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COVER NOTE

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COMMISSION STAFF WORKING DOCUMENT

Digital Solutions for Zero Pollution

Accompanying the document

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions

Pathway to a Healthy Planet for All
EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'

{COM(2021) 400 final} - {SWD(2021) 141 final}

Contents

1. Introduction

The EU has embarked on a green and digital transition. The two dimensions are closely interrelated, and the Commission has taken the lead to drive these transitions and to focus investments on recovery and resilience efforts in these areas. In relation to the green transition, pollution has been identified as one of the four major planetary crises alongside the climate, biodiversity and resource crises.[1] Pollution affects our health and our environment; it threatens our natural environment and is one of the major reasons for biodiversity loss. The Commission's Zero Pollution Action Plan for air, water and soil[2] addresses the pollution challenge in view of achieving the zero pollution ambition for a toxic free environment, complementing the Chemicals Strategy for Sustainability towards a Toxic-Free Environment (CSS)[3].

The 2019 European Green Deal[4] recognises the potential of digitalisation to achieve the environment and climate aims and the necessity to explore sustainable digital technologies as essential enablers of the changes needed for a just green transition. Reference is made to digital technologies such as Artificial Intelligence (AI), 5G, cloud and edge computing and the Internet of Things (IoT) as having the potential to accelerate and maximise the impact of policies to protect the environment and to address climate change[5].

In February 2020, the Commission adopted its new Digital Strategy ('*Shaping Europe's Digital Future*')[6] along with its first two pillars: the European Data Strategy[7] and a White Paper on Artificial Intelligence.[8] The European Digital Strategy sets a vision for a transition to a healthy planet and a new digital world. It emphasises the need for the twin challenge of a green and digital transformation to go together, and points to the digital component as key in reaching the ambitions of the European Green Deal.[9] It also recognises that digitalisation contributes to environmental degradation, e.g. through high energy and resource use and that these impacts need to be reduced. The European Data Strategy recognises the need for availability of data for the public good. Among other uses, the Data Strategy indicates that data can serve to address societal challenges, combat environmental emergencies and to tackle environmental degradation and climate change. It sets an objective to capture the benefits of better use of data. Ensuring the availability of data and improving data usage are essential for tackling these societal, climate and environmental challenges.[10] The White Paper on Artificial Intelligence acknowledges the potential of AI to find solutions to societal challenges such as environmental degradation.[11] However, AI technology also has a significant environmental footprint, and these environmental impacts of AI systems throughout the whole AI lifecycle are addressed in the Coordinated Plan on Artificial Intelligence 2021[12]. Finally, the Commission's new Industrial Strategy for Europe[13] points to

[1] COM(2020) 652
[2] COM(2021) 400
[3] COM(2020) 667
[4] COM(2019) 640
[5] COM(2019) 640, p.9
[6] COM(2020) 67
[7] COM(2020) 66
[8] COM(2020) 65
[9] COM(2020) 67, p. 1
[10] COM(2020) 66
[11] COM(2020) 65, p.25
[12] Annex to COM(2021) 205

the twin ecological and digital transitions and the role of new technologies in supporting a sustainable transition. The Industrial Strategy also indicates the need for investment and innovation to deliver these new technologies.[14] It illustrates the significant business opportunities in these areas.

Reacting to the Commission's initiatives, the 2020 Environment Council conclusions[15] on '*Digitalisation for the Benefit of the Environment*' recognise the huge potential digitalisation offers in reaching the goals of the European Green Deal. In its conclusions the Council concurs with the Commission on the potential of the twin green and digital transition and emphasises it is a necessary approach to economic recovery after the COVID-19 pandemic. The conclusions stress an inclusive digital transition which limits the negative impacts of digitalisation while fully exploiting the opportunities of digitalisation. The conclusions also point to topics where the EU needs to act to best achieve the twin transition, giving the Commission political guidance on areas in need of specific attention.

One of the areas the Council encourages the Commission to act in are digital solutions for zero pollution. The conclusions encourage the Commission '*to develop an ambitious policy agenda for using digital solutions to achieve the zero pollution ambition*'.[16] By translating this request of the Council into practice, this document intends to give Member State administrations at all levels, the private sector and civil society an introduction to some available digital solutions for a better understanding of existing pollution challenges, to show examples and opportunities of applying digital technologies for pollution prevention and reduction while avoiding rebound effects, to guide towards available funding and investment opportunities and to encourage the take-up of these digital solutions to achieve the zero pollution ambition. In the same breath, the Commission will indicate, e.g. through development of a common open data platform on chemicals as announced under Chemicals Strategy for Sustainability, how digital solutions are applied to increase effectiveness and efficiency of processes assessing and managing chemical risks by the Commission, EU Agencies and the Member States authorities. Moreover, the document presents some examples of national strategies for green and digital transformation with the focus on highlighting digital zero pollution solutions. All this aims to inspire and promote the uptake and further development of clean digital solutions across the public and private sectors, and to help guide investments and encourage innovation and business opportunities in these areas.

New digital technologies are transforming every aspect of our lives. With the increasing use of sensors and IoT, data collected by satellites, GPS, Galileo - the European Global Navigation Satellite System, and social networks, we have seen a tremendous growth of data generated that – when combined with digital infrastructure and AI solutions – can facilitate evidence-based decision-making and expand our capacity to understand and tackle climate and environmental challenges. Data, algorithms and insights can provide actionable evidence on the state of the environment and interactions between the economy, society and the environment. If effectively leveraged, digital technologies can contribute to overall emissions reductions by up to 15%.[17]

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[13] COM(2020) 102

[14] COM(2020) 102, p.1

[15] Council conclusions on Digitalisation for the Benefit of the Environment (DOC 13957/20 of 11/12/2020) and press release

[16] Council conclusions, paragraph 18

[17] World Economic Forum, 2019

The **open public consultation** on the Zero Pollution Action Plan looked at two questions on digital solutions for zero pollution seeking to gather views of experts on the digital tools and services and how they can be used for achieving the zero pollution ambition[18].

In response to the first question, 36% of the respondents completely agree with the statement that significant investment is needed in innovation and digitalisation to help achieve the 'zero pollution ambition, followed by that digital solutions offer significant potential for reducing pollution (27%). Opinions diverge more when it comes to the statement on the use of digital tools by administrators to trace pollution and inform the public, where only 5% of the respondents completely agree and 12% completely disagree. Similarly, 12% of the respondents completely disagree with the statement that administrations are using digital tools to implement EU pollution legislation and enforce rules on the ground.

In response to the second question, nearly half of the respondents (48%) completely agree that information about pollution for consumers and businesses is an area with a big potential for pollution prevention, reduction and remediation. This is followed by data generation and monitoring of pollution (46%), data analytics and artificial intelligence (36%) and data transmission and management (32%). Based on the share of 'I don't know' responses, respondents are least sure about the potential of digital twins and models (42%), blockchain and distributed ledger technology (37%), and 3D printing or additive manufacturing (33%) as areas with a big potential for pollution prevention (see Figure 1).

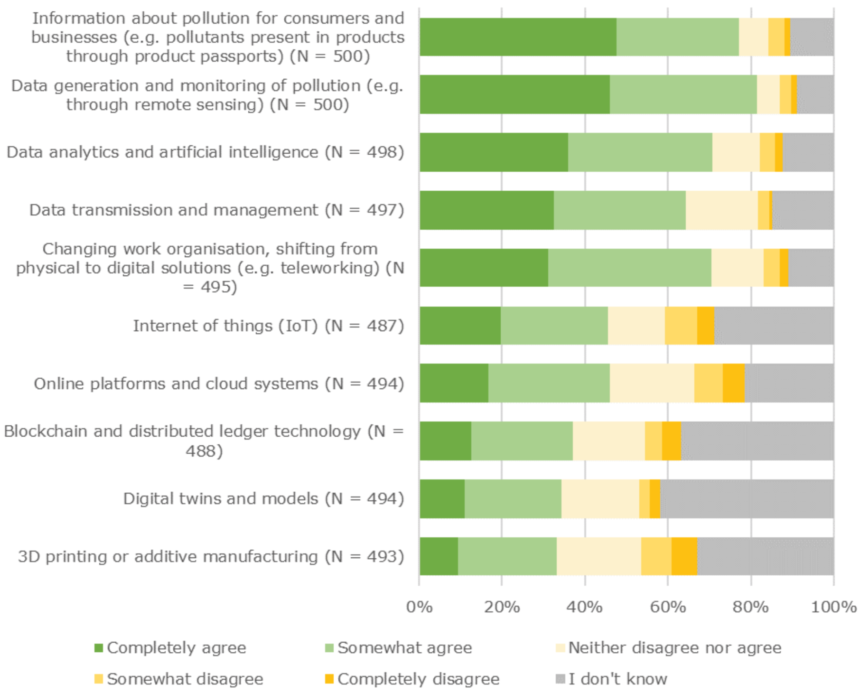

Figure 1: Feedback on the online public consultation on the question: "In your opinion, what are the areas of digital application with the biggest potential for pollution prevention, reduction and remediation?" (Ecorys 2021, see footnote 18)

[18] Ecorys (2021): "Consultations on the EU Action Plan towards a zero pollution ambition for air, water and soil", Synopsis Report (see 'Have your say' portal').

This paper will first discuss the role and relevance of pollution data[19] in section 2, and section 3 will point to possibilities digitalisation can provide in different areas and provide concrete examples of digital solutions already in use in different sectors. Section 4 will give an overview of available funding and investment opportunities. Finally, the last sections of this paper will discuss the pollution risks related to digital solutions (section 5), give some examples of Member State strategies with relevance for this paper (section 6) and provide some concrete recommendations on how to further the use of digital solutions to achieve the zero pollution ambition (section 7). Annex I of this paper will give a short overview of available digital technologies that can help reach the zero pollution ambition. The technologies listed in Annex I are not necessarily the only available technologies that can be deployed for such use, and new digital solutions are constantly being developed.

While processes related to monitoring and reporting as required by existing EU policy frameworks benefit from opportunities provided by digitalisation, these specific processes will be discussed by another Staff Working Document[20] accompanying the Zero Pollution Action Plan for Air, Water and Soil[21].

2. Pollution risks from digitalisation

Although the environmental benefits of digital solutions can largely outweigh their negative environmental impacts, the pollution risks related to digitalisation should not be overlooked. This section will give a brief overview of negative environmental impacts of digitalisation. Digital solutions need to be deployed sustainably and possible rebound effects avoided and addressed.

Digitalisation has a significant environmental footprint with the main impacts linked to energy and resource use. Different studies estimate the total greenhouse gas emissions of the ICT sector as a whole between 2-4% which accounts, e.g. for 8-10% of the European electricity consumption[22]. Part of this energy demand is used to generate, store and use data. Some of this energy is used by digital technologies such as blockchain and artificial intelligence, which can be deployed to aid the environment, but also consume a lot of energy[23]. Additionally, with 16kg of e-waste per person in 2019, Europe is the continent with the highest per capita waste generation[24] and although it is also the continent with the highest rate of formal e-waste collection and recycling, we currently recycle only around 40 % of our e-waste.[25]

As data flows increase, the energy consumption of data centres is bound to grow. Within the EU, data centres accounted for 2.7% of electricity demand in 2018 and will reach 3.2% by

[19] In the context of this document, the term pollution data is to be interpreted in a wide sense meaning all data relevant in one way or another for the measurement and understanding of pollution, be it data on the actual emissions or data on background conditions of soil, water or air.
[20] SWD(2021) 141: 'Towards a monitoring and outlook framework for the Zero Pollution Ambition'
[21] COM(2021) 400
[22] See e.g. Lotfi Belkhir and Ahmed Elmeligi (2018), ICTfootprint or the SHIFT project
[23] https://emagazine.com/environmental-effects-of-blockchain/
[24] https://globalewaste.org/map/
[25] Circular Economy Action Plan (2019) https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

2030 if development continues on the current trajectory.[26] Beyond energy consumption, data centres are also significant consumers of electronics and producers of electronic waste. The European Green Deal aims for the EU to become climate-neutral by 2050, and the Digital Strategy has announced '*initiatives to achieve climate-neutral, highly energy-efficient and sustainable data centres by no later than 2030 and transparency measures for telecoms operators on their environmental footprint*.' The Commission is currently exploring a number of policy options to achieve this objective.

Today's data centre landscape is a mix of large actors who commercially sell their capacity (often non-EU but with infrastructure operated in the EU) and actors who own their own data centres, notably many publicly owned data centres (hospitals, universities, public administrations etc.). The former are already fairly energy-efficient because of their own cost-cutting efforts, to the point where some already claim to be 'highly' energy-efficient; whereas the latter often lack the skills and technological and financial means to increase their energy efficiency. Over the last decade, efficiency gains have allowed keeping the increase in energy consumption under control, but the potential to unlock these gains is becoming smaller. The assessment of potential measures will be further supported by a study 'Greening cloud computing and electronic communications services and networks: towards climate neutrality by 2050'[27] which also looks at the wider environmental impacts. This study will feed into the on-going review of the Energy Efficiency Directive (EED)[28] and the Industrial Emissions Directive (IED)[29] and help assess whether also data centres should be covered by a similar permitting regime as industrial plants, with a view to minimise their harmful emissions/impacts.

