Technical Annex

Harnessing Artificial Intelligence for the Earth

January 2018

pwc

TECHNICAL ANNEX
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Background
PwC and the World Economic Forum partnered to research and understand the opportunity of applying Artificial Intelligence (AI) to tackle some of the Earth's most urgent environmental challenges. This technical annex accompanies the main report on "Harnessing Artificial Intelligence for the Earth" and forms part of the "Fourth Industrial Revolution for the Earth" initiative, a major global initiative of the World Economic Forum in partnership with PwC and the Stanford Woods Institute for the Environment. It is part of a wider publication series that highlights opportunities to solve the world's most pressing environmental challenges by harnessing technological innovations supported by new and effective approaches to governance, financing, and multi-stakeholder collaboration.

Technical annex contents
This Technical Annex contains two sections to support the findings and recommendations presented in the main report:

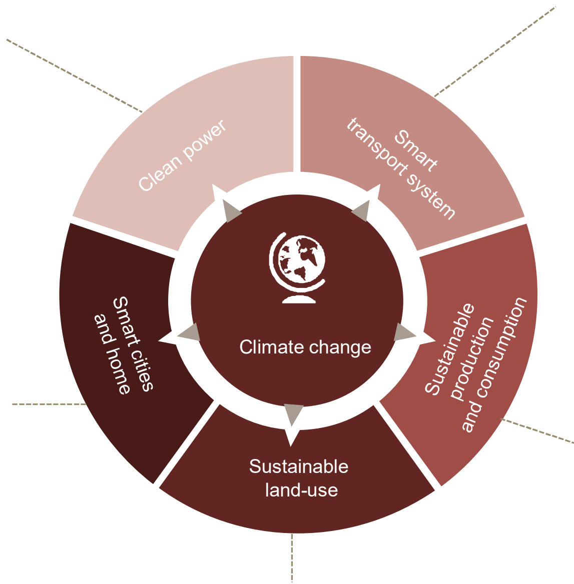
- Annex I: detailed descriptions of AI applications by challenge and action area (in the main report only the graphics are presented in the section titled *The AI opportunity for our environment*);
- Annex II: a table containing current use cases of AI applications for the environment, organised by environmental challenge area.

Annex I: Detailed descriptions of AI applications for Earth challenges

In the main report in the section titled *The AI opportunity for our environment*, we highlight, by environmental challenge area, the broad range of emerging use cases in Figure 3. Here we provide a short description of each of the graphics in Figure 3, summarising the opportunity of AI for the six environmental challenge areas: climate change, biodiversity and conservation, healthy oceans, water security, clean air, and weather and disaster resilience. The descriptions below are not meant to be exhaustive, but provide an overview of some of the most prominent emerging AI applications.

Figure 3a: AI applications by action area: climate change

Climate change



Clean power

- Optimised energy system forecasting
- Smart grids for electricity use
- Predict solar flares for protecting power grids
- Renewable energy plant assessments
- Optimised decentralised & peer-to-peer renewable energy systems
- Optimised virtual power plants

Smart transport system

- On-demand shared transport mobility
- AI-enabled electric cars
- Autonomous vehicles for efficient transport
- Vehicle to infrastructure communication and optimisation
- Optimised traffic flows
- Integrated cost-efficient transport systems
- Demand-response charging infrastructure

Smart cities and home

- Smart traffic light & parking systems for urban mobility management
- Optimised sustainable building design
- Energy-efficient building management systems
- Auditory responsive lighting & heating
- Optimised urban-level energy generation and use
- Analytics & automation for smart urban planning

Sustainable production and consumption

- Supply chain monitoring and transparency
- Active optimisation of industrial machinery & manufacturing
- Digital twins for lifespan performance optimisation
- Smarter fresh-food replenishment
- Smart recycling systems
- Integrated municipal & industrial waste management

Sustainable land-use

- Early crop yield prediction
- Precision agriculture & nutrition
- Hyper-local weather forecasting for crop management
- Early detection of crop issues
- Automated & enhanced land-use change detection for avoided deforestation
- Monitoring health & well-being in livestock farming

Source: PwC research

AI has the potential to transform the way in which climate change is tackled. In clean power, for example, machine learning is being used to match energy generation and demand in real-time, realising more fully the potential of "smart grids", decreasing unpredictability, and increasing efficiency, power balancing, use, and storage of renewable energy[1]. For example, Agder Energi[2] is using AI and the Cloud to predict and prepare for changing energy needs in Norway, particularly given the rapidly-increasing penetration of electric vehicles. Such approaches can also lower the need for excess 'idle' capacity. Neural networks for renewable power are also being developed to improve the energy efficiency and reliability. For example,

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[1] World Economic Forum, *Top Ten Urban Innovations*, October 2015, available at: http://www3.weforum.org/docs/Top_10_Emerging_Urban_Innovations_report_2010_20.10.pdf.

[2] Agder Energi homepage, viewed December 2017, available at: https://www.ae.no/konsernet/om/english/

DNV GL use sensors attached to solar and wind power generation plants to supply data for machine learning monitoring capability, enabling remote inspection of sites, predictive maintenance, and energy resource forecasting[3]. This increases control and maintenance efficiency lowering costs of solar and wind energy.

Within buildings, machine learning algorithms are also being deployed to analyse data from millions of smart sensors and meters to provide predictions on energy usage requirements and cost[4]. AI is also being used to provide auditory cue responsive lighting and heating from buildings to streets to optimise energy use, while JTC[5] of Singapore is using AI to monitor, analyse and optimise energy efficiency in buildings. Machine learning algorithms are also being used at the design phase to model energy efficient building layout further optimising buildings' efficiency in both the production and, more important, in-use phase[6].

For smart transport, machine learning algorithms employing car-sourced information are already widely used to optimise navigation (e.g., Waze and Google Maps) and increase safety, congestion and traffic flows (e.g., Nexar)[7][8]. At the urban-level, these capabilities translate to an ability to integrate public and private modes of transport to create an efficient city mobility service by looking for patterns in transport demand, optimising routes and improving efficiency and safety[9]. AI guided autonomous vehicles (AVs) - including machine vision algorithms and deep neural net techniques - will enable a transition to mobility on demand over the coming years, and decades[10]. Connected AVs present opportunities to unlock substantial greenhouse gas reductions for urban transport: examples include route optimisation that reduces driving miles and congestion, eco-driving algorithms that prioritise energy efficiency, programmed "platooning" of cars to traffic, and autonomous ride-sharing services that reduce vehicles miles

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[3] DNV GL, *Making Renewables Smarter: The benefits, risks, and future of artificial intelligence in solar and wind*, 2017, available at: https://www.dnvgl.com/publications/making-renewables-smarter-104362.

[4] PwC, *Fourth Industrial Revolution for the Earth Harnessing the 4th Industrial Revolution for Sustainable Emerging Cities*, November 2017, available at: https://www.pwc.com/gx/en/sustainability/assets/4ir-for-the-earth.pdf.

