existing systems; others require wider infrastructural or even socio-economic change.

Figure 7 The four stages of technology innovation and the feedback and spill overs that improve successive generations of design[xxiv]

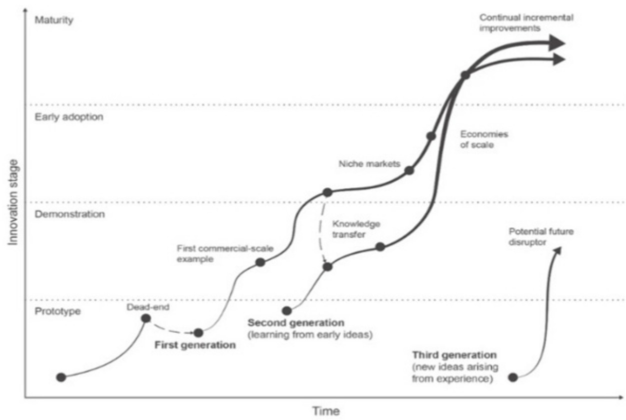


Table 2 in the Appendix describes key climate change mitigation and adaptation technologies by sector and end-use and their technological readiness. While CCMTs broadly cover the mitigation of emissions, CCATs have two distinct types of adapting to climate change: hard technologies and soft technologies.

This categorisation can be further disaggregated into four types: traditional; modern; high technology; and future technology[xxv]. Traditional technology is usually developed in the course of adapting to variable and extreme climatic conditions, meaning that these types of technologies can be improved in consideration of local contexts[xxvi].

The CCATs described in Table 2 are mainly hard, infrastructure-based technologies, with a few soft, strategy and/or attitude-based technologies, mainly in end-use segments like transport, where behavioural shifts are necessary for switching to more sustainable modes for climate action.

Of the hard, infrastructure-based technologies, an overwhelming amount are to do with disaster risk management, followed by resource and carbon management.

WHAT ARE THE SYNERGIES BETWEEN MITIGATION AND ADAPTATION TECHNOLOGIES?

Several CCMTs and CCATs share synergies, mostly in sectors that have an immediate and direct impact on the health and welfare of consumers. These include the power and/or electricity sector; water; transport; and buildings, which include habitat/living space, healthcare (hospitals, clinics, etc.), education (schools, universities, learning centres), and work (offices, workspaces, remote working stations, work-from-home setups).

Table 2 (see Appendix) highlights some of these key cross-cutting synergies. In the power sector, these include technologies like hybrid renewable energy and low power consumption devices, alongside special design specifications that can achieve higher generation as well as withstand climate impacts.

In South Korea, the Korea Adaptation Center for Climate Change (KACCC) established the Programme for Strengthening Adaptive Capacity of Local Governments and Supporting Localised Adaptation Models to develop adaptation solutions for the power sector with mitigation benefits[xxvii]. For example, renewable energy generation systems are paired with low-power consumption equipment in households through passive house or green building technologies that not only reduce power demand but mitigate emissions.

In the buildings and urban spaces sector, Los Angeles has successfully begun implementation of the LA Green New Deal CAP, which promotes the growth of an equitable urban tree canopy (prioritising increasing canopy cover in areas of greatest need) and implementation of green infrastructure, cool roofs, and cool neighbourhoods.

These measures are intended to help reduce the risks residents face from heatwaves, floods from extreme rainfall events, and drought (as natural landscapes release water more slowly than concrete), as well as assisting in the CAP's target of reducing overall GHG emissions by 40% from 2015 levels by 2030 en route to carbon-neutrality by 2045[xxviii].

In the power infrastructure segment, the high voltage transmission system of England and Wales, owned by National Grid, has developed underground cabling that can adapt electricity T&D systems to climate change effects by protecting key elements of the infrastructure from climate change events like storms, forest fires, lightning, strong winds, and water/snow accumulation[xxix].