The environmental impacts of digitalisation linked to pollution are less researched than the climate and energy impacts of digitalisation. A literature review[30] looked specifically at evidence of environmental impacts other than energy use and greenhouse gas emissions. Most of the pollution-related risks were indirect, in particular linked to the extraction of raw metals (cobalt, palladium, tantalum, silver, gold, indium and magnesium and other critical raw materials (CRMs)) as well as the production of microelectronic components. This is often analysed in life-cycle analysis (LCA) of ICT goods (e.g. phones, tablets, etc.), data centres or transmission networks. According to these LCAs, this contributes to fossil depletion, abiotic resource depletion, global warming, freshwater eutrophication, human toxicity, freshwater toxicity, marine toxicity, and terrestrial toxicity for ICT hardware[31]. However, available LCA studies applied to ICT are often not homogeneous or consistent, adopting disparate methodological choices. It is envisaged to promote in future the harmonisation of these LCA studies with the method for the calculation of the EU Product Environmental Footprint[32].

[26] Commission study 'Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market', SMART 2018/0028
[27] ongoing project
[28] Directive 2012/27/EU
[29] Directive 2010/75/EU
[30] Öko-Institute (2019): Impacts of the digital transformation on the environment and sustainability
[31] Öko-Institute (2019): Impacts of the digital transformation on the environment and sustainability, p.80
[32] https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html

Additionally, the potential risks to human health and the environment related to the production and use of chemicals needed for digitalisation should be recognised, while being already addressed under the relevant chemicals legislation.[33]

Furthermore, cooling water used in data centres can also be a concern causing heat and chemical pollution in rivers or lakes and having an overall large footprint on water consumption. E.g. a company's plan to build a vast data centre in central Luxembourg hit the headlines[34] because of concerns on the data centre's water consumption. It was estimated that the data centre's operation requires 10 million litres of water per day, which is about 10% of the country's overall water consumption with the excess heat being discharged into the river. The total amount of industrial waste heat in the EU is estimated to be 3,140 TWh. Waste heat from data centres is in the order of 56 TWh (2%)[35].

This is also one of the reasons why data centres require an environmental permit in some Member States such as Finland and Ireland.[36] During environmental permit consideration, the matters examined can include topics such as air emissions from diesel generators, storage and loading of generator fuel and other chemicals, water use and sewerage, noise, transport, waste including hazardous waste such as heavy metals and oils, impacts on soil and groundwater and impacts of water-cooled data centres on the receiving water bodies. The focus of the examination ultimately depends on the volume of the data centre's operations, its location, cooling and backup power solutions and other aspects.[37] In practice, permit regulations in Finland are issued particularly on the storage and treatment of waste and hazardous substances and on generator emission limits and, in the case of water-cooled data centres, the conveyance of water into water bodies. Air emissions from diesel generators with a rated thermal input equal to or greater than 1 MW are addressed by the Medium Combustion Plants Directive.[38]

Finally, e-waste contains precious materials and hazardous substances. Although the exports of e-waste to non-OECD countries are banned, a portion of the unaccounted e-waste goes to informal disassembly in developing countries, primarily in Africa and Asia.[39] This has already led to severe water and air pollution, soil contamination, and adverse health impacts for workers and the local population. In this context digital solutions such as tracking and monitoring of shipment of waste can be deployed to control and avoid e-waste pollution in Europe and abroad. Inappropriate collection, recycling, disposal of waste from metals (e.g. palladium, gold, copper) extraction and refining also causes toxicity and land use. At the same time, there are almost 700 million devices in Europe that are "hibernating" in EU households and that if recycled, could lead to the recovery of a lot of CRMs[40]. Overall, the pollution related pressures and impacts of digitalisation are still poorly understood and more research is needed. Nevertheless, this should not stop efforts to reduce energy use,

[33] Öko-Institute (2019): Impacts of the digital transformation on the environment and sustainability, p.72
[34] See article in Luxembourg Times of 21/11/2019
[35] Pärssinen, Wahlroos, Manner, & Syri (2019) in Oeke-Institute (2019)
[36] https://emagazine.com/environmental-effects-of-blockchain/
[37] Ministry of Transport and Communications 2020: The ICT sector, climate and the environment – Interim report of the working group preparing a climate and environmental strategy for the ICT sector in Finland
[38] Directive (EU) 2015/2193
[39] See also the CWIT project ("Countering WEEE Illegal Trade") at https://www.cwitproject.eu/
[40] Öko-Institute (2019): Impacts of the digital transformation on the environment and sustainability, p. 14,16 and 80

greenhouse gas emissions and resource use through better circularity, because these measures will implicitly also reduce the pollution footprint of digitalisation.

3. Zero Pollution Data

Data are the centrepiece of the digital agenda. Digitalisation has already helped generate, share, manage and re-use data more efficiently but latest technologies offer radically new solutions which are not yet commonplace. For example, once large amounts of data ('big data') are available, artificial intelligence and machine-learning algorithms can help analyse these data more effectively and allow processing and assessing large volumes of data which previously seemed a daunting task. Data and insights can help improve resource governance decisions, target financial investments, and change consumption and production patterns[41]. To achieve that, it will be important that 'big data' are digested and sense is made by creating knowledge and insights that are easily understandable and actionable.

[41] https://wedocs.unep.org/bitstream/handle/20.500.11822/27627/MeaProg2019.pdf

The monitoring of the implementation of environmental policies, and in particular those related to pollution, often require extensive data resources. Data collected to develop and implement environmental policies include:

- The quality of our environment, the air we breathe, the water we use, the contamination of soils, levels of pollution in species and ecosystems or accumulating in humans (so-called biomonitoring);
- Identification of polluting chemicals and their properties including understanding their impacts;
- The emissions, discharges and losses in the environment;
- The pollution sources and activities;
- The tracing and transfer of pollution in processes or via products;
- The underlying economic driving forces;
- The measures taken to address pollution and their effectiveness.

Such data are often generated and/or managed by public authorities on the basis of legal requirements, but also by academia and research entities investigating pollution related questions. The private sector also collects a lot of environmental data, but the data are not always publicly available. Increasingly, however, data held by the private sector are becoming available. Moreover, citizens and civil society can play an important role in generating pollution-related data (see *Digital Solution Story: CleanAir@School*) but they can also be engaged in debates and policy making which generates valuable opinions and contributions to the policy debate. For this, it is essential that environmental data are transparent, comprehensible and accessible to all actors at the relevant level of granularity. In other words, it is important for environmental and pollution data to be findable, accessible, interoperable and reusable. Applying these FAIR principles[42] are essential for the data to be used to their full potential.

Digital Solution Story: CleanAir@School
The CleanAir@School project encouraged school children to measure pollution levels, learn about air quality issues and promote actions for cleaner air. Pupils and teachers across Europe were given simple, low-cost devices to measure levels of nitrogen dioxide (NO_2) around their schools. Nitrogen dioxide is one of the key air pollutants harming human health in Europe, and it originates principally from road transport which is why it's a problem in urban areas. Children participating in the project measured nitrogen dioxide levels around their schools, while learning about air quality issues and ways to tackle them at the same time. One of the aims of the project was educational, but it also explored the use of data collected by citizens in complementing 'official' air quality monitoring data.[43]

Over the past decades, such data became digital, replacing gradually (but not yet fully), the analogue handling of data and information. Since 2007, the organisation, infrastructure and management of environmental data has also been standardised through the INSPIRE Directive[44] which implements the FAIR principles. But implementation is lagging behind and the full potential of such infrastructure investment is still to be realised.[45] In addition to the INSPIRE directive, many efforts in thematic domains are ongoing to improve standardisation

[42] see GO FAIR (http://go-fair.org)
[43] https://discomap.eea.europa.eu/cleanair/#
[44] INSPIRE: Infrastructure for Spatial Information in Europe (Directive 2007/2/EC)
[45] COM(2016) 478

for interoperability. For example for the marine environment the efforts under the European Marine Observation and Data Network (EMODnet)[46] and the Marine Strategy Framework Directive[47] use and complement the INSPIRE standards to bring the data holdings together. Promotion of IUCLID format for efficient exchange of any chemical information, extensively employed by the industry and the regulation (e.g. REACH), together with exchange standards developed under Information Platform for Chemical Monitoring (IPCHEM) will further contribute to efficient sharing under the common open data platform for chemicals. These efforts will also feed into the development of common open data platform by 2023 that was announced by the Chemicals Strategy.

More recently, digitalisation offered a number of new tools and opportunities which are applicable across all areas of pollution control policies. Such opportunities are related to generation and monitoring, collection and transmission, management, analytics and dissemination of data and actionable information. In more concrete terms, the application of digital solutions and data for the environment are manifold in particular (see also figure 2):

- Improving the evidence base, including the identification of emerging pollutants;
- Involving and engaging with citizens;
- Enhancing implementation and compliance;
- Strengthening the decision-making and solution finding process (governance);
- Reducing pollution by improving existing systems digitisation (e.g. smart mobility), smart applications or feedback processes.

In addition, data can be used to create innovative services, nudge behavioural change (including through network effects) and create new business models. Information and Communication Technologies (ICT) can dematerialise certain sectors, through novel business models, for example by increasing value-added in relation to natural resource use, by making the value chain more efficient or for example by focusing on the utility derived from a product (e.g. kilograms of clothing washed, kilometres driven, etc.) and not on the value of the product itself[48].

[46] https://emodnet.eu/en
[47] Directive 2008/56/EC
[48] https://core.ac.uk/download/pdf/16390705.pdf

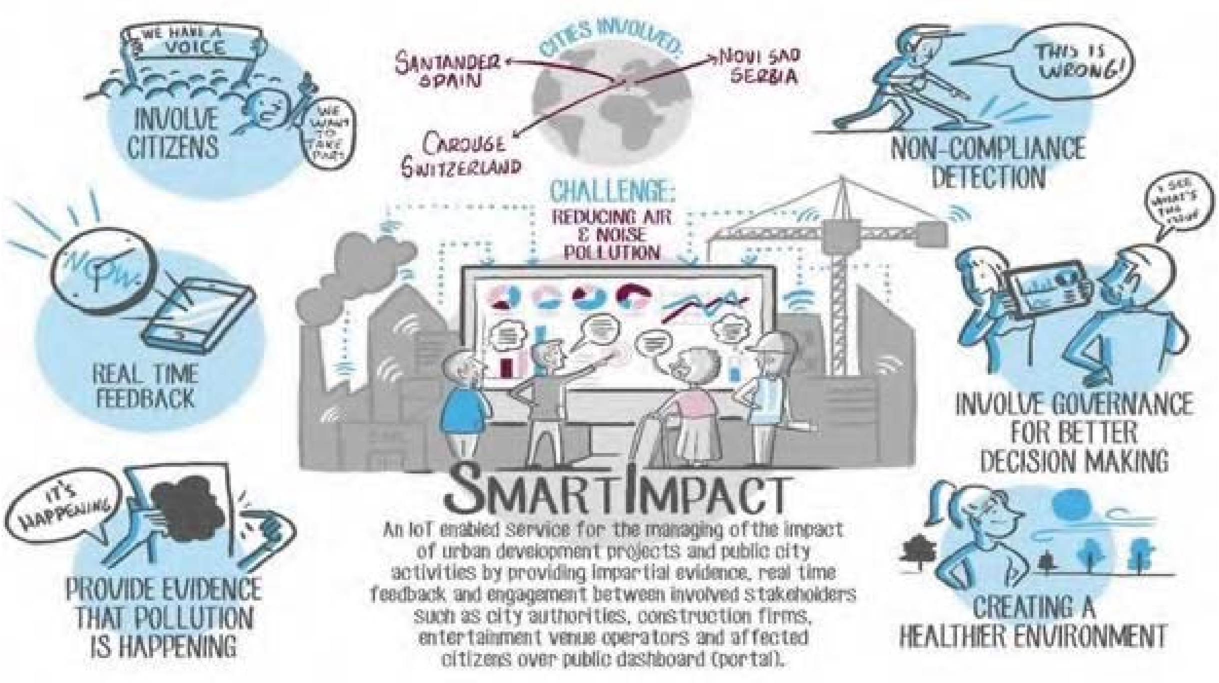

Figure 2: Using digital solutions and data for environment policy end implementation[49]

The European Data Strategy as well as the 'Green Data for All' initiative[50] are driving these developments in the EU. In addition, UN Environment is also working on a concept of the 'Digital Ecosystem for the Environment', which could be looked towards to provide inspiration from an international perspective.[51]

The pollution data aspects are briefly described in a generic way here and underpinned with some concrete examples in specific areas of application in the subsequent section.

3.1. Data generation and monitoring

The frequency of monitoring (e.g. of a pollutant chemical in waste stream) is often low, partly because it can be costly, and this may reduce reliability and robustness of the conclusions drawn from these data. Some parameters can be monitored with screening sensors which become increasingly powerful in collecting data automatically at very high frequencies and ever lower energy demands, hence lower costs. Examples exist for air[52], water[53] or noise[54] pollution. But also indirect measurement of pollution is possible, e.g. by

[49] INSPIRE Conference 2020 presentation by Srdan Krco (DunavNET)
[50] This initiative was announced in the European Data Strategy and it consists in evaluating and possibly reviewing the Directive establishing an Infrastructure for Spatial Information in the EU (INSPIRE), together with the Access to Environment Information Directive. It will modernise the regime in line with technological and innovation opportunities, making it easier for EU public authorities, businesses and citizens to support the transition to a greener and carbon-neutral economy, and reducing administrative burden.
[51] The Case for a Digital Ecosystem for the Environment: Bringing Together Data, Algorithms and Insights for Sustainable Development and The promise and peril of a digital ecosystem for the planet
[52] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6696184/
[53] https://www.researchgate.net/publication/342214402_Water_Monitoring_System_Embedded_with_Internet_of_Things_IoT_Device_A_Review
[54] https://www.mdpi.com/1424-8220/20/8/2256/htm

cameras detecting behavioural change of fish in case of water pollution[55]. Moreover, 'visible' pollution (e.g. oil, litter, nutrients causing algae blooms) can be detected and therefore monitored continuously with cameras or other sensors installed on satellites, planes, ships, drones or fixed installations. Citizen science can also be used to report such 'visible' pollution (see *Digital solution story: See it? Say it!*).