[5] JTC homepage, viewed December 2017, available at: http://www.jtc.gov.sg/Pages/default.aspx

[6] AI.Business, *Machine learning and energy efficient building design*, March 2017, available at: http://ai.business/2017/03/23/machine-learning-and-energy-efficient-building-design/

[7] Nexar, viewed December 2017, available at: https://www.getnexar.com/

[8] Waze, viewed December 2017, available at: https://www.waze.com/en-GB/

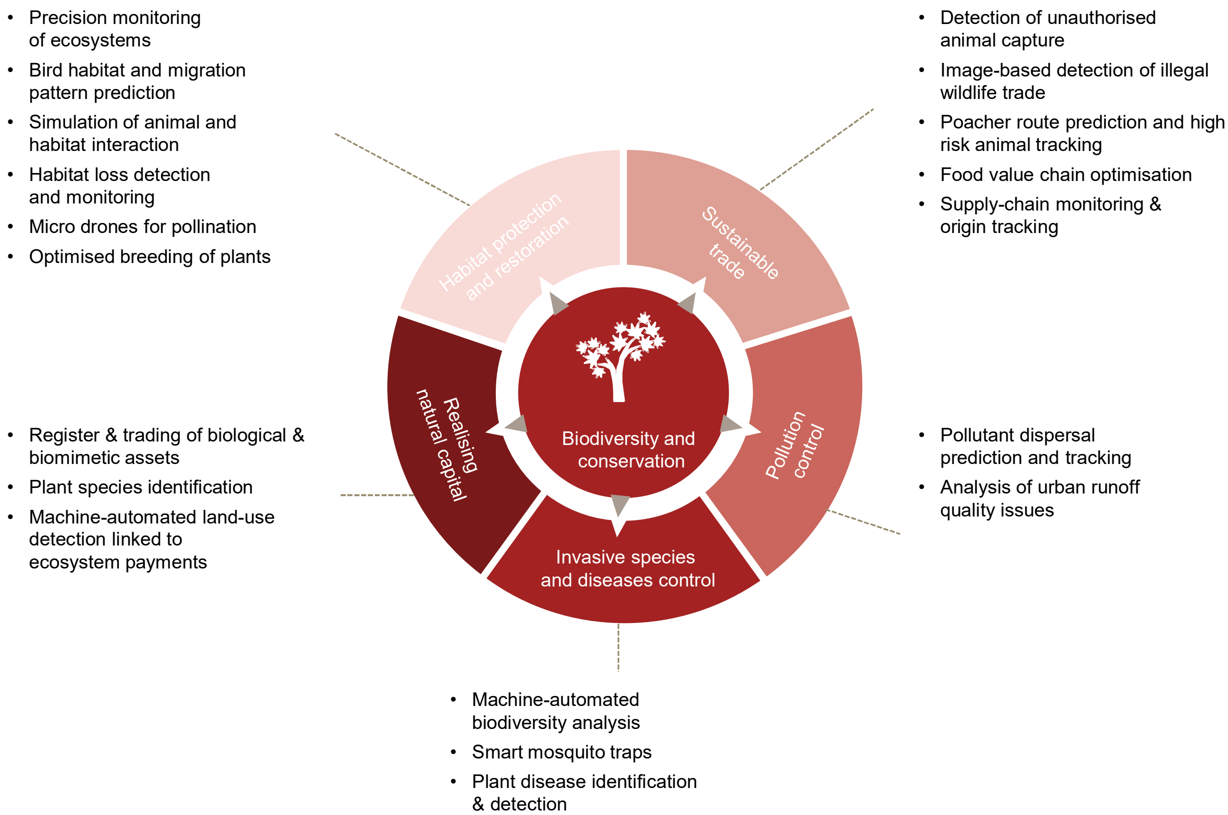
[9] PwC, *Fourth Industrial Revolution for the Earth Harnessing the 4th Industrial Revolution for Sustainable Emerging Cities*, November 2017, available at: https://www.pwc.com/gx/en/sustainability/assets/4ir-for-the-earth.pdf.

[10] WEF, *The driverless car revolution*, available at: http://reports.weforum.org/digital-transformation/the-driverless-car-revolution/.

travelled and car ownership[11]. Key considerations for maximising environmental impact include generating synergies with mass transit solutions and ensuring that AV fleets are in fact also zero-emissions fleets.

Biodiversity and conservation

Figure 3b: AI applications by action area: biodiversity and conservation



Source: PwC research

AI has the potential to transform the ways by which we monitor and conserve habitats. For example, AI provides the backbone for applications that, combined with satellite imagery, can automatically detect land-use changes, including cover analysis and forests, vegetation and monitoring of floods. For example, PlanetWatchers insights - using precision monitoring of landscapes - provides a resource for management of forest habitats to address the challenges presented by climate change related disturbances such as pests, damage, drought and fire[12].

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[11] Park, J., *Sensemaking/What will autonomous vehicles mean for sustainability?* Futures Centre, February 2017, available at: https://thefuturescentre.org/articles/11010/what-will-autonomous-vehicles-mean-sustainability.

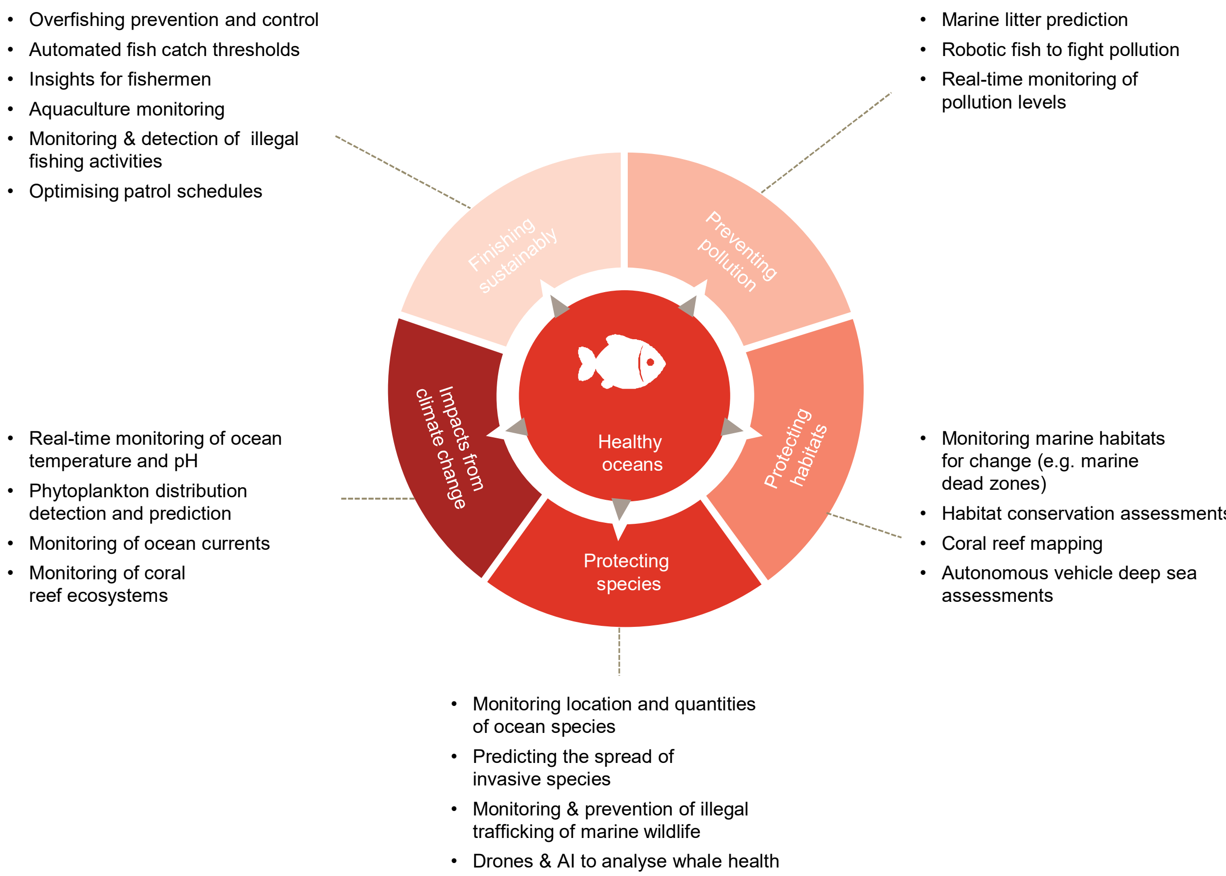
[12] PlanetWatchers, viewed December 2017, http://planetwatchers.com/.