Figure 8 Key climate change adaptation technologies with mitigation benefits[xxx]

The installation of underground cabling alleviates the requirement for further and more frequent investments in transmission infrastructure maintenance and repairs, thereby resulting in more secure energy supply and cost savings, as well as avoidance of indirect Scope 2 and 3 emissions from additional repair works.

Resource circulation in the waste management sector is another avenue for cross-cutting mitigation and adaptation technology. For example, government-led soft adaptation technology mandates like zero plastic in cities like Dubai, Alaminos in the Philippines, Austin in the USA, Flanders in Belgium, and Pune in India can enable zero plastic waste, eliminating one of main items of solid waste and ocean contamination.

In the agricultural sector, technologies like carbon farming mitigate the risk of soil erosion, improve soil fertility, and provide a buffer against drought. They enable sequestration of CO_2, resulting in lower GHG emissions associated with clearing of vegetation. Countries like Australia, France, and North America lead in carbon farming initiatives, with Australia's Cap-and-Trade Programme enabling farmers who sequester carbon to sell carbon credits to companies in need of carbon offsets[xxxi] .

In Hawaii, a Carbon Farming Task Force has developed incentives to increase the carbon content of soil. A 250-acre demonstration project attempted to produce biofuels from the pongamia tree which adds nitrogen to the soil. Similarly, one ranch husbanded 2,000 head of cattle on 4,000 acres utilising rotational grazing to build soil, store carbon, restore hydrologic function and reduce runoff[xxxii].

WHAT HAS POLICY LOOKED LIKE SO FAR?

Policy support for climate change technologies is somewhat different than historical investment and patenting trends indicate. Because policy at the local level is what often formulates community-level climate solutions with mostly immediate to near-term benefits, adaptation technologies receive the most support from local and municipal government bodies, particularly in climate vulnerable and/or poorer countries, rather than broader climate change mitigation technologies.

This is in contrast to more developed markets, where policy support has only recently begun shifting from a sole focus on mitigation technology in favour of adaptation technology to garner support for technologies and/or strategies/CAPs with overall mitigation benefits.

Policies that highlight this valuable integration of mitigation and adaptation technologies employ spatial theory and landscape approaches to guide climate action at the local and national level in a way that aligns with the Paris Agreement goals and/or various CAPs and NAPs.

For example, the Ecotowns Framework, a framework strategy developed for Asia's urban and peri-urban areas where economic losses from climate change are particularly high, works with at-risk municipalities and funding mechanisms like the Green Climate Fund to integrate adaptation benefits into mitigation policy[xxxiii] development that can assist countries in meeting their national climate goals.

In New York, the New York City Panel on Climate Change's Adaptation Assessment Guidebook provides an 8-step framework for linking the objectives of adaptation and mitigation technologies for informed, risk-based decision making[xxxiv] that contributes to the city's overall emissions mitigation goals.

On a more global scale, the UN's Adaptation Policy Framework employs a vulnerability assessment to measure the threats facing any given community and can provide a structure for seeking collaborative, mitigation and adaptation-integrated solutions that aid in achieving international climate targets.

Still, policy for adaptation technologies at the regional, intranational, and/or international level has typically lacked the support mitigation technologies receive. One reason for this is that adaptation technologies are largely considered part of "public goods", which pits them into the public welfare category, unlike mitigation technologies, which are considered "climate-altering" on the global scale, or "global climate trendsetters".

This has resulted in an observable low rate of international technology transfer with respect to adaptation activities relative to mitigation activities. This is problematic because firstly, the low rate of transfer is mostly observed in low-income countries; and, secondly, low-income countries are already highly exposed to climate change impacts, meaning that they have a greater need for simple, nontechnological adaptation solutions instead of "pure global good" mitigation solutions, given their current technological capacity.

However, international technology transfer has so far focussed mainly on mitigation technologies that may not fit a country's adaptation needs[xxxv].