Digital solution story: See it? Say it!
The '*See it? Say it!*' -app of the Irish Environmental Protection Agency makes it easy to report environmental pollution. The app can be downloaded to most smart phones, and enables citizens to report pollution when they see it. The app is very simple to use: when a user spots environmental pollution or dumping, they can take a photo of the pollution, add some simple details, and submit a complaint. The app will send GPS coordinates of where the photo has been taken, so it's easy for authorities to locate and investigate the problem.[56]

The power of these increasing possibilities is dramatically enhanced through the potential offered by the internet of things (IoT), since such sensors can be easily connected, or 'edge computing', since the (pre-)-analysis of data is already done through the small processors in the sensors. Such opportunities will not replace traditional monitoring efforts or needs but complement them. They allow for a more effective and efficient collection of data (e.g. samples could be taken only when the sensor data indicate a potential pollution) and, therefore, help increase responsiveness, relevance, resolution and certainty of pollution assessments based on these data.

3.2. Data transmission (real-time data) and management

For centuries, data were collected and transmitted through reporting, i.e. the transfer of the data and information from the data owner to the data user. First, we used paper and then increasingly digital means as computers entered our lives. While there are also other reasons for lags (e.g. quality control), such 'reporting' is often inefficient leading to, sometimes, considerable time lags between the data collection, processing, analysis and its publication.[57] This causes lack of efficiency and reduces the value of the results the more outdated the data are. Increasingly, real time data sharing ('machine-to-machine') is being used, and these technologies are becoming more and more powerful.

[55] https://www.researchgate.net/publication/325481761_Aquatic_Toxic_Analysis_by_Monitoring_Fish_Behavior_Using_Computer_Vision_A_Recent_Progress
[56] http://www.epa.ie/enforcement/report/
[57] see e.g. Fitness Check of environmental monitoring and reporting (COM(2017)312 and SWD(2017)230)

Digital solution story: Earth observation and Copernicus

Copernicus is the European Union's Earth observation programme. The satellite and in situ (non-space) observations Copernicus services deliver provide near-real-time data globally, and this data can be used to help us better manage our environment in a sustainable way and to understand our planetary processes. The data collected by satellites and in situ systems such as ground stations that deliver data from sensors on the ground, at sea and in the air, is processed and analysed by the Copernicus services, transforming the vast amounts of data into information that can be used by end users acting in a wide range of areas such as regional and urban planning, transport and mobility and agriculture. The main users of the Copernicus services are public sector actors, but the information services Copernicus provides are free and openly available to all users.[58] The strength of this unique European digital capacity, combining satellite and in-situ observations with state-of-the-art atmosphere model outputs and Artificial Intelligence, enabled Copernicus also to assess the impact of societal measures in scope of the COVID-19 on air pollution levels in Europe. Other examples are:

- 'Litter-TEP' application[59] is using the Copernicus Marine data to develop to forecast macro waste drift in the marine environment. Such tool allows running forecasts of ocean currents, waves and winds to monitor marine litter in the Atlantic European North West Shelves seas. It provides forecasts of marine macro waste drift (density, potential stranding on beaches) and, inversely, the likelihood of where the waste has entered the sea. The service takes into account waste from rivers and their related upstream watersheds, which collect surface litter after precipitation.
- The FML-TRACK service[60] support the reduction of floating marine litter pollution in south Eastern Bay of Biscay to help the collection of waste in the marine environment by public administrations, both at sea and on beaches. It combines video monitoring in rivers, satellite imagery at sea, and ocean observation and modelling to track floating marine litter and help reducing its presence in the coastal area. Beyond that, Earth Observations Data Cubes (EODC) are a new paradigm revolutionizing the way users can interact with Earth Observation (EO) data. They can provide access to large spatio-temporal data in analysis ready format. Systematic and regular provision of Analysis Ready Data (ARD) can significantly reduce the burden on users by minimizing the time and scientific knowledge required to access and prepare remotely-sensed data. The proliferation of data cubes and the availability of ARD is therefore lowering the barrier to access and utilise satellite "big-data" datasets.

A precondition for this is 'open data', the availability of the data in the public domain or accessible with a minimum of restrictions. In some cases, where opening data fully is not possible (yet), effective sharing of data under certain conditions should be ensured. Regulation on this has already been introduced some time ago (e.g. access to environment information directive or INSPIRE Directive[61]) and recently has received a new boost through the revised Open Data and Public Sector Information Directive[62] and concrete actions on chemicals data access and sharing under the Chemicals Strategy for Sustainability. As mentioned above, the Commission's Data Strategy has also made it clear that open public

[58] https://www.copernicus.eu/en/about-copernicus
[59] https://litter-tep.argans.eu
[60] https://fmltrack.rivagesprotech.frhttps://fmltrack.rivagesprotech.fr
[61] Directive 2007/2/EC
[62] Directive (EU) 2019/1024

data should become the norm in future (provided existing legislation on personal data protection and others are respected). The latter is particularly true for environmental and pollution data which must be, by default, open.

Open data enable to reverse the business process from sending the data from the owners to the users (reporting) to ensuring that the owners keep their data up to date and accessible and then the users can retrieve the latest data in real time. This was, e.g. used for creating global, daily updated, statistics on the evolution of the Corona crisis by the Johns Hopkins University[63] or is implemented in the context of the Air Quality Index[64].

For nearly all data relevant to zero pollution, the INSPIRE Directive sets out the rules and standards making such an approach applicable across different data domains. Many good examples exist on how such an approach has increased effectiveness and efficiency of data transmission and management.[65] However, there are considerable implementation gaps and more investment and efforts are needed to deliver on the promise that relevant pollution data can then be shared between administrations in near-real time.

It is important to note that the availability of so-called High Value Datasets[66], will also include some data relevant for zero pollution (or could in future) that Member States will have to make available, free of charge, in a machine-readable format, through Application-Programming Interfaces (APIs). Finally, beyond open data, the Commission foresees the creation of common European Data Spaces, including a Green Deal dataspace[67]. The common open data platform on chemicals with its vision to facilitate sharing access and re-use information on chemicals from all sources, as announced by the Chemicals Strategy for Sustainability, represents an important part of this dataspace. This will allow not just access to open data, but also effective data-sharing for all public and private data; i.e. getting access to data that may not be open, but be useful for innovative service creation. The proposed Data Governance Act[68] supports the governance of these dataspaces, strengthen data-sharing mechanisms within the EU, foster the availability of data for use and increase trust in data intermediaries. The EU-funded Support Centre for Data Sharing also provides support, technical tools and expertise to facilitate data-sharing.[69] Finally, the planned Data Act will foster data sharing among businesses, and between business and governments.[70]

3.3. Data analytics and digital twins

Tools for analysing data have become very powerful over the past years. With artificial intelligence and machine-learning, there is a significant potential to reduce the environmental and climate footprint, e.g. through smart buildings, the smart grid, smart circular economy, forecasting and observation, influencing the behaviour of individuals (see *Digital Solution Story: DigiTranScope*), and smart production systems and processes.

[63] https://coronavirus.jhu.edu/data
[64] https://www.eea.europa.eu/themes/air/air-quality-index/indexhttps://www.eea.europa.eu/themes/air/air-quality-index/index
[65] e.g. during the various INSPIRE Conferences
[66] More information on high value data sets
[67] The European Dataspaces will be rolled out gradually as of 2021 with support, e.g. from the Digital Europe Programme.
[68] Proposal for a Data Governance Act (COM(2020) 767)
[69] https://eudatasharing.eu/
[70] COM (2020) 767, p. 13

The data analytics is supporting better simulation of chemical properties and predicting potential hazard, exposure and fate of chemicals, supporting early warning, identification, monitoring strategies and prioritization of chemicals, and management of chemicals of concern. Development is in place to enable these tools to be seamlessly connected with the vast chemical datasets shared through the common open data platform.

Data- and physics (models)-based analytics have traditionally been quite separated approaches to generate informed predictions. With the advent of 'digital twins' for complex systems analysis purposes, possible nowadays due to significantly increased computing power and new data fusion approaches, a seamless fusion of both basic approaches has been achieved aiming ultimately towards having simulations indistinguishable from observations at very high levels of spatial and temporal resolution.

Local digital twins are digital models of a city. Local digital twins can model and visualise complex processes and data and thus have the capacity to tackle complex challenges for cities[71]. While urban planners have already been using 2D and 3D models and computer-aided design for years, the integration of real-time data from IoT devices, location, weather, traffic, people movement, and other sources has been a game-changer for urban planning and operations.[72] Local digital twins will enable cities to significantly improve their urban planning. Local Digital Twins will help cities, for example, make predictive sustainable mobility planning, create data-services related to extreme weather events, risk prevention and disaster resilience, better manage energy flows, or pursue their zero pollution ambition.[73] Various local digital twins have been created in Europe, such as the Amsterdam City Dashboard, the Helsinki Energy and Climate Atlas, the Rotterdam Digital Twin and the Flanders DUET Digital Twin (see *Digital solution story: the Flanders DUET Digital Twin*).

[71] https://www.mdpi.com/2071-1050/12/6/2307/htm
[72] See for example: 'Connecting urban environments with IoT and Digital Twins'
[73] See discussion forum here.

Digital Solution Story:

1. ***DigiTranScope***

The DigiTranScope project explored how the availability of data and the possibility to create virtual replicas (Digital Twins) of neighbourhoods, cities, and entire countries allows new forms of policy targeting. The project experimented with this in Amsterdam in the context of targeting policies to support increased energy efficiency in households. The opportunities offered by the Digital Twins and gaming environments (e.g. the whole of the Netherlands in Minecraft in the scale of 1:1) for new forms of participation and policy design were illustrated by an experiment done in Amsterdam, where 500 children came together with the local administration, industry and academics to use this virtual model in Minecraft to help design their vision of the future for their neighbourhood.[74]

2. ***the Flanders DUET Digital Twin***

An example of an EU-funded project on local digital twins is the DUET project.[75] The Flanders region in Belgium (Informatie Vlaanderen) is coordinating the DUET project together with strategic Flemish/Belgian partners such as IMEC, KUL and OASC. Flanders will use the Flanders DUET Digital Twin to help the city and its stakeholders explore correlations between mobility, air and noise data. The goals Flanders has set for the digital twin use are the following: '(1) Creating a Smart Region where all involved players can access available services and data; (2) Support cross-silo cooperation between sectors; (3) Involve citizens and companies active in policy-making processes to improve the quality of decision making and acceptance of the outcomes; (4) Setting up transferable services and data standards to maximise efficiency, scalability and open the market.' The digital twin will concentrate on implementing and evaluating actions and designing new measures by providing a tool that enables cross-domain evidence-based 'what if' simulations and opens the outcomes via dashboards and gamification techniques to the public.

Digital twins also have the potential to provide services for the assessment and prediction of environmental pressures, including their trends and extremes, at very high spatial resolution and close to real-time decision-making support at continental, country, coastline, catchment and city scales in response to meteorological, hydrological and air quality extremes. Such systems aim to seamlessly combine weather, hydrology and air quality observation and simulation capabilities at levels that represent a real breakthrough in terms of accuracy, local detail, access to information speed and interactivity. Corresponding digital twins should cover land-based pollution as well as waterborne pollution, and their impacts on the atmosphere, terrestrial ecosystems, freshwaters and the marine environment. Digital twins can be created on many different scales, a very large-scale example being Destination Earth, a project to create a digital twin for the earth (see *Digital solution story: Destination Earth*), or the Digital Twin of the Ocean, recently called under the Horizon 2020 Green Deal Call.[76] The Digital Twin of the Ocean aims at integrating and completing existing European assets such as Copernicus and marine research and data infrastructures with digital technologies such as AI and high performance cloud computing. These will be used to transform data into knowledge and to empower citizens, governments and industries to collectively share the

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[74] https://www.euscp.org/DigiTranScope.html)

[75] https://www.digitalurbantwins.com/

[76] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-gd-9-3-2020

responsibility of marine and coastal habitats, to support a sustainable Blue Economy and to mitigate and adapt to climate change.[77]

Digital solution story: Destination Earth
One headline project on digital twins relevant for the zero pollution ambition is *Destination Earth*.[78] It was announced in the European Data Strategy and will be financed partially through the Digital Europe Programme. Commencing in 2021, the initiative will lead to the development of a high precision digital model of the earth, a digital twin for the earth, which can be used to visualise, monitor and forecast natural and human activity on our planet. This will support Europe's efforts for a better environment as set out in the Green Deal. The breakthrough features expected to come from Destination Earth go beyond the significantly increased accuracy and availability levels of predictions coming from seamless fusion of observations across the entire digital continuum such as satellites, in-situ, IoT and citizen science. It will also lead to the open availability of and access to knowledge generation for non-experts, including an underlying quality mapping of all predictions generated resulting in a quality index. The results can therefore be used for operational outcomes (e.g. decision support purposes) in view of them being easily understandable.

3.4. Data visualisation and dissemination

There is a growing demand for data visualisation to enhance the overall dissemination of data and information. Powerful tools, which will be essential components of the digital twins, have emerged which give a quick insight into the data (e.g. through dashboards), support decision making (through business intelligence tools) and improve communication and information of others making things more memorable and attractive.