To monitor and control invasive species, machine learning and computer vision are being used to identify the presence of invasive species and diseases in plants by tracking them and eliminating them. For example, Blue River Technology uses computer vision and AI to detect and identify biodiversity changes, including the presence of invasive weeds[13].

Protection of wildlife trade is being realised by combining AI with drone aerial footage, for example, Neurala is working with the Lindbergh Foundation to track African wildlife, such as rhinos and elephants, and spot potential poachers in order to prevent their killing[14]. Objects of interest can be identified from sensory streams, and assist humans by sifting through terabytes of video, in real time, and identifying animals, vehicles, and poachers, both during daytime and nighttime.

Healthy oceans

Figure 3c: AI applications by action area: healthy oceans



Source: PwC research

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[13] Blue River Technology, viewed December 2017, available at: http://www.bluerivertechnology.com/.

[14] Lazzaro, S, 2017, *How a Tech Company Is Using Artificial Intelligence to Save Elephants From Poaching*, available at: http://observer.com/2017/05/artificial-intelligence-can-stop-elephant-rhino-poaching-in-africa/.

AI techniques are opening up various new approaches to protect and sustainably manage oceans.[15] Systems that use AI in combination with other techniques to gather data in hard-to-reach ocean locations support efforts to track provenance and fish sustainably, protect species and habitats, and to monitor the impacts of climate change.

AI is also unlocking new solutions to tackle illegal fishing. Machine learning techniques are being pioneered to guide more accurate patrol schedules, and early efforts are underway to apply vessel algorithmic patterns to satellite data combined with Automatic Identification System (AIS) data from ships to monitor illegal fishing activities (e.g., Global Fishing Watch)[16]. Such tracking will enable authorities to prevent overfishing and to control fisheries.

For species protection, some systems use image analytics and machine learning to track the numbers and locations of invasive species. One industry-NGO partnership with the Ocean Alliance uses drones to collect mucus samples from whales off the coasts of Patagonia, Mexico and Alaska to obtain DNA information, and scientists use AI to gauge the mammals' health – and by extension, measure the ocean habitat in which they live – in real-time[17].

Ocean conditions can also be monitored using AI-powered robots for detecting pollution levels and tracking changes in temperature and pH of the oceans due to climate change. Moreover, NASA uses satellite imagery and machine learning computer modelling to predict the current and future conditions of the world's oceanic phytoplankton[18]. Autonomous ocean exploration technologies - utilising advances in AI, robotics and nanotechnology - are also under development to help survey the ocean floor at high resolution to help with species identification and mapping and natural resource management[19].

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[15] World Economic Forum, *Harnessing the Fourth Industrial Revolution for Oceans*, November 2017, available at: http://www3.weforum.org/docs/WEF_Harnessing_4IR_Oceans.pdf.

[16] Global Fishing Watch, viewed December 2017, available at: http://globalfishingwatch.org/

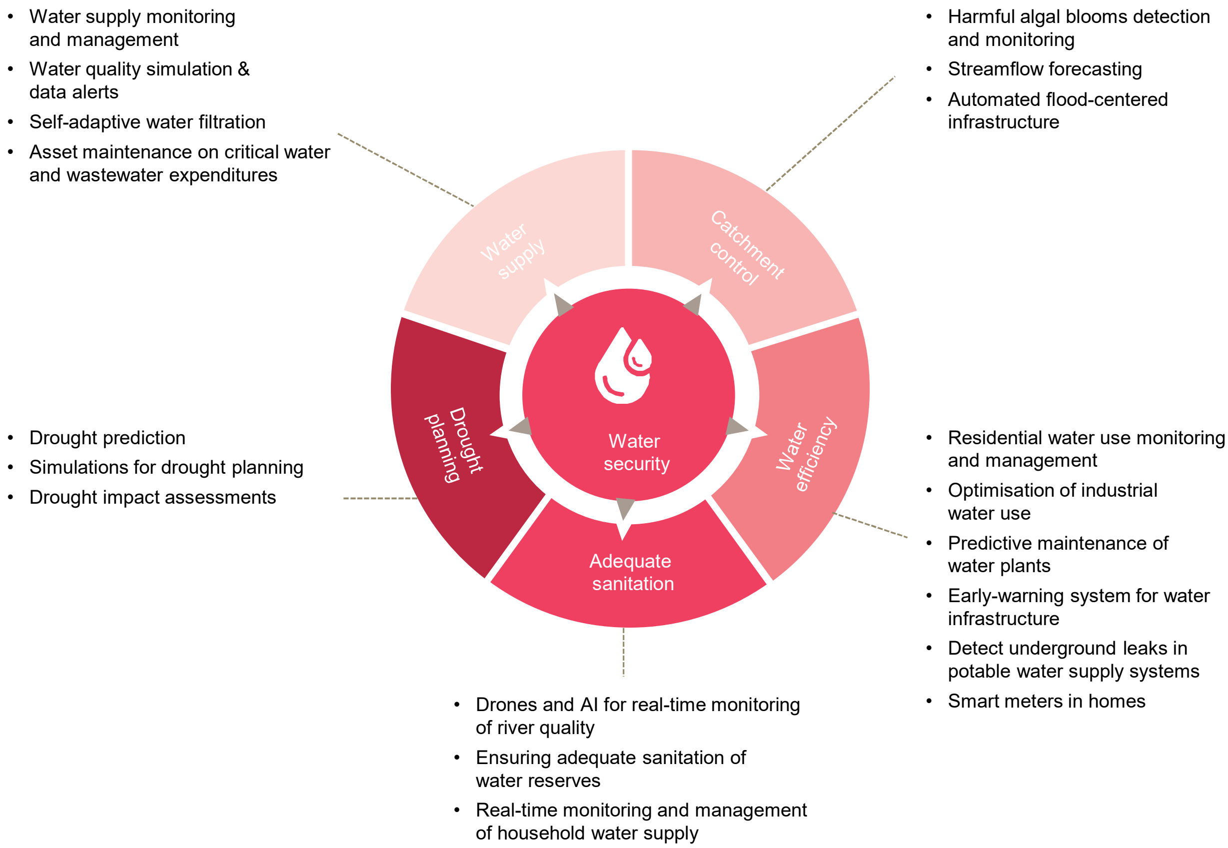
[17] INTEL, *Parley 'Snotbots' and Intel AI technology part of a mission to protect the world's oceans*, June 2017, available at: https://newsroom.intel.com/news/snotbots-intel-ai-technology-part-mission-save-worlds-oceans/.