Few adaptation inventions have been transferred across borders relative to CCMTs and non-climate-related innovations. Some cross-border transfers of patented inventions for climate change adaptation do occur, but predominantly between a small group consisting of high-income countries and China[xxxvi].

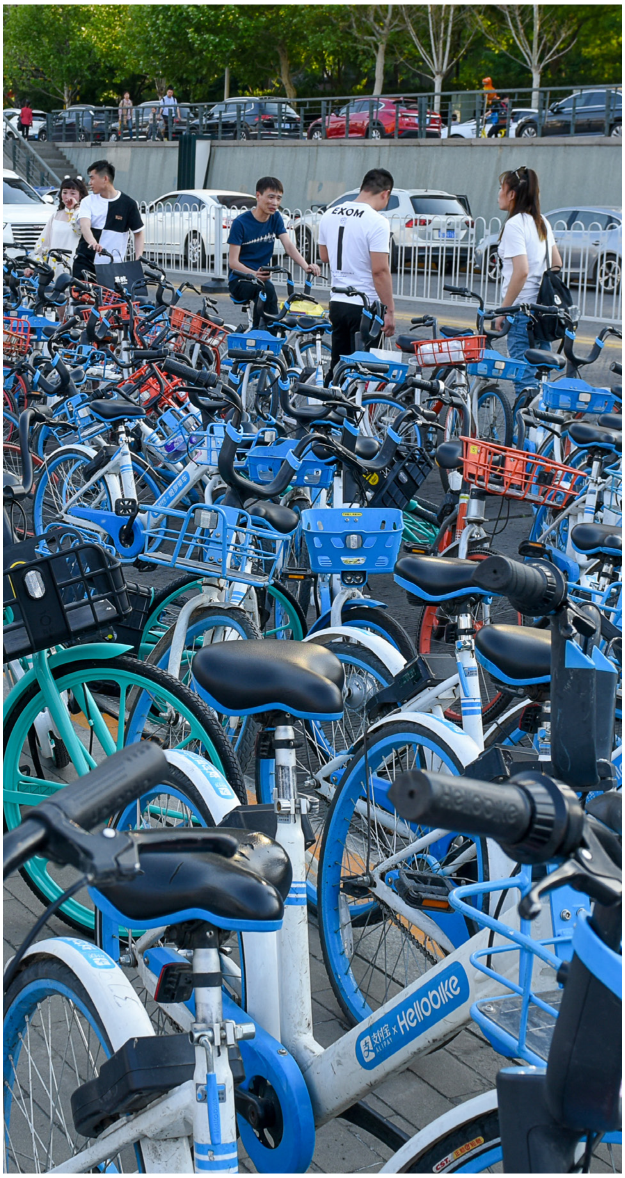


Table 3 Summary of policy criterion that can encourage integration of adaptation and mitigation technologies[xxxvii]

Criterion	Description
Coherent NAPs and alignment with development goals (and/or SDGs)	• Identify medium- to long-term adaptation needs employing spatial theory and landscape approaches that can be met by mitigation technologies • Employ expert scientific, policymaking, civil, and technological panel for qualitative judgement of aligning NAP with development goals
Ease of implementation	• Establish regulations and policy before launching or adopting new adaptation or mitigation technology to ensure rate of diffusion of technology is supported • Advance utilisation of local resources to bolster in-country capacity to implement technology
Encouragement of private investment	• Qualitative scaling for required adaptation and/or mitigation technology by expert scientific, policymaking, civil, and technological panel • Feasibility study with existing investors in climate change technology so far • Spur investment in local innovation and R&D
Improve	• Modelling statistics and in-country R&D; localisation of innovation • Qualitative judgements by expert scientific, policymaking, civil, and technological panel • Productivity analysis under different climate scenarios • Productivity inputs for each stage of development – R&D, demonstration, deployment
Alignment with international targets to reduce GHG emissions	• Targeted community-specific support for adaptation vis-à-vis more general support (e.g. carbon tax) for mitigation • GHG emissions budgets • Quantitative assessments of changes in net carbon footprint across all sectors that can utilise integrated mitigation and adaptation technologies

Technology transfer, therefore, does not seem to be driven by adaptation needs, but by the level of the recipient countries' technological absorptive capacities. Countries with strong technological capacities currently face lower adaptation needs, but the mismatch between adaptation needs and technology availability could have important consequences for mitigating temperature increases in more vulnerable and/or poorer countries.