Digital solution story: The European Atlas of the Seas and WISE-Marine
The European Atlas of the Seas provides information about Europe's marine environment and is the ideal tool for schools, professionals, or anyone wishing to know more about the European seas and its coastal areas. Users can view predefined and ready to use maps, covering topics such as nature, tourism, security, energy, passenger transport, sea bottom, fishing stocks and quotas, aquaculture, and much more. Users can also benefit from an enriched catalogue with more than 200 map layers, covering a wide range of topics, to explore, collate and create their own maps. These maps can be printed, shared and embedded in articles or presentations.[79] The European Atlas of the Seas contains some information on pollution, but more information specifically on environmental and pollution aspects can be found in WISE-Marine, which has also set new standards of visualisation by presenting the data collected as part of the Marine Strategy Framework Directive implementation in visual form (such as maps and dashboards).[80]

Data, and more importantly knowledge visualisation have become an area for significant further research needs. As non-experts can increasingly access specialised digital resources, the importance of how data are used and presented has become more and more important.

[77] https://ec.europa.eu/info/sites/info/files/research_and_innovation/green_deal/gdc_stakeholder_engagement_topic_09-3_digital_ocean.pdf
[78] https://ec.europa.eu/digital-single-market/en/destination-earth-destine
[79] https://ec.europa.eu/maritimeaffairs/atlas_en
[80] https://water.europa.eu/marine

There is a significant potential for misinterpretation of sustainability related predictions and analytical results if the data are not presented in a clear way. Visualisation of data can be used to 'connect the dots' related to the granularity of the data used, but it is important to be cognisant of the target audience.

3.5. Data services

Electronic data services and the use of standardized Application Program Interfaces (APIs) are the main building blocks for guaranteeing interoperability and cross-domain reuse of data between systems, end-users, processing platforms and European data spaces.

The use of pollution and other related data, combined for example with spatial data can unleash new innovations that respond to societal needs such as reducing the negative impact on the environment. This can also contribute to engaging citizens, businesses and civil society in the collaborative design, production and delivery of public services and to facilitate interaction between public administrations and businesses and citizens.

4. Digital solutions: examples and use cases

The aim of this section is to give some concrete applications of some of the digital technologies discussed in previous sections and in Annex I. They are grouped in the thematic areas of relevance for achieving the zero pollution ambition and the areas and examples covered are illustrative but not exhaustive.

4.1. Smart, sustainable and resilient cities and communities

Smart cities and communities use digital technologies to reduce resource input and improve the quality of life for their citizens. When carefully designed, they are therefore optimally positioned to demonstrate how the envisaged 'twin digital and green' transition can be accomplished. Clean solutions can strive to create healthy environments with minimal environmental stressors, maximise the efficiency of energy (see above *Digital Solution Story: DigiTranScope*) and material use, create a zero-waste system, support renewable energy production and consumption as well as promote carbon-neutrality and reduce pollution.[81] [82] The use and combination of clean technologies, such as for example IoT and AI applied to urban systems will foster innovative business models, new services and better resource management (see *Digital Solution Story: AI4CITIES*).

[81] https://journalofbigdata.springeropen.com/articles/10.1186/s40537-019-0221-4
[82] McKinsey Global Institute, 2018

Digital Solution Story: AI4CITIES

An example of a project aiming to use AI for solutions to accelerate carbon reductions is the AI4CITIES-project. The solutions developed as part of the project might also have synergies with reductions in air pollution, or give inspiration on how AI can be used for pollution reductions in addition to climate action. AI4CITIES is the first European Pre-Commercial Procurement (PCP) action seeking to turn Cities Carbon Neutral with the use of Artificial Intelligence. 2020-2022. It brings together a group of leading European cities and regions (Helsinki, Amsterdam, Copenhagen, Tallinn, Stavanger and the Paris Region), in the intersection of 'smart cities' and greenhouse gas emissions reduction, in order to speed up and steer the creation of new breakthrough solutions in how AI can support cities' climate action commitments.[83]

While cities and communities may have data and digital technologies available, they need to act together to increase impact and allow a stronger control over the final solutions chosen. One of those collective efforts at the EU level will be around the planned creation of a dataspace for climate-neutral and smart communities as part of the Green Deal (common European environmental) dataspace. This data space will facilitate the access, sharing and re-use of locally-relevant data in areas such as mobility, energy, climate and zero pollution for cities aiming to pursue a twin digital and green transition. Recent studies[84] indicate that cities should implement interoperable, urban data platforms using a common set of open standards in order to remain flexible in choosing their technology providers and create value from their data for the common good. This approach, promoted by the 'Living-in.eu'[85] movement and community will also allow the management of cross-domain data and help cities ensure citizens' digital rights. Finally, it is considered that artificial intelligence and local digital twins can be a powerful means for cities and communities to make well-informed decisions.

[83] https://ai4cities.eu/
[84] Erasmus Centre for Data Analytics, 2020
[85] https://www.living-in.eu/

Digital solution story: SynchroniCity

The Internet of Things (IoT) and Artificial Intelligence (AI) can be used to improve the lives of citizens and to grow local economies in cities and communities. SynchroniCity was an EU-funded large-scale pilot that aimed to develop a global market for such IoT- and AI -enabled services. Under the SynchroniCity project, various digital applications with the potential to address air pollution were put forward:

- Clean Air School Districts (CAST) (by the company Leapcraft[86]) implements air quality and noise sensors as a part of smart cities and communities. In this pilot, emissions data are collected, which are then used to test new strategies to control emissions, drive awareness and encourage change in behaviour.[87]
- Autonomous Air Quality Management (AAQM) will provide tailor-made solutions to improve air quality in public spaces. It will help citizens understand the importance of air quality. Cities will also benefit, as the IoT and AI -based system will make air quality management more efficient, real-time overview of air quality will be provided and costs will be saved through autonomous planning. AAQM provides a full cycle solution and integrates all the necessary steps. It collects data on air quality via data sensors, applies relevant open data for analytics to the planning process, provides automatic alerts and schedules necessary maintenance tasks, and executes the required follow-up and reporting.[88]

Clean Air School Districts is commercially available, while Autonomous Air Quality Management is still under development.

4.2. Smart mobility reducing air and noise pollution

The Commission's Sustainable and Smart Mobility Strategy recognises the key role of digitalisation in modernising the transport system.[89] The European Industrial Strategy points at the key role of smart and sustainable mobility industries in driving the shift towards a twin digital and green transition.[90] Digital technologies provide a vast amount of solutions for reducing pollution from transport, ranging from solutions already widely in use such as digital navigation apps allowing to re-route along the most efficient or cleanest route preventing and avoiding traffic jams to solutions such as autonomous vehicles, one of the key application areas of AI. AI-based autonomous vehicles have been estimated to lead to annual emission reductions of 2-4 %.[91]

Cooperative intelligent transport systems can make transport safer and more efficient. For instance, Green Light Optimal Speed Advisory (GLOSA) systems provide drivers with speed advice that allows them to pass traffic lights during a green interval. This can help reduce the amount of pollutants being emitted into the air from traffic. Additionally, 'smart traffic lights' can reduce the number of stop-and-go waves and could be used to give priority to public transport or cyclists. These AI-based solutions can lead to a reduction of driving time and subsequently reduction in air emissions.[92] According to estimates, the reduction of stop-and-

[86] www.leapcraft.dk
[87] https://synchronicity-iot.eu/project/clean-air-school-districts-casd/
[88] Autonomous Air Quality Management under Synchronicity project
[89] COM(2020) 789
[90] COM(2020) 102
[91] Igliński & Babiak, 2017; Liu, Zhao, Liu, & Hao, 2019; Pyper, 2014
[92] Vox Creative, 2018

go waves, i.e. the introduction of a 'green wave' can potentially lower the levels of air pollution by 10-40%.[93]

As with most application areas, data is key for smarter, more sustainable traffic. Enhanced traffic management requires data collected through vehicles and sensors, and more interaction between infrastructure and vehicles. Digital technologies and data enable the use of MaaS (Mobility as a Service) applications, which make it possible to combine and to compare the sustainability of different options and encourage public transport and active modes. Cycling can be made more attractive through intelligent transport solution such as data collection on bicycle use, better information provision and interactive systems for bike-sharing.

Connected and Automated mobility is enabled by digital solutions and could encourage car-sharing schemes, smoothen the use and therefore accelerate the uptake of electric vehicles and ultimately free up parking space for other purposes in urban areas. Electric vehicles do not emit exhaust emissions, thus providing positive impacts on local air quality. They can also help reduce noise pollution from traffic, especially in urban traffic where speeds are low.[94] New digital-based technologies such as smart and bidirectional (V2G) charging have the potential to automatically distribute the available power between the charging points and the electric vehicles that are being charged simultaneously (see *Digital solution story: Smart electricity grid and e-mobility*). In particular, V2G enables to balance variations in energy production and consumption making use of the energy storage capacity of electric vehicle fleets to increase integration of renewable energy sources (RES) into the smart grid.

Digital solution story: Smart electricity grid and e-mobility

The RUGGEDISED project[95] is a smart city project to test, implement and accelerate the smart city model across Europe. Working in partnership with businesses and research centres, six cities will demonstrate how to combine ICT, e-mobility and energy solutions to design smart, resilient cities for all. This means improving the quality of life of citizens, reducing the environmental impact of activities and creating a stimulating environment for sustainable economic development. Rotterdam is one of the cities participating in the project, and will be implementing 13 smart solutions, two of these solutions being solutions to minimise and optimise the usage of electricity and avoid peak load demands in the electrical network by using photovoltaic (PV) panels. PV panels will be installed on the roofs of public buildings, and solar heat will be transformed into direct current electricity and stored in a direct current (DC) battery. All electric buses will get their electricity from loading poles connected to the battery by means of an electric DC grid. Additionally, private electric cars will also be charged with electricity from the electric grid. Replacing about 270 conventional buses with electric buses will result in improvement of air quality in the whole region as well as a reduction of the carbon footprint of public transportation.[96]

Electronic tolling make tolling operations more efficient, especially when applied network-wide and without physical barriers. Electronic tolling can efficiently reduce pollution from both heavy- and light vehicles in road transport provided that the tolls incentivise sustainability, for example via differentiated distance-based tolls. Finally, digital technologies can make it easier to share info about and enforce Urban Vehicle Access Regulations

[93] Coensel, Can, Degraeuwe, Vlieger, & Botteldooren, 2012
[94] https://www.eea.europa.eu/highlights/eea-report-confirms-electric-cars
[95] https://ruggedised.eu/home/
[96] https://ruggedised.eu/fileadmin/repository/Factsheets/Ruggedised-factsheet-R5-R6-Rotterdam.pdf

(UVARs), which reduce air pollution in cities, but are only useful if people get correct information on the diversity of UVARs and if these rules can be enforced (see *Digital solution story: UVAR Box*).

Digital solution story: UVAR Box
The EU-funded project UVAR Box aims at fostering the real-time information of road users about urban and regional access schemes and will carry out a pilot project focusing on enabling road users, in particular motorists (i.e. both professional and non-professional drivers) to be fully informed about urban and regional access schemes. This includes working on the needed enablers, i.e. standardisation and data provision for the integration of the information in tools such as apps or navigation devices.[97]

The benefits of digitalisation are not restricted to road transport. Digitalisation of waterborne transport and ports also creates opportunities for economically, environmentally efficient, socially inclusive, secure and sustainable waterborne transport. For example, Big Data Analytics, including vessel traffic service (VTS) data and tide data, can be used to forecast expected times of arrivals or departures of vessels in seaports.[98] This enables the better utilization of suprastructures on port terminals while avoiding congestion pollution caused by a long time to berth and gate for ships and trucks respectively in sea and inland[99] port areas. At the same time, this gives ships and trucks the possibility to adjust their speed, reducing fuel consumption and greenhouse gas and air pollutant emissions.

The applications of digital technologies in transport with the potential to help achieve the zero pollution ambition are not limited to the applications mentioned above. The potential solutions are manifold and can result in benefits for the environment such as reduction of air and noise pollution and greenhouse gas emissions, as well as monetary savings and increase in transport efficiency from all sectors.

4.3. eHealth and environmental pollution

The major non-communicable diseases (diabetes, cardiovascular diseases, cancer, chronic respiratory diseases and mental disorders) together account for an estimated 86% of the deaths and 77% of the disease burden in the European Region. Environmental pollution has been linked as a cause to many of these diseases. Among the top 10 of non-communicable diseases driven by environmental pollution, cancer has the sad honour to rank first. Hence, linking efforts on eHealth with pollution data and solutions can make a tangible difference in addressing these health risks.

In the context of the Europe’s Beating Cancer Plan the potential of data and new technologies is explored. It is key to have better infrastructure in place to ensure up-to-date and comparable health data that allows us to use it for research purposes as well[100]. The planned European Health Data Space (EHDS) will help to advance on this as it would foster the exchange and sharing of different kinds of health data (electronic health records, genomics, registries, etc.) in Europe. The European Health Data Space will promote safe and secure cross-border health data exchange and support research into new preventive strategies,

[97] https://uvarbox.eu/
[98] https://www.seatrafficmanagement.info/ and first ideas on ‘Digitalization of Seaports’
[99] https://www.clinsh.eu/
[100] https://ecis.jrc.ec.europa.eu/

treatments, medicines, medical devices and outcomes[101]. The European Health Data space is not limited to cancer but applies for all areas of health and care. Data on environmental pollution could be a valuable contribution to this and hence a link to the Green Deal Data Space could be envisaged. E.g. The strengthening of interoperability and linkages between environmental and health data can bring large benefits to predicting the general health status of populations. Digital solutions will facilitate sharing data between sectors.

Another example of links between environmental and health data relates to data collected in the water sector from sewage monitoring. It can be used to detect for example the presence of the COVID-19 virus in the population[102], the use of illegal drugs or the amount of over-the-counter antibiotics being consumed by the population (see *Digital solution story: sewage monitoring and population health*).