[18] Biba, E, *3 ways artificial intelligence will save the day*, GreenBiz, June 2016, available at: https://www.greenbiz.com/article/artificial-intelligence-knight-shining-armor.

[19] X Prize Ocean Initiative, viewed December 2017, available at: https://www.xprize.org/oceaninitiative.

Water security

Figure 3d: AI applications by action area: water security



Source: PwC research

Water is at the nexus of food, energy, environment and urban issues. Enabled by AI, scientists and engineers can simulate the performance of reservoirs and project water usage for a geographical area, in combination with weather forecasts, making better informed policy decisions. Valor Water Analytics, meanwhile, is combining AI with industry intelligence and operational interactions to manage smart meter assets[20]. Their approach enables them to identify leaks, understand water flows in real-time, and see whether meters are malfunctioning. Elsewhere, Water Smart Software offers a data analytics platform, utilising machine learning, to provide utilities with information and strategies, including the ability to check water flows or spot anomalies[21]. Moreover, Flo Technologies uses machine learning to provide real-time data on water quality sending alerts to user's smartphones.

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[20] Valor Water Analytics, Valor product overview, viewed December 2017, available at https://www.valorwater.com/solutions-overview/.

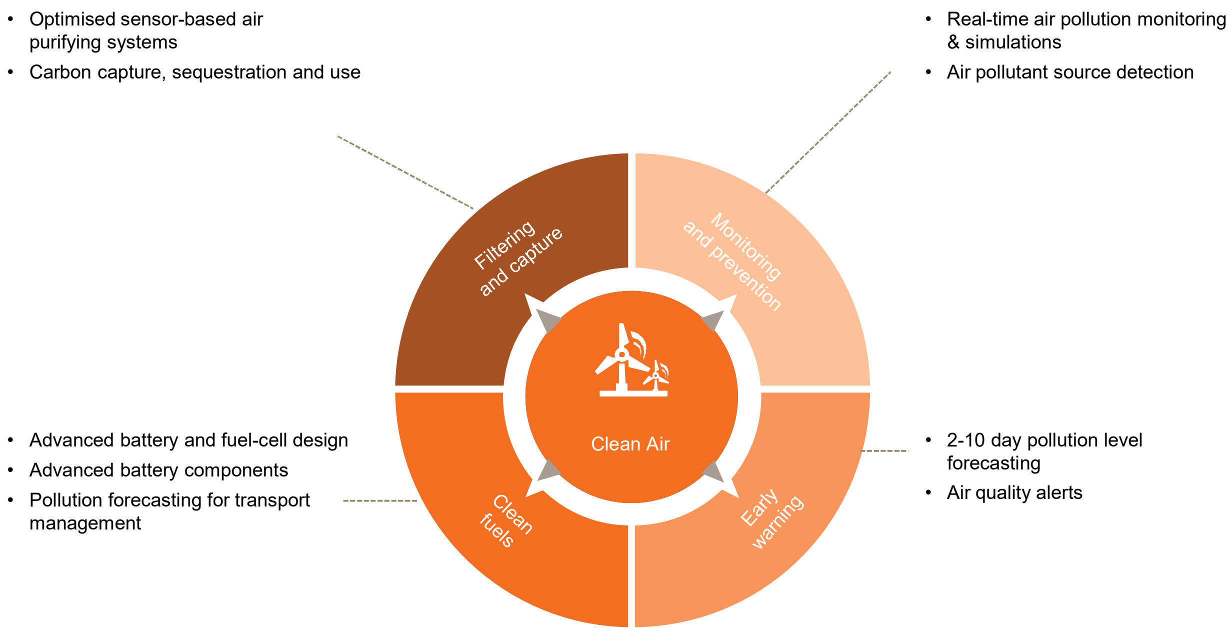
[21] Stenstedt, L., *Using Machine Learning To Assess Infrastructure Replacement Needs,* Smart and Resilient Cities, October 2017, available at: https://www.smartresilient.com/using-machine-learning-assess-infrastructure-replacement-needs.

Syracuse, N.Y. uses an AI system to analyse its aging water infrastructure to identify specific locations of leaks-prone pipes to repair[22]. While Water Planet's IntelliFlux incorporates AI to analyse data from pressure sensors and determine optimal performance of filtration systems, minimising water loss[23].

As well as supply and efficiency, AI - working with satellite data - can help forecast weather patterns and analyse soil and surface water conditions to predict drought conditions to help people and sectors affected[24]. Scientists can also use machine learning combined with physical models to conduct water plan scenarios and evaluate capital investments, crisis management plans, and potential outcomes of water-planning decisions.

Clean air

Figure 3e: AI applications by action area: clean air



Source: PwC research

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[22] Bruno, D., *How Mathematicians in Chicago Are Stopping Water Leaks in Syracuse*, Politico magazine, April 2017, available at: https://www.politico.com/magazine/story/2017/04/20/syracuse-infrastructure-water-system-pipe-breaks-215054.

[23] Water Planet, *Kevin Costner, Water Planet Team Up to Advance Sustainable Water Reuse with Smart Membrane Products*, PR Newswire, March 2017, available at: https://www.prnewswire.com/news-releases/kevin-costner-water-planet-team-up-to-advance-sustainable-water-reuse-with-smart-membrane-products-300427906.html.

[24] Tan, R. Perkowski, M., *Wavelet-Coupled Machine Learning Methods for Drought Forecast Utilizing Hybrid Meteorological and Remotely-Sensed Data*, Int'l Conf. Data Mining, avilable at: http://worldcomp-proceedings.com/proc/p2015/DMI8051.pdf.

For clean air solutions, some of the early examples concentrated around filtration and capture. For filtration, air purifiers (e.g. ARCADYA's) use machine learning to record air quality and environment data in real-time and adapt filtration efficiency[25]. AI applications are also driving advances in real-time air quality monitoring; for example, the company AirTick uses smartphone cameras as a proxy for air pollution sensors harnessing image recognition and machine algorithms to analyse images across a city at low cost[26]. Elsewhere, air pollution forecasting tools are being developed by start-up AirVisual, IBM, and Microsoft for cities like Beijing[27]. IBM's Green Horizons initiative combines machine learning and IoT, harnessing data from air quality stations and more widespread sources, such as traffic systems, weather satellites, and stations, as well as industrial activity, topographic maps, and even social media, to develop predictive analytics for 2 to 7-10 day forecasts[28]. Both IBM's and Microsoft's tools blend traditional physics-based models of atmospheric chemistry and weather with machine learning models.

In terms of air quality alerts, such AI-based systems can now provide forecasts of resource intensive and polluting behaviours. Simulations powered by AI can enable residents of urban areas, such as Beijing, to receive warnings about air quality.[29]

Moreover, the use of AI in new connected platforms that harness data from vehicles, radar sensors, and cameras to optimise traffic flow in urban areas is also improving air pollution due to its impact on reducing stationary vehicles and stop-start driving.[30] In terms of mobility, AI is also being used to optimise advanced battery design to improve the effectiveness and efficiency of electric vehicles, whose increased uptake will further improve air quality.