Integrating adaptation technologies with mitigation benefits and vice-versa is therefore imperative in effectively reducing a country's climate vulnerability and helping it meet important climate goals. Some criterion that can help in this regard are summarised in Table 3.

The oil and gas industry is the perfect example of a sector at the crossroads of both climate change mitigation and adaptation technologies. For major oil and gas producers, the sector is often the backbone of their national economy, and supports employment, lower energy costs for consumers, and ensures energy security, which is pivotal for human welfare and advancing crucial climate goals.

Incidentally, some of the largest oil and gas producers in the world are also some of the world's most climate vulnerable today. These include countries like Iraq, Kuwait, Saudi Arabia, the UAE, and Qatar in the Middle East, Libya in North Africa, and Nigeria, Texas, the Gulf of Mexico, South America, and certain parts of Russia.

This places the aforementioned countries in a unique position to overcome the challenges posed by climate change by driving forward the benefits of integrated mitigation and adaptation solutions, as well as contribute to their countries' climate efforts.

Oil and gas companies in these countries can be the harbinger of various socio-economic benefits to communities at their sites of operation through adaptation technologies with mitigation benefits. These are summarised in Table 4.

Table 4 Opportunities from climate changes challenges for oil and gas producers utilising adaptation technologies with mitigation benefits[xxxviii]

Technology	Mitigation Benefit	Adaptation Benefit
Enhanced flare capture capacities	Reduction of GHG emissions	Reduction of pollution harmful to local communities and land/water resources
Enhanced carbon capture capacities	Reduction of CO_2 emissions	Reduction of pollution harmful to local communities and land/water resources
Upgraded oil and gas infrastructure	Reduction of associated Scope 1 and 2 emissions	Reduces risk of leakages, overflows and spills; reduces risks of accidents and health hazards due to influxes and overpressure
Enhanced water capture capacities	Promotes circular economy model by utilising wastewater for site operations	Frees up crucial freshwater resources for local consumption
Hybrid renewable energy systems	Reduction of emissions; green power for operations	Surplus power can be fed back into the grid for local consumption
Direct air capture (DAC)	Drawdown of atmospheric CO_2 from site operations; utilisation of subsurface reservoirs for safe CO_2 disposal	Can leverage natural gas plants in favour of renewable energy sources and output new fuels (synthetic) for transport requirements of local communities
Biofuels and hydrogen	Reduction of GHG emissions from transport; enhanced efficiency of own operations	Leveraging existing gas stations for biofuels, fast-charging, and hydrogen refuelling

Localisation of climate action can enable the adoption of simpler and cheaper adaptation technologies while simultaneously improving capacity for mitigation of climate change.

Governments have a key role in reforming existing institutional capacity in line with international climate agreements and national programmes, whilst maintaining a strong emphasis on climatic technologies – those that can achieve near-term benefits to climate impacts in the short-term, but also hold potential for integration with mitigation activities.

Such co-benefits and trade-offs between mitigation and adaptation activities need to be considered when developing and transferring climatic policies and technologies, particularly from developed markets to emerging ones.

Funding in the form of government grants, as well as from the private sector will be integral in ensuring the continuation of innovation and scaling-up of adaptation technologies even after mitigation technologies mature and/or peak. This is because local contexts continue evolving, and climate effects may alter depending on the application of certain mitigation technologies. Digitalisation will be an essential element of adaptation which can enhance local efforts in climate risk management and resource allocation.