Digital solution story: sewage monitoring and population health
The EU-funded project SCOREwater will use a sensor network connected to the SCOREwater online platform to monitor wastewater from the sewer network in Barcelona. AI based on machine learning will be used to obtain information at a neighbourhood scale on practices such as dietary habits and household waste management. The gained information will be used to reduce the discharge of antibiotics into the environment, promote healthier dietary habits, prevent damaging discharges of wet wipes, oils and greases into the sewer system and decrease sewer maintenance costs by the means of surveys, education campaigns and social media campaigns. [103]

The burden on health systems caused by non-communicable diseases, respiratory diseases in particular, due to environmental pollution including air pollution remains an important public health challenge. In this context the Commission in 2021 launched a call for best practices on the prevention on non-communicable diseases[104] under the Steering Group on Health Promotion, Disease Prevention and Management of Non-Communicable[105]. The work on digital solutions to reach zero pollution and thereby reducing the burden caused by non-communicable disease due to environmental pollution will take account of the research activities under the Horizon Europe programme and the relevant projects under the EU4Health programme.

Understanding health and environmental impact from pollution is already an integral part of chemical policy implementation, resourcing data from multiple sources (soon to be available jointly under the common open data platform) to identify chemicals of concern and develop appropriate risk management measures.

To conclude, the benefits of sharing data between the environmental and health sectors are clear, and new digital solutions can contribute to both collecting relevant data in a more efficient way, but also to sharing data seamlessly and effortlessly between different sectors for the benefit of all. These can in turn trigger technical measures and policy actions to

[101] Already now, citizens from 7 Member States can share their data with healthcare professionals of their choice when travelling abroad, using MyHealth@EU digital service infrastructure. Other 8 Member States are expected to join in 2021.
[102] https://ec.europa.eu/environment/pdf/water/recommendation_covid19_monitoring_wastewaters.pdf
[103] https://www.scorewater.eu/
[104] https://webgate.ec.europa.eu/dyna/bp-portal/
[105] https://ec.europa.eu/health/non_communicable_diseases/steeringgroup_promotionprevention_en

reduce pollution in targeted sectors or areas. Efforts towards zero pollution and the application of digital solutions to reach this ambition can benefit both the health sector and the environment. Likewise, health data can be used to support action towards zero pollution.

4.4. Digital Water Protection

Digitalisation of the water sector through technologies such as artificial intelligence (AI), digital twins, digital data spaces, disruptive technologies and instrumentation and circular economy digital water innovations can result in significant environmental, operational and economic benefits. Digital water solutions reduce the environmental impact of water operations via a) reductions in energy demand for water supply and sanitation services; b) better control of emissions from wastewater treatment plants; c) enhanced capabilities for real-time, in situ water quality monitoring; and d) increased water use efficiency across sectors and reduced leakages. Digitalisation is a critical tool in advancing global water security and protecting the planet's water resources sustainably. Overall, digital technologies provide a wide array of possibilities for achieving the zero pollution ambition in the water sector.

The EU has recognised the link between ICT and water protection and promoted the possibilities digitalisation brings to the water sector by establishing the ICT4Water cluster, a community of 61 EU-funded research and innovation projects on digital innovations for water.[106] In the context of the cluster, several studies and reports on digital water have been published in previous years[107] More recently, their reports look at the business models, research and innovation opportunities ("*The need for digital water in a Green Europe"*[108]*, "Business models for digital water solutions"*[109] and *"ICT4Water cluster: vision and showcases"*) .

Digital solution story: Smartening water management
Digital solutions to improve management of drinking water sources, treatment and supply is a rising priority in European projects. The Fiware4Water[110] project is smartening management tools by testing real-time operational monitoring, management and control of source water. The project is testing online sensors for water quality parameters (temperature, turbidity and conductivity) and the use of AI for water quantity and quality analytics. Furthermore, for drinking water supply systems in urban areas, the project is introducing real-time monitoring of water quality parameters and water quality and quantity analytics by integrating sensors (e.g. chlorine and pressure sensors) into an online control system, assessing multi-parameter water quality probes.

Many of the technologies developed in ICT4Water projects have been successfully commercialised, and the digital solutions developed target challenges such as real-time modelling, operational and preventive management of water systems (see *Digital solution story: Smartening water management*), AI-based monitoring of plastics in urban networks, new computer vision-based methods to assess the condition of sewers, and drone-based technologies to perform effective inspections. Of the EU-funded projects, three main digital

[106] https://ict4water.eu/
[107] Action Plan for Digital Market Water Services (2018) ; Action Plan implementation report (2020)
[108] ICT4Water publication (2021a): "The need for digital water in a green Europe"
[109] ICT4Water publication (2021b): "Business models for digital water solutions"
[110] https://www.fiware4water.eu/

solution types, data driven intelligence, smart sensors/drones and models/simulation account for the 67% of the ICT technologies used so far.[111]

Based on experiences from the ICT4Water cluster, many digital solutions for achieving the zero pollution ambition in the water sector already exist. The use of data analytics, IoT (see *Digital solution story: IoT in water monitoring*), cloud computing, augmented intelligence, blockchain and the development of digital twins in the water sector give new capabilities to analyse, automate, correct in real time, predict and minimise risks to the natural environment. In addition, digital solutions can be deployed to raise awareness and involve citizens and consumers and influence their behaviour. Furthermore, digital solutions for the water sector are not restricted to water suppliers' infrastructure. Domestic water distribution systems can also benefit from digitalisation. Among other things, digitalisation can offer more information to citizens about household water consumption and raise their awareness on the sustainable use of water.

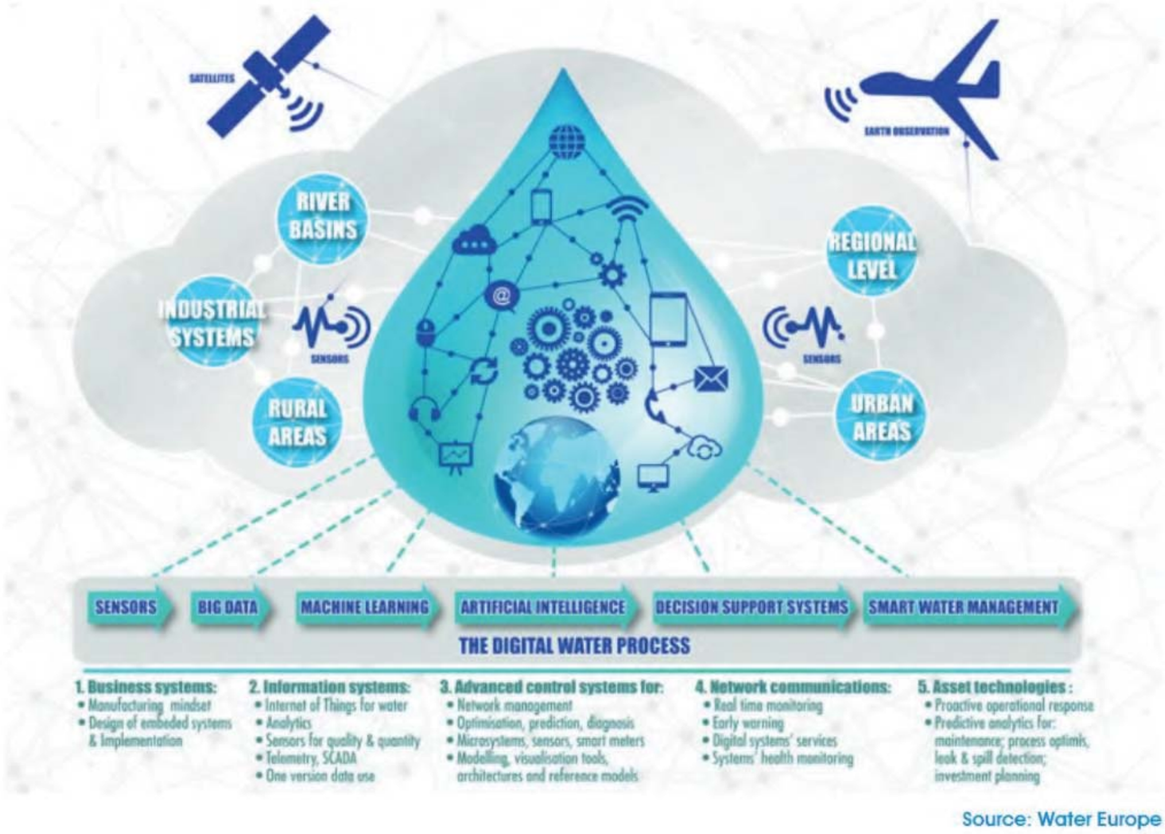

Figure 3: The Digital Water Process[112]

[111] ICT4Water publication (2021b): "Business models for digital water solutions"
[112] https://watereurope.eu/wp-content/uploads/2020/04/WE-Water-Vision-english_online.pdf

Digital solution story: IoT in water monitoring
The Fenix Hub for Zero Power Water Monitoring developed by Aqua Robur Technologies was an EU-funded project, and it received the European Commission Horizon Prize in 2019. The Fenix Hub is a self-powered IoT device designed for the water sector. Each hub operates autonomously and is placed throughout the water network, while interconnected wirelessly. Because the Fenix Hub is self-powered, it results in a reduction of energy consumption, differentiating it from other wireless sensor harvesting technologies on the market.[113] The Fenix Hub is one of the ICT4Water projects that has been successfully commercialised and is on the market.

While there is an increase of digital adoption in water, the sector still lags behind other industries in integrating new, smart technologies into the whole water cycle and ecosystem. Their increasing uptake, further development and commercialisation are essential to achieving the zero pollution ambition in the water sector, from user to sea. New innovations provide possibilities and solutions to issues related to water quality and quantity, providing new opportunities for strengthening water monitoring from source to tap. The success of digital solutions does not, however, depend only on the product itself but also on its safe integration into utilities systems.

4.5. Digital Marine Protection

The potential of digital solutions for the oceans is vast. New digital technologies can contribute to greatly enhancing our knowledge of the oceans – although our knowledge of our seas and oceans is constantly growing also thanks to the EU policy framework, much of the marine environment is still unknown to us. It has been said that the moon and Mars are better mapped than the bottom of our oceans. With new technologies such as satellite imagery, sensors and drones, the amount of data collected from the ocean has greatly increased and will continue to increase. By using new analytical tools such as artificial intelligence and machine learning and solutions such as cloud computing for storage of data, our understanding of the oceans can be increased and shaped into a form that is useful for decision-makers. Citizen science can also help contribute to an increase in marine knowledge, and digital solutions such as mobile apps make it increasingly easy to involve citizens in knowledge-gathering and monitoring activities related to pollution (see *Digital solution story: the Marine LitterWatch app* for more information). Based on new information in a well processed form, informed measures to fight ocean pollution can be taken.[114]

[113] https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/prizes/horizon-prizes/zero-power-water-monitoring_en
[114] http://www3.weforum.org/docs/WEF_Harnessing_4IR_Oceans.pdf

Digital solution story: the Marine LitterWatch mobile app
The European Environmental Agency has developed a mobile application called the Marine LitterWatch to help strengthen marine litter monitoring and widen the European database on marine litter. It is an app which enables communities all around Europe to report their sightings of marine litter on beaches in order to gather more comprehensive knowledge on the types and amounts of marine litter found on European beaches. This citizen science initiative uses modern technology to engage citizen communities and provides a web portal and public database to collect and share data on marine litter. The information gained can be used on an EU, regional and Member State level to further define measures needed to combat pollution from marine litter. The Marine LitterWatch app can be downloaded free of charge and is available for iPhone and Android devices.[115]

New technologies allowing real-time data collection will also provide new opportunities for monitoring the marine environment. For example, they are expected to have an impact on improved monitoring of fisheries. Drones are already used for enforcement purposes as they can identify that an illegal act has taken place at sea. They may also be used for gathering scientific data needed for fish stock assessment[116] Drones have already been used to, for example, strengthen port control and monitoring of pollution from ships into the air and sea[117] as well as oil pollution response in several European ports, including the Belgian port of Antwerp in collaboration with the European Maritime Safety Agency (EMSA).[118] Used as a complementary tool in the overall surveillance chain which includes satellite imagery, vessel positioning information and surveillance by manned maritime patrol aircraft and vessels, EMSA's Remotely Piloted Aircraft Systems Service (RPAS) increases the maritime situational awareness with additional sources of data. RPAS can carry sulphur oxide (SOx) sensors in order to measure the sulphur content in the plume emitted by the ship, and therefore estimate the sulphur content of the fuel burnt by the vessel. Based on the percentage of sulphur identified, this allows Member States to possibly target inspections to see if further follow-up is required. All information is transmitted to THETIS-EU[119], the database where alerts and outcome of the Port State Control inspections are recorded.[120]

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[115] https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/marine-litterwatch
[116] Girard & Du Payrat, 2017
[117] COM(2018) 188: Report on implementation and compliance with the sulphur standards for marine fuels set out in Directive (EU) 2016/802
[118] https://www.emsa.europa.eu/newsroom/latest-news/item/4059-belgian-port-of-antwerp-using-emsa-rpas-for-pollution-monitoring.html
[119] https://portal.emsa.europa.eu/web/thetis-eu
[120] http://www.emsa.europa.eu/we-do/surveillance/rpas.html

Figure 4: The Fourth Industrial Revolution's game-changers for oceans, source: World Economic Forum[121]

Due to recent scientific and technical developments, EU benefits from multiple initiatives to monitor and observe its marine waters beyond the existing legislative commitments and to gather available data.[122] [123] The Commission is currently developing an initiative on ocean observation, with the aim to achieve a common EU approach to collection of ocean data. Marine data is collected in different Member States and for different purposes, and sometimes the same data is collected by different actors. The aim of the ocean observation initiative is to achieve a common EU approach to measuring the state and dynamics of the ocean and the organisms that inhabit it, which will allow data to be used for many different purposes[124]. In addition, international cooperation on marine data helps enhance EU's knowledge of marine environment and pollution.