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[25] ARCADYA, Accessed December 2017, Available at http://www.arcadya.io/.

[26] Rutkin, A., *Pic-scanning AI estimates city air pollution from mass of photos*, New Scientist, February 2016, available at: https://www.newscientist.com/article/2076562-pic-scanning-ai-estimates-city-air-pollution-from-mass-of-photos/.

[27] Laurson, L. 2016 *AI and Big Data vs. Air Pollution Physics simulations and AI combine to give pollution forecasts to city dwellers in Beijing and beyond*, IEEE Spectrum, available at: https://docs.google.com/document/d/12q80NkOl8ei67VGaUsud00NXcBukUEnMEhs6NxXF8bU/edit

[28] IBM, 2017, Green Horizons, *Harnessing the power of cognitive computing and IoT to help fight pollution and climate change*, available at: http://www.research.ibm.com/green-horizons/#fbid=dQJLQ99TYMS.

[29] Laursen, Lucas, *AI and Big Data vs. Air Pollution*, IEEE Spectrum, December 2016, available at: https://spectrum.ieee.org/energy/environment/ai-and-big-data-vs-air-pollution.

[30] Newcastle University, *Stop-start driving in city centres creates higher pollution levels*, December 2014, available at: http://www.ncl.ac.uk/press/news/legacy/2014/12/stop-startdrivingincitycentrescreateshigherpollutionlevels.html.

Weather and disaster resilience

Figure 3f: AI applications by action area: weather and disaster resilience

Source: PwC research

Many of the emerging applications for weather and disaster resilience focus on the ability to forecast extreme weather and natural disasters. Predictive analytics powered by AI, along with IoT, drones, blockchain, and advanced sensor platforms can help governments and the scientific communities monitor tremors, floods and windstorms, as well as sea level changes and other possible natural hazards, in real-time with thresholds for automated triggers, that enable early evacuations when needed. In Indonesia, PetaBencana.id combines multiple open-source sensors, AI, and people's social media reports for real-time flood mapping in the capital, Jakarta.[31] AI is also being used with image analytics to process social media information to provide real-time extreme weather forecasts based on people's images and posts, for example,

[31] OECD, Embracing Innovation in Government: Global Trends – Case Study PetaBencana.id, available at: https://www.oecd.org/gov/innovative-government/embracing-innovation-in-government-indonesia.pdf.

IBM building on The Weather Company whom they acquired[32]. In addition, The Yield[33] is a Tasmanian agtech company using sensors, analytics and apps to produce real-time weather data, helping growers make smarter decisions reducing water and other inputs.

A number of meteorological agencies, tech companies (e.g. IBM, Palantir), insurers, and utilities are also using big data analytics and AI combined with more traditional physics-based modelling approaches to model the impact of extreme weather events on infrastructure and systems to inform disaster risk management strategies. The models can be used to predict direct damages in addition to loss amplification due to business interruption risks from electricity outages or transport closures. AI simulations are also being applied to evaluate disaster resilience strategies.

In addition to predicting extreme weather and natural disasters, natural language processing and machine learning techniques are increasingly being used to communicate disaster information to the public in response to queries. Moreover, in terms of real-time response planning, deep-learning algorithms and image analytics can use seismic data, structural data for buildings (age of structure, materials used etc.), social media data, and also satellite images to coordinate and prioritise disaster relief efforts, from determine which parts of a city will be most at risk to monitoring the flow of people and resources[34].

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[32] Nguyen, D.T., Mannai, A. Joty, S. Sajjad, H. Imran, M. Mitra, P. 2016 *Rapid Classification of Crisis-Related Data on Social Networks using Convolutional Neural Networks*, Qatar Computing Research Institute – HBKU, Qatar

[33] The Yield homepage, viewed December 2017, available at: https://www.theyield.com/our-company/the-yield-story

[34] McLaughlin, S. Larino, D., *Artificial Intelligence May Revolutionize Natural Disasters*, September 2017, available at: https://cee.engineering.uiowa.edu/news/artificial-intelligence-may-revolutionize-natural-disasters

ANNEX II: Detailed use cases by challenge and action area

In this Annex, we detail a broad range of over 80 use case applications of AI for the Earth - across the same challenge and action areas. The use cases were uncovered during the course of our research, which included both desk-based research and interviews with a range of stakeholders at the forefront of applying AI across industry, big tech, start-ups, research and government.

Climate change			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Clean power	*Optimised energy system forecasting*	Machine learning and deep learning analysis of electricity consumption patterns to make intelligent, real-time decisions in order to maximise the efficiency of energy use (multiple case studies).	More efficient production, better use of resources, and lower environmental impacts.
	Smart meter enabled smart grids	Machine learning algorithms to analyse the data from millions of smart meters to provide predictive analytics solutions for smart grids (e.g. Grid4C).	Suppliers understand the peak usage time and the downtime at the granular level and use this data to optimise overall electricity supply.
	Data-driven smart grids	AI to better analyse data gathered across electrical grids, enabling utilities to predict and meet the constantly changing energy needs and demands (e.g. Agder Energi utilising Microsoft's cloud).	A more effective, reliable and autonomous electrical grid, while encouraging customers to consume more renewable energy.
	Solar and wind energy plant assessment	Sensors attached to solar and wind power generation plants to supply data for machine learning monitoring capability, enabling remote inspection of sites, predictive maintenance, and energy resource forecasting (e.g. DNV GL).	Increase efficiency of control and maintenance tasks, in turn lowering costs of solar and wind energy.

Climate change			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
	Solar flare prediction	The use of machine learning algorithms to forecast solar flares, e.g. using Solar Dynamics Observatory's vast data sets.	Predicting when solar flares will happen could reduce disruption to both power grids and satellites.
Smart cities and homes	*Energy efficient building design*	Machine learning to simulate energy consumption during building design phase to guide energy efficiency in building design and operations (e.g. the Energy-Plus model).	Support planning of building layouts to enable optimised energy consumption.
	Energy efficiency of buildings in use	AI-enabled intelligent ecosystems that integrate different systems together, allowing to remotely monitor, analyse and optimise building systems (multiple case studies, including JTC).	Enhances energy-efficiency across systems and buildings.
Smart transport systems	*Smart traffic flow management*	Street lights with AI algorithms that uses data from radar sensors and cameras to detect traffic and build a street light timing plan that maximises efficiency of traffic flow (e.g. Surtrac) or informs optimal traffic navigation (e.g. Nexar).	AI-controlled traffic lights and real time vehicle navigation systems to ease congestion and reduce air pollution.
	On-demand response to transport mobility	AI can be used to analyse data (e.g., weather and user behaviour) to generate insights that inform the management of transport networks across a city, enabling a more efficient mobility service.	Increased efficiency and utilisation of transportation. Ultimately enables a connected autonomous fleet with energy consumption benefits.
	AI enabled autonomous vehicles	AI - including machine vision algorithms and deep neural net techniques - is critical to enabling the deployment	Connected AVs present opportunities to energy usage reductions including route optimisation, eco-driving algorithms that prioritise