New regulatory settings will be necessary, particularly as innovation increases. These should be adapted to gather climate-based data across different geographies that can inform climate-related issues in remote and far-flung communities.

Governments should narrow the acceptability gap for better adoption of integrated technological solutions, and use existing networks (between communities and cities, and between countries regionally and internationally) for knowledge sharing and transferring of technologies.

Table 2 Key climate change mitigation and adaptation technologies by sector and/or end-use[xxxix]

Sector		Climate Change Mitigation Technologies			Climate Change Adaptation Technologies		
		Technology	Technology Readiness	Achievements to Date, **if not**, Improvements Needed	Technology	Technology Readiness	Achievements to Date, **if not**, Improvements Needed
Power & Electricity Generation	Mature Renewables	Solar PV	Mature	• Mature technology that achieved cost parity with even the cheapest fossil fuels in 2013+	Decentralised generation systems	Mature	• Reduce the need for large facilities in high-risk areas and minimise climate risk, although not all regions with higher climate vulnerability have access to these adaptation technologies
		Wind					
		Offshore Solar & Wind			Robust design specifications (passive airflow beneath mounting structures for solar; special turbines to handle higher wind speeds)	Early Adoption / Demonstration	
		Floating					
		Biomass & Waste		• Mature and cost-competitive technology • Limited by feedstock availability & local pollution			
	ables	Ocean Energy	Early Adoption	• Used in limited geographies (ocean in South Korea, US West Coast, Scotland; geothermal in Indonesia, Kenya, Turkey, California, Iceland) • Limited supply chains for expansion	Modifying spillways; automated lowering of floating systems	Small Prototype	• Mostly in R&D currently with limited small-scale prototype to increase viability of ocean energy in climate vulnerable coastal areas
		Geothermal			Higher flood protection and substitution of air-cooled systems	Small Prototype	• Small-scale prototypes with some application in SE Asia countries
		Space-based Solar Energy	No Prototype	• Mostly conceptual, might require space manufacturing to limit launch of materials into space	Geoengineering (solar radiation management)	Small Prototype / No Prototype	• Several limited small-scale prototypes for marine cloud brightening, cirrus cloud thinning, space-based techniques, and stratospheric aerosol scattering, but no large-scale prototypes tested
	Nuclear	Fission (Gen I-III reactors)	Mature	• Long relicensing; very widespread in EU, US, China, Russia	Redundant cooling systems	Mostly Mature	• Redundant cooling systems mostly mature technology in countries / regions utilising nuclear energy (fission) for power
		Fission (SMRs)	Early Adoption	• Russia's Akademik Lomonosov is producing energy from two 35 MW(e) SMRs. Other SMRs are in the licensing stage in Argentina, Canada, China, Russia, South Korea, US. Lower upfront capital cost per unit, but economic competitiveness still to be proven			
		Fusion	Small Prototype	• Massive technical challenges in achieving sustained net-energy output			
	Hydrogen	Turbines	Demonstration	• Can be fitted into existing power plants and run on less pure forms of H_2, which can be carried in any form	~	~	~
		REE-free Production		• Eliminates the need for precious metals-based electrolysers	~	~	~
Infrastructure	Long-duration electricity storage	Flow Batteries	Large Prototype	• Large surface area for electrodes and membrane separators increases costs; no production economies of scale achieved	~	~	~
		Liquid Air Energy Storage	Small or No Prototype	• Currently only one developer; can provide energy efficiencies of 25%-70%			
	d Management 'echnologies	Ultra-high voltage	Early Adoption	• Advantage of large capacity, high efficiency, low loss, low footprint, and good safety, but only operational in China currently	Specifying redundancy in control systems; multiple T&D routes	Mostly Mature	• Mostly mature technology in climate vulnerable regions prone to flooding and/or strong winds, but less prevalent in poorer countries
		Submarine cable	Mature	• Mature technology operational since 1956, but limited locations			
		Superconducting transmission (SuperGrid with H_2)	No Prototype	• Currently at conceptual stage; will require supercooled hydrogen-carrying transmission lines to be subterranean	~	~	~