While increasing the knowledge we have of our marine environment is important, existing digital solutions can already provide solutions to combat ocean pollution. It is possible to act even while knowledge gaps remain. Possibilities are vast and new digital technologies such as AI and blockchain can have much to offer to strengthen marine protection and help achieve the zero pollution ambition in the marine environment. To achieve the

[121] http://www3.weforum.org/docs/WEF_Harnessing_4IR_Oceans.pdf
[122] SWD(2020) 60
[123] These include the European Marine Observation and Data Network (EMODnet), Copernicus Marine Service (CMEMS) and the European Ocean Observing System (EOOS).
[124] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12539-Ocean-observation-sharing-responsibility

aforementioned it is also crucial to combine digital solutions for the detection of pollution in fresh water systems with those implemented for the marine environment. Marine pollution is often generated on land and transferred to the sea through surface or sub-surface waterways. Digital solutions can have a significant role in pollution detection at source and monitoring.

4.6. Digital solutions for farming and aquaculture

Besides the important contributions digitisation is making in innovation, eliminating chemicals of concern from these economic cycles, the transition to zero pollution sustainable farming can be significantly enhanced through technological, digital, and space-based solutions. One of the objectives of the post-2020 Common Agriculture Policy (CAP) is to increase the competitiveness of European agriculture. The potential of new technologies to achieve this has been recognised. These new technologies can be deployed not only to increase productivity, but also to increase sustainability with positive impacts on biodiversity and pollution control.[125] Digital solutions can be adopted and provide benefits in all the agricultural subsectors independent of the type of farms and of the level of digitalisation already achieved – they can benefit both small and large farms and organic farms as well as conventional farms. However, the specific technologies that are best suited for different types of farms varies.

Digitalisation of European farming is already happening, and digital tools can bring many advantages for striving towards the zero pollution ambition in agriculture while fostering socio-economic benefits for rural economies as well. Digital technologies such as drones can be used to monitor on-line crop yields, soil health and plant nutrient needs while integrating weather forecasts to map any existing or predictable plant health issues allowing spot spraying of crops. Sensors to monitor, observe and produce near real-time data can be used in making decisions on for instance the optimal amount, place and time for use of fertilisers or pesticides (see *Digital solution story: Satellite data for precise use of fertilisers*), or the right amount of feed to give livestock.[126] Optimising fertiliser and pesticide use can result in a reduction of unwarranted pesticide use (e.g. in parts of fields were the target pest is not present at levels causing damage) as well as a reduction of pollution caused by excess nutrients. To support the efficient use of fertiliser and to boost the digital skills of the farming sector, the Commission's proposal for the post-2020 CAP included the use of the Farm Sustainability Tool (FaST) (see *Digital solution story: Digital tool to help improve farm nutrient management*).

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[125] CAP Specific objectives…explained - Brief No 2
[126] See EIP-AGRI seminar (2020)

Digital solution story: Digital tool to help improve farm nutrient management
An open source platform compliant with the minimum elements and functionalities of the Farm Sustainability Tool (FaST) has been developed with pioneer EU Member States in 2020, with the intention of be localised and deployed in other Member States. The digital tool provides advice in the use of fertilisers using a mobile application and a web based solution and helps comply with legislative requirements related to nutrient management, resulting in less pollution by nutrients. Farmers, has access to space data from Copernicus and additional functionalities based on Galileo. The modular platform also enables the reuse and interoperability of data from various public sector and user generated data[127]. For the implementation of this service in the frame of the CAP, Member States can reuse the technical solution developed with the help of the Commission of can develop or adapt existing solutions available at national level. To foster similar applications in the market and boost their effectiveness in reducing pollution, it is paramount that public administration translate their obligations and limits relating to the use of fertilisers into digital format, machine readable and accessible by these applications used by farmers.

Digital solution story: Satellite data for precise use of fertilisers
The EU-funded project Fatima[128] developed operational methods for the assessment of the spatial variability of crop nutrient and water requirements using EU space technologies (Copernicus, Galileo). The solutions developed were tested in real cases across Europe including pilot applications in commercial farms in Austria, Spain, Greece, Czech Republic, France, Italy and Turkey. The perspectives of the project included the transference of these developments to the commercial sector.

Sensor technology can also be installed on-farm to monitor soil, air and water properties, production rates, livestock and specific characteristics of the crops. These on-farm sensors can be installed in the form of networks connected to the IoT. Data gathered by these sensors can then be used to monitor requirements derived from legislation and other processes such as external inputs in crop production, traceability and animal welfare.[129] Sensor technology paired with IoT applications can also be applied to automatically identify infestation events, making it possible to apply pesticides on a reduced scale. Overall the applications of digital technologies to support the implementation of integrated pest management are vast (see *Digital solution story: eco-innovative weeding with laser*).

Digital solution story: Eco-innovative weeding with laser
WeLASER is working to produce a precision weeding equipment which will allow the elimination of the use of herbicides, while simultaneously improving productivity and competitiveness. To achieve this aim, the EU-funded project merges various current technologies such as high-power laser sources and autonomous mobile systems. A smart central controller based on AI, IoT and cloud computing uses data gathered by a digital perception tool to command an autonomous vehicle connected to a laser-based weeding tool. The solution the project aims to produce will reduce the amount of pesticides applied.[130]

[127] https://fastplatform.eu/
[128] http://fatima-h2020.eu/
[129] https://www.iot-catalogue.com/
[130] https://welaser-project.eu/

In addition to the agricultural sector, also aquaculture industry can benefit from digital solutions to increase its environmental sustainability and lessen pollution caused by fish farming. While it can be difficult to monitor and perceive things happening underwater with the human eye, digital technologies based on machine perception tools and underwater cameras can be deployed to inform more efficient and sustainable aquaculture practices. An example of such a software system is the tool called Tidal (see *Digital solution story: Precision aquaculture*).

Digital solution story: Precision aquaculture
An underwater camera system and a set of machine perception tools called Tidal can be used to monitor and interpret fish behaviours. The developed software monitors thousands of fish at the same time and collects environmental information related to, for instance, temperature and oxygen levels. These data then give fish farmers information they can use to make informed and environmentally friendly decisions on managing their pens such as optimising the amount of food put in the pens. This can result in a reduction of nutrient, chemical pollution and costs.[131]

The potential of digital innovations in both the agriculture and aquaculture sectors is vast and not limited to precision farming. Digital solutions can find applications in for instance agroecological farming, where there is still large scope for research and innovation.[132] Land and forest management can become more efficient and sustainable with the help of data from EU space technologies (Copernicus, Galileo), digital technologies such as blockchain as well as digital technologies for the communication of product labelling can improve traceability and transparency of information about the sustainability of the food products, digital platforms and sensor based applications can be developed to shorten supply chains and minimise food loss and food waste, and access to online AI-based advisory services can provide land managers, food producers and SME food processors in rural areas with life-long education. A key enabler for the digital transition and social inclusion in rural areas is access to fast broadband internet as well as last-mile and edge solutions.

[131] https://blog.x.company/introducing-tidal-1914257962c3
[132] https://www.arc2020.eu/digital-revolution-agriculture-agroecological-approach/

4.7. Digital transformation of industry

Digital technologies are changing the face of industry and the way we do business. The industrial sector has the potential of both developing innovative clean technology solutions and applying new digital technologies to reduce the environmental impacts of the sector itself as set out in the European Industrial Strategy.[133] While much has been done in many sectors of industry in striving towards more sustainable practices, industrial activities remain a large source of pressure on the environment causing air, water and soil pollution in addition to greenhouse gas emissions and waste generation.[134] New digital technologies find applications in a wide range of industrial sectors contributing to the zero pollution ambition in the industrial sector.

In the context of industrial emissions monitoring and control, the online availability of information, improved permit sampling and remote sensing as well as the use of AI in installation control systems could help drive best available technologies to even better performance. Industrial emissions can be monitored online and data on emissions can be made available publicly in real time using new digital technologies. The deployment of these solutions can lead to both a reduction of administrative burden for industry actors in reporting emission data to authorities but also increase the speed at which authorities can intervene where exceedances of set limits happen. Remote sensing can contribute to more effective compliance assurance, and this context data from Earth Observation satellites such as the EU Copernicus data can be used to better assure compliance with emissions norms.[135] Various citizen science initiatives have also contributed to the monitoring of industrial emissions (see *Digital solutions story: citizen science and odour pollution*).

Digital solution story: citizen science to tackle industrial odour pollution

The D-NOSES Horizon 2020 project is a relevant initiative to tackle odour pollution from different industrial sectors. Through Responsible Research and Innovation (RRI), citizen science and co-creation tools, the project empowers citizens to drive change. Odour pollution is difficult to measure, but the D-NOSES project engages local communities in data collection and reporting based on odours perceived by citizens. The perceived odours can be reported through a mobile application, the Odour Collect, and gathered data will be validated by odour experts. The project utilizes digital tools that map and measure the odour problem and engages relevant stakeholders in finding solutions. Through a series of local pilots across Europe and the world, the project aims to input the basis for future policy work in the domain of odour pollution. Collected data will be made publicly available in the International Odour Observatory.[136]

Most industries produce wastewater. Digital systems have been fundamental in the design and operation of Decision Support Systems (DSS) that allow for enhanced effluent control through reuse of wastewater at precisely defined, fit-for-purpose quality levels in heavy industry operations. The system compares these data with the requirements of the intended water reuse application and activates the adequate treatment process accordingly. By closing this loop, such approaches can indirectly reduce the amount of treated wastewater reaching

[133] COM(2020) 102
[134] https://www.eea.europa.eu/themes/industry/industrial-pollution-in-europe
[135] https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupMeetingDoc&docid=25588
[136] https://dnoses.eu/about-d-noses/

the environment.[137] Various projects under the ICT4Water cluster have targeted precisely these integrated digital systems. These projects have aimed at reducing abstraction and point-source pollution pressures by setting up small loops within water networks to open the accessibility of the reuse or recycle of otherwise wasted resources like waste, and process water, fuels and other materials. Examples of these ICT4Water projects include Project Ô, SMART-Plant and INTEGROIL (see Digital solution story: INTEGROIL for more information on the INTEGROIL project and Annex 1 for more information on Project Ô and SMART-Plant).

Digital solution story: Integroil
The ICT4Water cluster project Integroil[138] employed Machine Learning to optimize processing of wastewater from oil refineries - one of the most water consuming sectors. The decision support system (DSS) is based on data driven intelligence replacing human intervention, and thus optimizing operations by reducing energy and maintenance costs and use of expensive chemicals. The project can ensure 75 % water recycling with a 75% lower energy footprint. Significant cost savings are also achieved by optimizing the use of chemicals and by replacing human intervention with autonomous systems (the DSS). The solutions developed in the Integroil project are now being adapted for application in the metallurgy sector – another big water consumer and polluter.

Chemical production is one of the most polluting sectors. While investments in modernisation of chemical production plants have been made, significant investments are still needed for a green and digital transition in the chemical sector. The European chemicals strategy for sustainability points to the necessity of greening and digitalising the production of chemicals. It also highlights the opportunities these novel industrial processes and technologies can bring to the sector by applying for instance IoT, AI, smart sensors and robotics.[139]

New digital technologies are constantly being developed and deployed in different industrial sectors around Europe. The European Commission has developed means to monitor the development and deployment of advanced technologies in industry. The Advanced Technologies for Industry (ATI) Website analyses and systematically monitors the uptake of advanced technologies by EU industry. The Digital Transformation Monitor identifies key trends in digital transformation and measures progress. The Advanced Manufacturing Support Centre aims to create an EU-wide network to support SMEs in assessing the potential of adopting advanced digital technologies.[140] Advanced green and digital technologies and their deployment present both big potential for growth in Europe, but also give solutions that can lead to a greener economy and less polluted environment.

4.8. Digital solutions for plastic pollution

While plastics are a central and important material in our economy, they harm the environment. The Circular Economy Action Plan aims to help businesses and consumers use

[137] EASME contribution
[138] https://integroil.eu/
[139] COM(2020) 667
[140] https://ec.europa.eu/growth/industry/policy/advanced-technologies/support-tools_en

resources in a more sustainable way.[141] It recognises the role of digitalisation in driving the transition towards a circular economy. European businesses are frontrunners in innovations related to circularity, and the EU has the means and funding available to support further innovation and help bring concrete solutions to the market.