Climate change			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
		of, and vehicle mix transition to Autonomous vehicles (AVs). Multiple use cases of application by Tech Firms, start-ups and Automotive companies.	energy efficiency, programmed "platooning" of cars to traffic, and autonomous ride-sharing services that reduce vehicles miles travelled and car ownership.
	AI enabled electric cars	Electric car drive time data (weather conditions, traffic volumes, tyre wear and driver behaviour) and machine learning to predict journey energy requirements with increased accuracy (e.g. Spark EV Technology software).	Journey prediction information can be used to increase the efficiency of energy-use between vehicle charges, and increases vehicle range.
Sustainable land-use	*Reduced losses in the supply chain*	Machine learning to better forecast the amount of food grocery stores and consumers need each day and minimise waste (multiple case studies).	Assists businesses and consumers in managing and monitoring supply chains to reduce loss and waste.
	Early crop yield prediction	Remote sensing and ground data is used in deep learning models to predict crop yield with high spatial resolution (county-level) several months before harvest (multiple case studies).	Helps set appropriate food reserve levels, identifies low-yield regions - avoiding wasted resources - and improves risk management of crops.
	Precision agriculture	Drones are automated using machine learning techniques and have sensors to provide 24 hour monitoring of field conditions (plant health, soil condition, temperature and humidity), allowing farmers and field staff to immediately address any crop anomalies that the sensor may have recorded.	Better crop management and resource use through flexible rationality. Taking action to address a specific goal related to that environment.

Climate change			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
	Data-driven farming	The application of AI enables seamless data collection from various sensors, cameras and drones, in an attempt to put data in the hands of farmers for them to improve crop yields (multiple case studies, incl. Microsoft FarmBeats collaboration).	Data-driven solutions that assist farm productivity.
	Global crop production monitoring	Satellite and weather data coupled with machine learning techniques to model complex systems, such as forestry and agriculture (e.g. Descartes Labs).	Provides high-resolution and high-accuracy forecasts to inform crop and supply management and improve crop yields.
	Hyper-local weather forecasting	Satellite imagery, soil data and hyper-local weather data to generate hyper-local weather forecast information for farmers to provide insight on when to plant, fertilize, spray, irrigate, and harvest crops (e.g. HydroBio).	Provides insights to enable maximisation of crop yield and minimisation of resource use, for instance, through informing irrigation requirements to minimise water wastage.
	Early detection of crop issues	AI for early detection of crop issues to improve crop yield and revenue for farmers (e.g. DeepFarm).	Early identification of crop yields contributes to more sustainable farming.
Sustainable production and consumption	*Supply chain monitoring and transparency*	Natural language processing tools to analyse and interpret environmental, social and governance data about global supply chains. For example, water consumption, energy efficiency, workplace conditions (e.g. eRevalue).	Monitors suppliers and informs supply chain management conditions to improve efficiency and reduce deforestation an.

Climate change			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
	Monitoring health in livestock farming	Facial recognition to track and follow individual cows in large herds, turning visual information into actionable data (e.g. Cainthus).	Reduce inefficiencies in food production and improves sustainability in supply chains.
	Smart recycling systems	Recycling stations using neural network to gather real-time feeds to select and sort the right items from the belt.	Smart bins enable identification of a wide range of food and beverage cartons so as to separate non-recyclable, from recyclable, products.

Biodiversity and conservation			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Habitat protection and restoration	*Habitat loss detection and monitoring*	Spatial modelling uses an artificial neural network architecture to track changes in forest cover over time, and produce a map with areas at high risk for forest loss.	Inform land-use decisions and prioritise conservation efforts.
	Precision land-use mapping	Geographic Information System (GIS) and machine learning models to generate accurate land-use models, and simulate the impact of different land-use activities, and planting options (e.g. Microsoft and ESRI collaboration with Chesapeake Conservancy).	Land-use mapping under different planting scenarios enables optimised conservation to protect and restore local habitats.
	Bird habitat and migration pattern prediction	Crowd sourced bird observation reports and remote sensing data, which uses machine learning to predict where there will be changes in habitat for certain species and the paths along which birds will move during migration is collected (e.g. the eBird model).	Pattern predictions can help decision makers to decide how best to protect the habitats of birds.
	Simulation of animal and habitat interaction	Use of machine learning techniques to simulate animal behaviour in response to a variety of variable conditions.	Simulations of interactions can help people understand what form of animal activity leads to the most resource deficits.
	Precision monitoring of forest habitats	Satellite sensors, advanced machine learning algorithms, and cloud computing to monitor natural forest habitats, and predict the impact of weather and environmental changes (e.g. The PlanetWatchers program).	Precision monitoring provides a resource for management of forest habitats to address the challenges presented by climate change related disturbances such as pests, damage, drought and fire, to improve the overall productivity of the forest.

Biodiversity and conservation			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Invasive species and disease control	*Plant disease identification and detection*	AI-driven systems that uses image analytics based analysis of crowd sourced image data to understand the identification, prevention, and treatment requirements of crops (e.g. Plantix).	Supports optimal treatment and watering of crops, which helps reduce unnecessary product and water use.
	Machine automated biodiversity analysis	Computer vision and AI to detect, identify, and make management decisions about the biodiversity of a habitat. For example, the presence of invasive weeds (e.g. Blue River Technology).	Enables significant savings in the volume of pesticides being sprayed when tackling weeds, whilst optimising fertiliser use for crops.
	Smart Mosquito traps	Machine learning systems that can differentiate between the mosquitoes that they want to trap/not trap, building a more efficient and effective trap (e.g. Microsoft).	Detects infectious diseases in the environment before they cause potentially deadly outbreaks of viruses or other dangerous diseases.
Pollution control	*Pollutant dispersal prediction and tracking*	AI-enabled modelling is used to more accurately predict the dispersion of pollutants under complex environmental conditions.	Reduction in the level of reactive nitrogen reaching natural ecosystems, reducing threats to plant diversity.
	Analysis of urban runoff quality issues	Models of various highly variable physical phenomena in the water, accurately predicting the level of biochemical oxygen demand (BOD), ammonia-nitrogen, nitrate-nitrogen, and ortho-phosphate-phosphorus.	Neural networks can monitor urban stormwater pollution levels and enable the development of better water resources management.

Biodiversity and conservation			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Realising natural capital	*Optimised breeding of plants*	Use of machine learning to leverage insights about how crops have performed in various climates, to predict which genes will most likely generate beneficial traits in plants.	Identifies genetic sequences that relate to qualities to help crops more efficiently use water, nutrients, adapt to climate change, or resist disease.
	Monitoring species	Open resource databases where pattern recognition from photograph records is used for tracking individual animals. For example, for whale shark monitoring (e.g. Wildbook).	Automated species recognition and monitoring with increased accuracy informs conservation efforts.
	Biodiversity mapping	Open resource that uses crowdsourced biodiversity data and machine learning capability for accurate identification and tracking of species (e.g. iNaturalist).	Classification of new species and monitoring numbers and location of endangered species, informing conservation efforts.
	Plant species identification	Use of deep learning to identify plant species that have been pressed, dried and mounted on herbarium sheets in order to support digitisation of natural-history museum collections.	Digitise the records of past and present biodiversity to provide a valuable resource for future conservation work.
	Machine-automated land-use detection	Urban areas can be detected in satellite imagery using various machine-learning approaches (e.g., supervised, unsupervised, and semi-supervised) which turn high-resolution imagery into land cover maps.	Provide information on how land-use is changing, helping governments to make informed decisions about when, where, and how to most effectively deploy conservation efforts.