	ctrification	Electrified primary aluminium	Mature	emit oxygen instead of carbon during the smelting process which accounts for the vast majority of process emissions	~	~	~
		Electrified primary steel	Small Prototype	• Limited developers so far; seek to use electrolysis supplied from a carbon-neutral grid to produce steel from iron oxides	~	~	~
		Electrified chemicals	Small Prototype	• Limited small prototypes involves chemical synthesis with renewable electricity to reduce carbon emissions	~	~	~
		Electrified cement	Small Prototype	• Limited developers: exploration of tech to use electricity in heating process of cement production; use of nanocarbon black to conduct electricity, emit heat, and eventually store energy (?)	~	~	~
		Electrified high-temperature heat	Demonstration / Early Adoption	• Available for steam reforming and cracking in the petrochemical industry, but still in R&D/pilot phase for melting in glass furnace, calcination of limestone for cement			
	Electrolytic metals production		Mature	• Mainly used for non-ferrous metals to produce at exceptional purity grades (99.99+%)	~	~	~
	High-temperature heat	Large-scale heat pumps	Early Adoption	• Large, industrial sized heat pumps can use renewable energy or waste energy from buildings and processes to provide heating and cooling			
		Latent heat storage	Large Prototype	• Solid/liquid phase change is utilised, with melting used to store heat and solidification used to release heat (e.g. solar thermal plants)	~	~	~
		Sensible heat storage	Early Adoption	• Fairly widespread use in solar thermal power plants, where concentrated sunlight produces temperatures of approximately 550°C to 1500°C that can be directly used or stored			
	Hydrogen	PEM / Alkaline Production	Early Adoption	• Massive global deployment targets, underpinned by several operational projects in EU, US, Canada	~	~	~
		Solid Oxide Electrolysis / Anion Exchange Membrane Electrolysis	Demonstration	• Promising but requires significant upscaling • AEM performance still lower than what can be achieved with conventional technologies			
		ATR with CCUS / partial oxidation with CCUS	Demonstration	• HyNet ATR-GHR plants undergoing FEED; Shell has a POx commercial technology that it uses in its GTL plants which is being adapted for the production of hydrogen	~	~	~
	Carbon Capture / Carbon Use	Ammonia – physical absorption	Early Adoption	• Aqueous ammonia used to capture CO_2 with quick reaction rate, high removal efficiency, and high loading capacity of CO_2	~	~	~
		Smelt reduction – oxygen rich – physical adsorption	Demonstration	• Promising technology that requires more progress on equilibrium adsorption capacity and multi-cyclic stability	~	~	~
		Cement – chemical absorption	Demonstration		~	~	~
		Carbon absorbing concretes (Carbon Use)	Large Prototype	• Few large-scale prototypes in the world, but require significant scaling down of costs and scaling up of technology to be commercially viable; still not sufficient to be considered a "carbon sink"	~	~	~