The possibilities of digital solutions for increased circularity leading to a decrease in plastic pollution are manifold. In addition to digital solutions providing real-time data for monitoring and reporting, digital technologies can contribute to circular economy objectives by contributing to value chain coordination by for instance providing better service information for consumers and product information for repairers, enabling platforms and tracking for asset sharing or reuse and resulting in better waste management through the use of smart sensors to improve Pay as You Throw (PAYT) systems.[142]

Digital tags in products can facilitate the exchange of data between stakeholders and machines. Tagging can potentially lead to an increase in efficiency of Extended Producer Responsibility (EPR) systems and improve market surveillance as well as help a better recycling of materials. The HolyGrail project is developing tags to facilitate the sorting of packages and thus help increase their recycling (see *Digital solution story: digital watermarks and chemical tracers for high-quality recycling*).[143]

Digital solution story: digital watermarks and chemical tracers for high-quality recycling

The HolyGrail project aims to improve the sorting of post-consumer packaging with the help of chemical tracers and digital watermarks. Collection of plastics after use is not sufficient if the collected plastics cannot then be sorted efficiently. Improved sorting of plastics can improve both the quality and the quantity of recycled plastics on the market. One way that more efficient sorting can be achieved is by tagging items by using a digital watermark or a chemical tracer. Both are machine-readable codes or identifiers that facilitate the sorting of products by pointing the sorting system to a database where information on how the product can be recycled can be found. This will in turn make the sorting process more reliable and efficient, and increase the amount of plastics that are efficiently recycled.[144]

Increasing circularity will result in a reduction of plastic waste ending up in the environment, but will not directly contribute to the removal of plastics already in the environment. Marine plastic pollution is a type of pollution that has gained an increasing amount of attention in the past years. A majority of marine plastic pollution originates from land-based sources, and once it is in the sea, it is not easy to get out. However, new technologies such as blockchain have been deployed to incentivise the collection and further recycling of marine plastics. The Plastic Bank is an example of such a scheme already deployed in various areas of the world (see *Digital solution story: blockchain technology fighting ocean plastic pollution*).[145]

[141] https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF
[142] Draft SWD on Digital4Circular
[143] Draft SWD on Digital4Circular
[144] https://www.newplasticseconomy.org/assets/doc/Holy-Grail.pdf
[145] https://www.pwc.com/gx/en/sustainability/assets/blockchain-for-a-better-planet.pdf

Digital solution story: blockchain technology fighting ocean plastic pollution
Blockchain technology can provide an incentive to fight ocean plastic pollution by means of recycling initiatives, such as the Plastic Bank. The Plastic Bank is a blockchain-based banking platform. The system awards those who collect plastic waste from the ocean and deliver it to a Plastic Bank branch with digital vouchers that are stored on their mobile phones. These digital vouchers then function like money and can be spent on daily necessities. Just like a normal bank, people can access their rewards and check their balance. Because the system uses blockchain, it is secure and usually transparent. All information related to transactions people make – when they use their vouchers to for example pay for school tuition fees – is stored on a distributed blockchain ledger. The plastic that is delivered to Plastic Banks is then recycled for use by firms partnered with the Plastic Bank. The blockchain ledger also tracks the movement of the recycled plastic. The system is fully deployed in Haiti, Indonesia and the Philippines.[146]

Big data and AI also provide opportunities to monitor marine plastic and micro-plastic pollution. Recent work shows that unmanned aerial systems (UAS) along with computer vision methods provide a feasible alternative for marine litter monitoring on beaches. This includes citizen science UAS data acquisition and annotation protocol combined with deep learning techniques to automatically detect and map marine litter concentrations in the coastal zone. There are also initiatives to use unmanned underwater vehicles (UAV) and satellite data, in combination with AI and crowdsourcing, for image annotation, representing a cost and time-effective ancillary to well-established field survey methodologies. More specifically, machine learning algorithms can be applied to images acquired from UAV to detect and measure plastics in underwater environments. The innovative potential of the proposal lies in the integrated approach, using Earth observation data from aerial and underwater drones and satellites, crowdsourcing/citizen science, and AI for marine litter detection.[147]

Digital solutions provide many opportunities to strive towards the zero pollution ambition for plastic pollution. By utilising the possibilities of digitalisation in a shift towards a circular economy, less materials will end up as non-recyclable waste, and a more efficient recycling scheme will prevent plastics from entering the environment. For the plastic pollution that is already where it shouldn't be, a range of digital solutions can be developed and used to help address this issue.

[146] https://plasticbank.com/
[147] E.g. "A Citizen Science Unmanned Aerial System Data Acquisition Protocol and Deep Learning Techniques for the Automatic Detection and Mapping of Marine Litter Concentrations in the Coastal Zone"

4.9. Addressing soil pollution with digital solutions

Soil contamination is a widespread problem across Europe, which can in turn impact ecosystems and water bodies. There are around 2.8 million sites in Europe where soil polluting activities have taken or are taking place. Of these sites 694 000 have been already identified and registered in national and/or regional inventories.[148] Mineral oils and heavy metals are the most common contaminant in soil. Soil contamination is caused by several reasons; municipal and industrial waste disposal and treatment, metal industries and petrol stations as well as in some countries mining being leading causes for soil pollution.[149]

Around 19 % of registered sites in Europe need, or might need, remediation or risk reduction measures, including natural attenuation. To be able to address soil contamination, it is necessary to, amongst other things, gather geographically located monitoring data to be able to correctly identify and further characterise contaminated areas. Digital data obtained through remote sensors such as Landsat[150], SPOT[151] and Copernicus, aerial/drone images or in-situ monitoring stations as well as designed and automatised sampling patterns can first help to characterise soils subject to pollution (Digital Soil Mapping) and then contribute to a more effective and efficient acquisition of monitoring data on the pollution itself (*Digital solution story: the SoilTakeCare project)*.[152]

Recently, the Commission services have developed machine learning models to map the diffuse soil pollution. An example is the Deep Neural Network (DNN) learning model that was developed to map mercury (Hg) distribution in European soils[153]. Another example of machine learning is the Generalized Linear Models (GLM) used to investigate the factors driving copper distribution in EU soils[154]. AI and machine learning can be deployed to analyse data gathered by sensors to optimise soil conditions, and blockchain can be utilised for soil properties data collation from distributed sensors.[155] [156]

[148] Status of local soil contamination in Europe. Ana Payá Pérez and Natalia Rodríguez Eugenio, Status of local soil contamination in Europe: Revision of the indicator "Progress in the management Contaminated Sites in Europe", EUR 29124 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-80072-6, doi

[149] https://www.eea.europa.eu/highlights/soil-contamination-widespread-in-europe

[150] https://landsat.gsfc.nasa.gov/

[151] https://earth.esa.int/eogateway/missions/spot

[152] The nature and detection of unauthorized waste dump sites using remote sensing
Sergij Vambol, Viola Vambol, Muniyan Sundararajan, Iqbal Ansari , Ecological Questions, Vol 30, No 3 (2019) DOI: http://dx.doi.org/10.12775/EQ.2019.018
Detection of waste dumping locations in landfill using multi-temporal Landsat thermal images ; Jasravia Gill, Kamil Faisal, Ahmed Shaker, Wai Yeung Yan, Waste Management & Research: The Journal for a Sustainable Circular Economy, Vol 37, Issue 4, 2019 , https://doi.org/10.1177/0734242X18821808
Hani Abu Qdais & Nawras Shatnawi (2019) Assessing and predicting landfill surface temperature using remote sensing and an artificial neural network, International Journal of Remote Sensing, 40:24, 9556-9571, DOI: https://doi.org/10.1080/01431161.2019.1633703

[153] https://esdac.jrc.ec.europa.eu/content/mercury-content-european-union-topsoil

[154] https://esdac.jrc.ec.europa.eu/content/copper-distribution-topsoils

[155] http://www3.weforum.org/docs/Harnessing_Artificial_Intelligence_for_the_Earth_report_2018.pdf

[156] http://www3.weforum.org/docs/WEF_Building-Blockchains.pdf

Digital solution story: the SoilTakeCare project
The EU-funded SoilTakeCare project developed digital, innovative, low-cost diagnostic and monitoring tools for addressing soil contamination. The project developed new, cheaper sensors that can be used for monitoring of contaminated areas, applied biomonitoring to contaminated areas and developed a new methodology to quantify volumes of contaminated matter by using an in-situ Lidar scanner and drone photogrammetry. The scanner was used for rapid and accurate digital elevation of smaller contaminated areas, whereas drones were deployed for the mapping of larger surfaces.[157]

Good quality soil is essential to us as all human activities are related to soil in a way or another. Degradation of soil quality has a negative impact on human health, biodiversity and linked ecosystems services as well as the climate. These are reasons why it is necessary to strive for the zero pollution ambition in soil pollution, and new digital innovations and technologies have the potential to aid in identification, mapping and monitoring of contaminated areas, understanding impacts on waterbodies as well as the remediation of contaminated soil[158].

5. Funding and Investment Opportunities for Zero Pollution Data and Solutions

As illustrated in the previous sections, there is a vast amount of innovation and business opportunities and potential in digital applications for zero pollution. Both the public sector and private sector can benefit from these opportunities and the post-COVID recovery will unlock significant amounts of private and public investment. In the framework of the Recovery and Resilience Facility, the EU Member States are currently preparing their national Recovery and Resilience Plans. These aim to direct at least 20% of their expenditure to investments and reforms that support the digital transition, including greening the digital sector Moreover, the new Multi-Annual Financial Framework has been adopted and it offers also possibilities to invest in digital solutions for zero pollution (see Annex II for overview). Overall, the priority for the EU funding instruments is to support a green and digital transition. Investments which combine the strength of both worlds can result in unlocking the business opportunities and innovation which will help create a more sustainable, pollution free world.

This is echoed by the 2020 Environment Council conclusions on 'Digitalisation for the Benefit of the Environment'[159] which '*urges Member States to mobilise public and private investments, including via Recovery and Resilience Plans, in digital technologies that contribute to achieving environmental objectives, as well as in environmentally friendly ICT, and to raise awareness within the economy, in particular the financial sector, of sustainable investments, notably through the swift completion and adequate use of the taxonomy on sustainable finance as a reference*.'

Overall, the digital economy has a huge economic potential. The EU's 2020 Digital Strategy states that '*implementing reforms and stepping up investments in Research and Development and technological deployment could yield 14% of cumulative additional GDP growth by 2030*'.[160] A significant component of the digital economy is the drive for open data.

[157] https://ec.europa.eu/regional_policy/en/projects/Portugal/soiltakecare-low-cost-solutions-to-diagnose-and-clean-up-soil-contamination
[158] The EU Soil Observatory will also foster using such technologies.
[159] https://data.consilium.europa.eu/doc/document/ST-13957-2020-INIT/en/pdf
[160] McKinsey Global Institute (2020): 'Shaping the digital transformation', Study conducted for the Commission

Environment and pollution data are and should be 'open data' per definition. They are mostly not personal data and, once collected, should be a common good since they help determine the health of people and the planet. Currently, the European open data market size is € 184.45 billion (in 2019) forecasted to increase to € 199.51 - 334.20 billion by 2025.[161] It employs 1.09 million people which is projected to have the potential to nearly double over the coming years. Through open data, significant efficiency gains and cost savings can be realised, e.g. cost savings for organisations that simply open up their own data and thereby reducing requests on access to information, cost savings thanks to acquiring others' open data for free or at marginal cost, and cost savings through efficiencies enabled by open data re-use. Based on estimates in a national study, the total amount of costs saved due to open data in the public sector can be in the region of €0.25 - €1.48 billion across Europe[162].

Open data also have significant benefits for many of the above-mentioned sectors, such as transport agriculture or health (see figure 5).

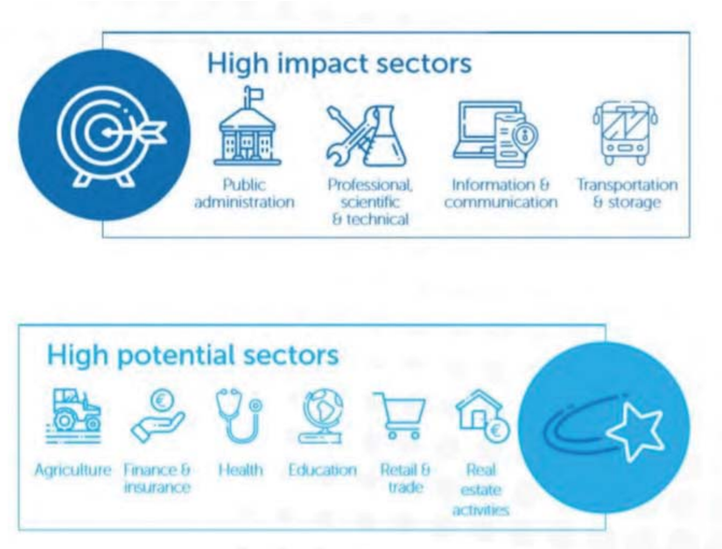

Figure 5: Sectors with high open data impact and potential[163]

Obviously, the zero pollution dimension of the digital and open data economy only accounts for a fraction of these benefits. However, some sectors estimates are available. E.g. the digital vision of Water Europe points to opportunities that will allow a transition to a water-smart society. It estimates that global utility company expenditure on data analytics will grow from $700m in 2012 to $3.8bn in 2020, with gas, electricity, and water suppliers in all regions of the world increasing their investment.[164] This increasing trend is likely to continue. Investing in opening up of environmental data is beneficial, because innovation based on the data will lead to benefits of an economic (including cost savings, efficiency gains, lower insurance costs and less climate-related damage) and a non-economic nature (such as cleaner air and

[161] European Data Portal: The Economic Impact of Open Data (2020)
[162] See p. 85 of JRC report 2020: "The Economic Impact of Open Data: Opportunities for value creation in Europe"
[163] See p. 37 of JRC report 2020: "The Economic Impact of Open Data: Opportunities for value creation in Europe"
[164] GTM Research, 2014 in Water Europe (2017): "The value of water"

fewer deaths caused by pollution). These benefits outweigh the initial costs spent on updating data infrastructure and data management processes by far.[165]

Another study looked at the technology developments in Sustainable ICT projects and sustainable financing trends with regards to climate change and circular economy, as a preamble to estimate the investment gap for Sustainable ICT projects in Europe. This study found that the total investment gap for the Sustainable ICT industry was estimated to be €14.2 – 19.2 billion across the period of 2021-2027[166]. In addition, investments in skills will be needed in order to optimally reap the benefits technological solutions can bring in addressing pollution. In this regard, the Skills Agenda for Europe, launched on 1 July 2020, aims to support skills for the green and digital transitions, among other things, to increase the number of professionals who master green technologies including their digital aspects.[167]

An overview of EU instruments that can be looked towards for providing funding for digital solutions and modernisation of data management can be found in Annex II.