Biodiversity and conservation			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Sustainable trade	*Smarter fresh-food replenishment*	Machine learning allows retailers to automate formerly manual processes and dramatically improve the accuracy of customer purchasing and ordering forecasts.	Addresses the common—and costly—problem of having too much or too little fresh food in stock, diminishing wasted food.
	Detection of unauthorised animal capture	Machine learning and pattern recognition to detect the capture of animals from sensor camera images (e.g. Protection Assistant for Wildlife Security (PAWS)).	Parks are better able to protect their animals and to tackle the global trade in unauthorised animals.
	Image-based detection of illegal wildlife trade	Apps which use image and pattern recognition software, to allow users to visually verify taxonomic derivatives at various taxonomic levels.	Supports elimination of the illegal wildlife trade and enables effective monitoring of the legal wildlife trade.
	Poacher route prediction and high risk animal tracking	Machine learning to track and predict the paths of both at-risk animals and the poachers who are hunting them (e.g. Neurala).	Information used to counteract and respond to illegal poaching activities (e.g. in Africa).

Healthy oceans			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Fishing sustainably	*Detection of unlawful fishing practices*	Software devices use machine learning to inform scientists and regulators on what creatures are caught to provide them with a full picture of legal harvests and detect unlawful operations.	Monitors legal and illegal catches to support sustainable fishing.
	Overfishing prevention and control	Algorithms embedded into fully automated software that workers use in fishing operations to identify fish and classify them by species.	Reduces the number of protected animals such as sharks and turtles that are accidentally caught along with tuna.
	Automated fish catch thresholds	Video footage from fishery operations is used for preliminary fish recognition using artificial neural networks, alongside counting and shape recognition, to arrive at an accurate estimate of how many fish can be caught.	Enables a more accurate estimation of numbers of fish and a better understanding of marine ecosystems informs fishing threshold decisions.
	Monitoring illegal fishing activities	Automatic Identification System (AIS) data from ships combined with other datasets and machine learning to monitor illegal fishing activities (e.g. Google Fishing Watch)[35].	Predicts commercial fishing behaviour in near real-time and helps to reveal ships where AIS transponders may be turned off, supporting law enforcement of protected marine areas.
Impacts from climate change (incl. acidification)	*Real-time monitoring of ocean pollution, temperature and pH*	AI-powered robots used for detecting pollution levels and tracking changes in temperature and pH of the oceans.	Provides accurate data on ocean pollution and pH which is used for developing biodiversity conservation action plans.
	Phytoplankton distribution detection and prediction	Machine learning to understand the distribution of phytoplankton in the oceans. And satellite	Valuable information for researchers attempting to understand the effect of changes in atmospheric CO2 on our planet.

[35] Clark, Liat, *Google's Global Fishing Watch is using 'manipulated' data*, Wired, November 2014, available at: http://www.wired.co.uk/article/global-fishing-watch-false-data-windward

Healthy oceans			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
		imagery and computer modeling to predict the current and future conditions of the world's oceanic phytoplankton (e.g. NASA).	
Preventing pollution	*Marine litter prediction*	AI techniques to define general litter categories that occur on beaches, and assess litter pollution occurrence (e.g. researchers in Turkey).	Fast and reliable estimations of litter categories inform research studies and management priorities of beaches.
	Robotic fish to fight pollution	AI-enabled robotic fish technology that detect potentially hazardous pollutants in the water, for instance from a leaking underwater pipe (e.g. European Commission-funded research).	Enables early identification of pollutants in water, which enables management activities to be undertaken before the pollutant level increases.
	Drones to analyse whale health	AI and drone capabilities to analyse data that drones collect via the blow, or snot, exhaled from whales when they surface to breathe (e.g. Intel are collaborating with Parley for the Oceans on its SnotBot initiative)[36].	Informs marine conservation efforts.
Protecting habitats	*Coral reef mapping*	Autonomous drones are AI-enabled to use machine learning to map the coral reef and automatically sift through data to track changes in the reef formation.	Monitoring the reef on an ongoing basis provides a valuable resource for conservation activities.
	Monitoring marine habitats for change	Drones are being developed to take detailed imagery of marine habitats and use machine learning algorithms to process data and	Drones are used to economically restore degraded ecosystems, for example, by planting mangroves.

[36] Gilbert, Elissa, Scientists equipped "SnotBots" — drones using sophisticated AI programs — to learn about whales, oceans and even human health, August 2017, available at: https://iq.intel.com/whale-snot-hold-secret-ocean-health/?cid=sem43700027467499372&intel_term=parley+for+the+oceans&gclid=EAIaIQobChMIhO6LzPqW2AIVAtVkCh1kMgRSEAAYAiAAEgL5p_D_BwE&gclsrc=aw.ds&dclid=CKuCpfP6ltgCFVIFgQodTewB-g

Healthy oceans			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
		determine the best location for planting as to ascertain which species are best fit for the area.	
Protecting species	*Predicting the spread of invasive species*	A system that uses image analytics and machine learning to track the numbers and locations of invasive species.	Track levels of invasive species in order to inform control activities.
	Prevention of illegal wildlife trafficking	Machine learning tools to processes data from the "dark web" to penetrate organised crime for protected marine wildlife (e.g. DeepDive).	Tools to prevent illegal trafficking of wildlife.

Water security			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Adequate sanitation	*Drones for real-time river quality monitoring*	Algorithms that use monitoring data from drones to automate the delivery of water quality reports (e.g. The University of Toronto).	Monitors the health of a body of water resourcefully, and provides recommendations for waterways management.
	Adequate sanitation of water reserves	Artificial Neural Network models have been developed and validated for predicting the pH at different locations of the distribution system of drinking water.	Monitors the quality of drinking water in urban areas.
	Real-time monitoring and management of household water supply	User-friendly cloud-based system for real time monitoring and management of household water supply. For example, Flo Technologies creates intelligent water monitoring and control system for single family homes.	Limit wastewater while also ensuring high quality water supply.
	Harmful algal blooms detection and monitoring	Machine learning techniques to train a smart device (cellular phone or tablet) to detect the presence of cyanobacteria in a small surface portion of a freshwater.	Reduce volume of harmful algal blooms which have severe impacts on human health and aquatic ecosystems.
Catchment control	*Stream-flow forecasting*	Machine learning techniques for modelling non-linear hydrological conditions, in order to generate short and long term streamflow forecasts and automate catchment management infrastructure.	Short-term (real-time) forecasting (e.g., hourly and daily) enables reliable operation of flood and mitigation systems. Long-term forecasting (e.g., weekly, monthly and annual), is important in the operation and planning of reservoirs, hydropower generation, sediment transport, and irrigation management decisions.