	Recycling	Zero Waste Technology	**Demonstration / Large Prototype**	• Mainly embodied as a principle of waste prevention in few key countries; mainly relies on the innovation of non-waste technologies but still too vague and loosely defined to be implemented at scale	Improved water development and supply systems for zero-waste systems	**Demonstration**	• Adoption low due to high cost of initial investment and lack of proper regulations
	Recycling	Waste-to-Energy (Dendro Liquid Energy)	**Small Prototype**	• DLE WTE operates at moderate temperatures, is 4x more efficient than anaerobic digestion, and doesn't need combustion; but still at relatively conceptual/small prototype scale	Water-related processing, storage, and distribution	**Small Prototype**	• Mostly in R&D currently with limited small-scale prototype; adoption needs more robust regulatory framework
Agriculture	Carbon farming, including biochar		**Mature / Early Adoption**	• Often done only by individual land owners who are given incentive to integrate methods that will sequester carbon through policies created by governments	~	~	~
Agriculture	Vertical farming		**Early Adoption**	• Space maximisation, higher crop yields, and allows for year-round food production in any climate; but very high power consumption	Agricultural resilience	**Mostly Mature**	• Mostly mature by 2021, but agricultural resilience requires continuous innovation to reduce power consumption of vertical farming
Agriculture	CH_4 and NOx reduction		**Mature / Early Adoption**	• Nitrification inhibitors and rotational grazing practices, low-CH_4 animal feeds and CH_4 capture in animal pens, but not regulated equally across global agricultural lands • Advancements on non-animal meat, fish and milk, but requires significant upscaling	Methane management & remote sensing	**Mostly Mature**	• Provides summary measurements of agricultural cover, surface conditions, and related changes at a variety of spatial and temporal scales
Agriculture	Biogas and biomethane		**Early Adoption**	• Enables the use of agricultural residues such as manure and slurry to produce green energy, but not at scale in major world agricultural sites	~	~	~
Agriculture	Direct Air Capture		**Large Prototype**	• Technology still lacks refinement and requires several more large-scale demonstrations before reaching scalability	~	~	~
Agriculture	Mineral sequestration		**Small Prototype**	• Mostly in R&D with limited small-scale prototypes; lack of proper environmental regulations around mineral sequestration	~	~	~
Agriculture	Biosequestration		**Large Prototype**	• Largely experimental, with little or no occurrence in production agricultural systems and thus are not yet mature enough to deploy at scale	~	~	~
Buildings	Passive solar heating and cooling		**Demonstration**	• Uses specific building systems to help regulate internal temperature by using solar energy selectively and beneficially to improve energy efficiency	Urban forests and green spaces	**Mostly Mature**	• Green spaces are mostly mature in some of the most densely populated urban cities of the world
					Trombe walls – heavyweight structures of concrete, stone, or other heavy material that capture solar heat	**Early Adoption**	• Used in some countries like Chile, Egypt to capture solar heat for passive cooling of building structures
Buildings	Energy harvesting		**Early Adoption**	• Ideal for smart building applications to improve sustainability and cut down on energy costs, mainly concentrated in the EU and US	Energy harvesting	**Early Adoption**	• Can be modified to harvest energy in a host of different climates and humidity conditions

Transport	EVs	New batteries / charging methods	**At Varied Stages, Li-Ion most mature**	• Internal thermal modulation charging to reduce charging times at early-stage prototype development; cobalt-free, silicon anode, solid-state and zinc-air batteries all at different stages of maturity	Product design that incorporates climate change risks into new technology	**Early Adoption**	• At varied stages of maturity with EV project developers actively incorporating climate change risk measures into new technology
					Climate change risk assessment and management for value protection		
		Autonomous Vehicles	**Large Prototype**	• Integration with ICT makes reduces electricity consumed and overall air pollution, but development still not at scale	Climate strategy integration	**Early Adoption**	
					Logistics and efficiency strategies (e.g. high utilisation rate of intermodal downshift)	**Demonstration**	• Mainly adopted by few logistic services companies enabling them to transport the same goods through different methods of transport to reduce emissions
	Shipping	Batteries	**Early Adoption**	• Technology gaining momentum, with over 400 vessels now hybridised with battery power	~	~	~
		Increased efficiency (drag reduction through bubbles)	**Early Adoption**	• Adds a layer of air underneath vessel to reduce hull friction; gaining traction with commercial shipping operators			
		Sky-sails (ships with kite propulsion)	**Large Prototype**	• Wind propulsion system detached from ship's hull and uses free wind power, saves fuel costs and reduces pollution			
		On-board CCUS	**Small Prototype**	• Intends to separate the CO_2 from a vessel's main engine exhaust and store it for offloading at a port, but too costly currently			
		H_2 / CH_3OH / NH_3, Synfuels	**Large Prototype**	• Strong potential to power shipping vessels while emitting zero GHG, but no commercial project yet			
	Aviation	Electric	**Mature**	• Mainly limited to drones and small unmanned aerial vehicles, but not for commercial passenger transport	High-tech weather / climate forecasting instead of using operationally restrictive worst-case scenario development	**Early Adoption**	• Allows aircrafts take advantage of favourable climate which could reduce emissions and the industry's impact on climate
		Hydrogen	**Small Prototype**	• Potential of uptake by 2035, with initial tests suggesting they can be as fast as traditional planes	~	~	~
		Sustainable Aviation Fuels (SAFs)	**Demonstration**	• SAFs from waste oils most mature SAF technology, but waste oils are highly resource-constrained and are already largely consumed by the road sector	~	~	~
		Contrail Reduction	**Large Prototype**	• Tweaking aircraft altitude using high-altitude long-range (HALO) G550 research aircrafts for data	~	~	~
		Radical designs (external turboprop, blended wing)	**Small Prototype**	• External turboprop can provide significant emissions reductions and fastest and most realistic path to zero emissions through the use of hydrogen-powered electric engines • Blended wing body better suited for zero emissions carbon-neutral airliners, fuelled by hydrogen	~	~	~

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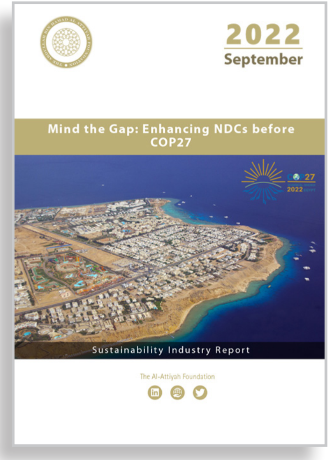

September – 2022

Mind the Gap: Enhancing NDCs before COP27

Under the Paris Agreement process, countries are required to submit new or updated nationally determined contributions (NDCs) at least every five years, and successive NDCs should represent progression and a higher level of ambition. The first round of new or updated NDCs was due in 2020.

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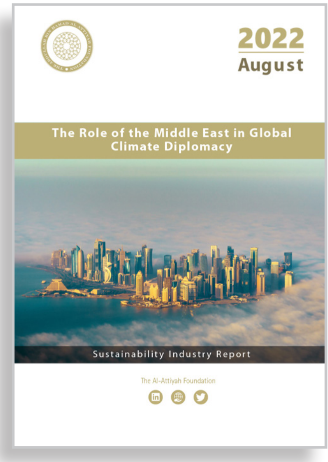

August – 2022

The Role of the Middle East in Global Climate Diplomacy

The Middle East is playing a growing role in international climate diplomacy through giant clean energy investments on its own soil, and also in emerging regions (particularly Africa).

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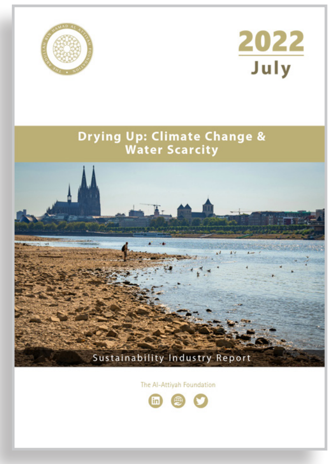

July – 2022

Drying Up: Climate Change & Water Scarcity

Climate change will alter patterns of precipitation, river flow and evaporation. At the same time, water use is increasing in many countries. This brings increasing challenges of providing sufficient, affordable, high-quality water for agriculture, human needs, and industry, while not depriving ecosystems.

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The Al-Attiyah Foundation

Tel: +(974) 4042 8000,
Fax: +(974) 4042 8099
www.abhafoundation.org

Barzan Tower, 4th Floor,
West Bay.
PO Box 1916 Doha, Qatar

AlAttiyahFndn
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