Water security			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Drought planning	*Accurate drought planning*	Machine learning enables accurate drought forecast by means of multiple drought-related attributes from precipitation, satellite-derived land cover vegetation indices, and surface discharge (multiple case studies).	Drought planning over a lead-time of 3 to 6 months, which can be crucial for agricultural planning, reservoir management, and authorities' allocation of water resources.
Water efficiency	*Residential water use monitoring*	Machine learning algorithms to detect inaccuracies or anomalies in water meter data (e.g. Valor Water Analytics).	Monitors water flow in real-time to maximise efficiency of water use by customers.
	Underground leaks detection	Detection of underground leaks in potable water supply systems through analysis of satellite imagery and machine learning (e.g. Utilis).	Enables more leaks to be detected and a reduction in water loss.
	Industrial water use optimisation	Machine learning algorithm to analyse disparate water data to develop optimal management and control protocols for the water management by utilities and industrial users (e.g. Pluto AI).	Automated identification of optimal water management to ensure efficiency of water use and associated energy conservation.
	Predictive maintenance of water plants	Machine learning to quickly and effectively analyse hundreds of variables that have an impact on a pipe's likelihood of failure.	Estimates current pipe corrosion and deterioration to ensure high water quality standards.
	Early-warning for water infrastructure maintenance	Machine learning models that assign risk scores to individual water mains on a map.	Analysis to help city planners prioritise mains for maintenance and replacement.

Water security			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Water supply	*Self-adaptive water filtration*	Machine-learning to analyse data from flow and pressure sensors continuously to determine optimal performance of filtration systems in environments where water quality varies. For example, the oil and gas sectors (e.g. Water Planet's IntelliFlux software).	Filter enables effective and high quality water filtration where influent water quality is variable, thereby minimising water loss.
	Water quality simulation	Numerical models used to simulate flow and water quality processes in coastal environments, with the emphasis traditionally being placed on algorithmic procedures to solve specific problems. AI has made it possible to integrate technologies into numerical modelling systems in order to bridge the gaps (multiple case studies).	Optimise water management decision-making.
	Water asset maintenance	Systems to integrate computer modelling with local authority planning, policy interventions and decision making, using dynamic feedback from the field, to modify models and decision making (e.g. Pluto AI).	Lengthens the lives of water assets, reducing leaks, and lowering water expenditure and loss.

Clean air

Action area	AI use application	Description of the role of AI	Potential environmental outcomes
Clean fuels	*Pollution forecasting for transport management*	AI leverages pollutant (e.g., carbon dioxide, and nitrogen oxides) and environmental data (humidity, solar irradiation, and temperature) to predict transport pollution intensity in urban areas (e.g. multiple case studies).	Pollution forecasting used for management response to minimise pollution impacts (e.g., congestion charge, traffic restrictions).
	Advanced battery and fuel-cell design	Advanced AI-enabled material modelling to improve battery-electric and fuel-cell cars (e.g. Toyota).	Improve battery-electric and fuel-cell car technology in order to reduce the cost of technology and enable transition to electric vehicle fleets.
Early-warning	*Pollution level forecasting*	Predicting air pollution levels by combining data from several different models. For example, Microsoft currently provide China's Ministry of Environmental Protection a forecast for Beijing for the following 12 hours, achieving 60 percent accuracy.	Manage urban air quality to protect the health of the public.
Filtering and capture	*Sensor-based air purifying systems*	Air quality sensors built into tablet devices. Using machine learning to analyse air quality while considering individual preferences, to adapt filtration efficiency (e.g. ARCADYA'S air purifying system).	Provides clean air at a personalised level to meet individual's needs.
Monitoring and prevention	*Real-time air pollution monitoring*	Machine learning tool to estimate air pollution levels from photographic evidence (e.g. AirTick).	Accurate real-time estimates of the air quality in individual's neighbourhoods to adapt behaviour accordingly.
	Air pollutant source detection	Smart indoor air quality monitors using neural network algorithms to associate a pollutant with a source in a given environment.	Provide real-time information of pollutant sources enabling individuals to manage scenarios.

Weather and disaster resilience			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Early-warning systems	*High impact weather event prediction*	Machine learning tools to improve the prediction skill for multiple types of high-impact weather, including thunderstorms and tornadoes (e.g. The US NOAA, UK Met Office).	Improves early prediction accuracy of high-impact weather events, to facilitate effective preparation.
	Social media enabled disaster response	Machine learning models integrating disaster crisis data from social media (e.g., tweets) to provide information that relates to particular crises, to inform disaster response activities (e.g. Qatar Computing Research Institute (QCRI)).	Assists during natural disasters, prioritising the efforts of first responders.
	Real-time natural disaster communication	The use of the latest web technologies, cloud computing, natural language processing, and machine intelligence techniques to communicate disaster information to the public in real time (e.g. IBM and Weather Company).	Processes and analyses social media feeds in real-time for improving flood monitoring and prediction, supporting flood preparedness, recovery and response.
Financial instruments	*Rapid, multi-source risk analysis*	Machine learning algorithms to scan web content to generate high-frequency, objective, and actionable risk scores, including social, geopolitical and climate risk (e.g. GeoQuant).	Inform smart climate and extreme weather policy and investment decisions.
	Smart investment decisions	Machine learning to filter and process resources from across the web (news, academic journals, press releases) to provide sustainable investment advice to clients (e.g. NewsConsole).	Supports evaluation of capital investment decisions under different scenarios (e.g., climate change).

Weather and disaster resilience			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
Prediction and forecasting	*Extreme weather risk prediction and preparedness*	AI combined with more traditional physics-based modelling approaches to model the impact of extreme weather events on infrastructure, including AI downscaling techniques (multiple use cases involving Met Offices, utilities, and tech firms),	Prediction and risk quantification to aid disaster preparedness decision-making for communities, businesses and governments.
	Weather-forecast-informed flight paths	Integrated public source data, and data from airplane sensors, to make predictions about weather conditions along flight paths (e.g. Panasonic).	Enables airlines to adjust their routes to reduce fuel use and improve on flight safety.
	Real-time weather predictions	Machine learning solutions that use sensors and data analytics to produce real-time weather data (e.g. The Yield, UK Met Office).	Helps growers to make smarter decisions that can reduce their water use and other inputs, while also increasing yield.
Resilience planning and disaster response	*Emergency risk communication*	Natural language processing and machine intelligence tools to communicate disaster information to the public (e.g. IFIS Knowledge Engine).	Users can receive answers to their questions on flooding (e.g., flood conditions, forecast, flood risk) in order to mitigate risk of natural disasters.
	Earth systems' response prediction	Machine learning to create 3-D living models of the entire planet. The vast amounts of data will enable the modelling of different conditions and predict how Earth's systems will respond (e.g. National Science Foundation and EarthCube, Planet Labs).	Support scientists to avoid catastrophic events or plan for unavoidable events (e.g., flooding) before they occur.
	Real-time flood mapping	Tools that combine data from open source sensors and social media reports to use machine learning for real-time flood	Provides accurate and up to date flood information for governments and local residents, for flood planning and response.

Weather and disaster resilience			
Action area	**AI use application**	**Description of the role of AI**	**Potential environmental outcomes**
		mapping (e.g. PetaBencana.id in Jakarta).	
Resilient Infrastructure	*Automated mitigation of flood risk*	Computing and machine learning to automatically control the flow of water through flood gates in response to changing conditions.	Constructs and manage natural landscapes that benefit biodiversity or mitigate the risk of natural disasters (e.g., flooding).
	Building-specific earthquake damage prediction	AI-enabled modelling using seismic data and structural data from buildings (age, materials, etc.) to prioritise which parts of a city will be most at risk from earthquakes.	Helps inform earthquake response management in order to mitigate impacts.

Source: PwC research

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