6. Inspirations from national strategies

The 2020 Environment Council conclusions on 'Digitalisation for the Benefit of the Environment'[168] encourage Member States to further explore and harness the enormous potential of digitalisation to help the EU achieve the goals of the European Green Deal and the transition to climate neutrality by 2050. It also stresses the importance of supporting and engaging with local and regional authorities and other stakeholders to support local strategies for green and digital transformation.

Some Member States have already addressed this call by developing a national strategy on 'digitalisation and the environment'. Two of the most recent of such strategies are briefly presented.

The **German** Digital Policy Agenda for the Environment was published in 2020, and it builds on various prior strategies and other policy measures. It focuses on the green and digital transformation pointing to areas where digitalisation can help achieve environmental targets. The agenda discusses both digitalisation as a means to achieve sustainable growth and the environmental footprint of the digital sector and discusses a wide range of applications of digitalisation on different fields such as mobility, energy, nature conservation, agriculture and water management and circular economy. It sets out strategic goals and builds on these goals to set over 70 concrete measures, some of them already underway and others to be initiated. Measures relevant for the zero pollution ambition include measures such as research on digitalisation in the transport sector, making the ecological footprint visible by means of virtual reality or augmented reality, a living laboratory for sustainable digital agriculture and deploying AI for sustainable consumer choices. [169]

[165] See JRC report 2020: "The Economic Impact of Open Data: Opportunities for value creation in Europe". This is also confirmed by the upcoming Impact Assessment accompanying the implementing regulation on High-value datasets.
[166] " Market study on InvestEU Financial Product for Sustainable ICT" Final Study Report
[167] COM(2020) 274
[168] https://data.consilium.europa.eu/doc/document/ST-13957-2020-INIT/en/pdf
[169] BMU 2020: Digital Policy Agenda for the Environment. https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/broschure_digital_agenda_eng_bf.pdf

Finland is currently in the process of finalising a climate and environmental strategy for its ICT sector. A substantive interim report has already been published and the final strategy containing recommendations for action is still in the process of public consultation. The Finnish strategy focuses on the environmental and climate impacts of the ICT sector and discusses how these can be controlled and minimised, but also points to the potential digitalisation has in achieving reductions in emissions and the opportunities of the green and digital transformation. The measures proposed include increasing awareness of the environment impacts of the ICT sector, developing digital solutions for the environment and climate and contributing to their deployment, improving the possibilities of making use of the heat pollution from data centres and taking into account environmental aspects when building electronic communications networks.[170]

Many countries have addressed the topic of negative environmental effects also in their national strategies and publications for specific digital technologies, such as artificial intelligence.[171] These and other existing national strategies as well as this paper on digital solutions for zero pollution might serve as inspiration for different Member State actors to develop such strategic documents, whether focused on zero pollution or with a wider focus on the green and digital transformation.

7. Conclusions and outlook

The green and digital transition can offer new opportunities for achieving environmental objectives provided that the environmental risks stemming from digitalisation are managed. This document has demonstrated this for the 'zero pollution ambition', where many use cases already exist. These examples represent only a small amount of all digital solutions for zero pollution, e.g. on effective collection of pollution data in different sectors. This document aims to introduce to these possibilities, encourage the sustainable deployment of digital solutions and start an exchange of good practices with the private sector, civil society and administrations. This can bring inspiration, innovation, investment and interaction to all actors wishing to contribute to the European Green Deal objectives, more specifically in relation to the zero pollution ambition.

Drawing from these initial lessons, the following conclusions can be formulated:

- ***Deployment of digital solutions for zero pollution must be sustainable***
  While digital solutions can bring significant benefits in terms of reducing pollution, it is important to ensure that their deployment is sustainable, taking into consideration the pollution and all other associated impacts, in particular energy and resource use impacting the achievement of the Green Deal objectives. Digital solutions are not a solution if they lead to decrease in sustainability in the long run. To this end, further research should be targeted towards looking at the systemic and long-term environmental impacts of digitalisation, and especially towards the pollution risks associated with digital solutions. In addition, the possible negative societal impacts of digitalisation, including increased social inequalities must be addressed. No one should be left behind.

[170] Ministry of Transport and Communications 2020: The ICT sector, climate and the environment – Interim report of the working group preparing a climate and environmental strategy for the ICT sector in Finland
[171] For analysis of Member States' efforts in AI and climate see JRC Science for Policy report, AI Watch National strategies on Artificial Intelligence A European perspective in 2020 (forthcoming)

- ***Many green investments will have a digital component – let's make best use of it by creating multiple benefits with the European Green Deal as a compass***
  Most of the current and future investments into climate and environmental projects, whether private or public, will have a digital aspect, whether it is data generation or use of digital tools. Digitalisation can have an integrating role and help to ensure that investments are multi-purpose, creating synergies between different goals (e.g. towards climate neutrality and clean air). The power of digital can therefore be used to create multiple benefits across the Green Deal objectives. To this end, it is important that environmental data (or those relevant to address environmental issues) respect the FAIR principles[172].

- ***Better use of digital tools to empower citizens as actors for achieving the zero pollution ambition as part of the wider European Green Deal***
  Citizen engagement in and support for the zero pollution agenda is crucial for achieving this ambition. Digital solutions can be used to engage the public in citizen science initiatives that will contribute to collect, analyze and disseminate pollution data as well as to raise awareness of pollution issues. Citizen science can also empower citizens and promote sustainable behaviour change.[173] In addition to citizen science initiatives, digital solutions can also be effectively deployed to inform and engage citizens on pollution-related topics and facilitate citizen access to pollution data. Involvement and participation of all is key to building a greener Europe as recognised in the Climate Pact[174]. In addition, the Zero Pollution Action Plan[175] includes a number of actions to help improve information and empowerment of citizens, such as the improvement of data and knowledge available on zero pollution through the dedicated monitoring and outlook framework[176].

- ***Digital solutions have a huge potential for improving compliance and enforcement of environment and pollution-related legislation both at a European and Member State level***
  The effective implementation and enforcement of environmental legislation can benefit from a wider application of digital solutions. Digital solutions can facilitate and contribute to aspects such as monitoring and reporting of pollution data, environmental inspections and a more holistic outlook to pollution data collected under different policy areas.

- ***Modernisation of administrations working with pollution-related issues needs to be accelerated to benefit from digitalization***
  Embracing the eGovernment agenda[177] is key to administrations at all levels working with pollution-related issues. Striving towards accelerated digitalisation and modernisation of administrations will bring benefits, including increased transparency and effectiveness, improved access to pollution data as well as facilitated participation of citizens in decision-making processes concerning their well-being and the state of

[172] data should be findable, accessible, interoperable and reusable
[173] SWD(2020) 149 and EPA Network: Citizen Science and the zero pollution ambition (2021)
[174] https://europa.eu/climate-pact/index_en
[175] COM(2021) 400
[176] SWD(2021) 141
[177] https://ec.europa.eu/digital-single-market/en/egovernment-action-plan

the environment. Moreover, it will help reduce administrative burden for businesses by implementing the "once-only" principle so they only need to provide information to public administration across the EU if effective data sharing is ensured. Investment in the generation and sharing of pollution data, processing and analytics is crucial not only to ensure the accessibility of the data, but also to ensure it can be effectively used to guide policy decisions on reduction of pollution.

- ***Digital skills and capacity building needs to be enhanced to allow for efficient use of digital solutions for zero pollution***
  Technology upgrades and deployment of new digital solutions are important, but it is equally important to ensure that zero pollution actors have the skills and capabilities to effectively use these new solutions. Increasing the amount of digital skills vocational education and training, as well as ensuring that digital competences are represented in environmental teams is key to better equip the environmental community for an effective and sustainable uptake of digital solutions for zero pollution. The Skills Agenda for Europe, mentioned above, and the Digital Education action plan aim to improve digital skills at all levels. In addition, the Digital Europe Programme, just launched at the beginning of 2021, aims to strengthen capacity and advanced digital skills needed for digital solutions for zero pollution, such as data analytics and big data use, artificial intelligence and supercomputing [178].

- ***Open 'zero pollution data' are an important contribution to the European Data Spaces***
  Most environmental and pollution data can be regarded as a common good and should be made openly available and easily accessible, with a view to reduce pollution. In this context the contribution of pollution data (and for its chemicals part the common open data platform on chemicals as announced under Chemicals Strategy for Sustainability) to the European Data Spaces and especially the Green Deal Data Space is very important.

- ***Big data can offer new insights into pollution problems and solutions if the large information is translated into knowledge***
  With the enormous increase in data comes the challenge to transform them into knowledge and actionable insights. Classical ways of knowledge generation will not necessarily work and new ways of ensuring quality, relevance and comparability of data will be needed. This challenge comes with opportunities. On one hand, new skills and expertise, such as those from data analysts, will become essential for most areas. On the other hand, artificial intelligence and other data analysis tools are increasingly available and help in transforming big data into knowledge.

- ***More networks bringing together environment and digital experts and communities need to be created with platforms to share good practices***
  Exchange of information, good practices, failures and successes is highly useful and strongly encouraged. This information exchange can take place via officially established platforms and networks but can also be of a more informal nature. In this context breaking the silos between the digital and environmental communities is

[178] https://ec.europa.eu/digital-single-market/en/news/digital-europe-programme-proposed-eu75-billion-funding-2021-2027

encouraged – both have a lot to learn from each other. The digital community has a vast amount of solutions and ideas for striving towards the zero pollution ambition, whereas the environmental community benefits from decades of environmental data and strong knowledge of the causes and consequences of pollution.

- ***Embracing the twin digital and green transition for zero pollution is crucial for all actors***
  While the public sector plays an important role in embracing the twin digital and green transition for zero pollution by means of digitalisation and modernisation of administrations, also the private sector, and especially SMEs, have the means to become important actors in producing and deploying digital solutions for zero pollution. The private sector is encouraged to embrace the digital and green transition and invest in developing sustainable solutions which can contribute to a greener, more "zero pollution world". These solutions and their demand will only increase in the coming years, making 'digital with a green purpose' a good area to invest in.

The extent to which these digital tools can prevent, reduce or help mitigate and remediate pollution still has to be investigated and demonstrated. So monitoring of effectiveness and efficiency of these must be factored in from the outset. But now that there will be significant public and private investments in the recovery phase from the COVID-19 pandemic, it is important to realise this potential and maximise the environment and climate benefits that digital investments can bring.

Recognising the opportunities from digital, the Commission has launched the flagship: **"Creating Living Labs for green digital solutions and smart zero pollution"** in the Zero Pollution Action Plan[179].

"In 2021, the Commission will, together with partners, launch Living Labs for green digital solutions and smart zero pollution to engage with regional and local authorities (for example through the Living-in.eu community) and other stakeholders to help develop local actions for green and digital transformation which contribute to the European Digital Green Coalition and the Climate Pact. By 2023, the Living Lab members will develop recommendations for a climate and environment-friendly use of digital solutions to accelerate zero pollution efforts, with a particular focus on citizen engagement."

When implementing this flagship, the Commission services will reach out to partners in order to help them setting up or continuing such Living Labs ideally within existing initiatives and frameworks. In particular, **partnerships of businesses** (B2B), **citizens and administrations** as well as in-between them (A2B, B2A, B2C) fostered through research and innovation are invited to create Living Labs to develop new ideas and deploy them most promising ones more widely. Pilot projects under the various EU financing programmes (see Annex II) can help to initiate such Living Labs.

Thereby, this activity will also support the **implementation of the Climate Pact[180]** with the aim to:

[179] COM(2021) 400
[180] COM(2020) 788

- Develop innovative ways to attract people and implement actions by promoting the use of the latest technologies,
- Organise interactive citizen dialogues as to what a zero emissions and zero pollution Europe means for their community and everyday lives and
- Support spaces enabling individual and team competitions, target setting and sharing of progress, such as applications enabling individuals and organisations to submit pledges.

It will also promote innovation and support the **European Digital Innovation Hubs** and the digital research agenda. It will build on sharing best practices, identifying data assets and help create the **Green Deal Dataspace** set out in the European Data Strategy with its thematic inputs on zero pollution, chemicals or smart and circular economy to improve the availability of more and better data from the public and private sector. Moreover, piloting and roll-out of digital solutions for **smart cities and communities** and the development of local digital twins under the Digital Europe Programme as well as actions supported by other EU funding programmes (e.g. the LIFE Programme) can help trigger investments to better understanding and visualizing pollution, engage all actors and promote technological solutions to the benefit of citizens, researchers, businesses and policy-makers at all governance levels. Whilst embedded in the Zero Pollution Stakeholder Forum, the 'Green Digital Solutions Hub' will create close links to other platforms and networks, e.g. the Circular Economy Stakeholder Platform and in particular make efforts to bring together the **Green City Accord** and the **Smart City initiatives**.

The **Zero Pollution Stakeholder Platform** will oversee the activities related to this flagship, exchange information and good practices as well as develop recommendations by 2023. These recommendations can play an important role to guide the future developments regarding digital solutions for zero pollution and cross-fertilise ideas across sectors and domains. It will involve administrations, business and civil society as well as international organisations to promote digital solutions that are sustainable.

In conclusion, digitalisation has an enormous transformative drive if it's disruptive, whilst cohesive powers are exploited in a sustainable manner. In other words, the dynamics that are already created by the EU's Digital Agenda and Digital Decade[181] need to be guided and managed in such a way that energy and resource use as well as pollution impacts of ICT solutions are mitigated and, if necessary, regulated.

[181] COM(2021) 118

Annex I: Digital technologies

The non-exhaustive list below summarises some of the existing digital technologies and illustrates briefly how they can become important solutions for achieving the zero pollution ambition. This overview of most relevant digital technologies is based on the EPC report '*Towards a green, competitive and resilient EU economy: How can digitalisation help?*'[182] and provided in alphabetic order:

- **Applications ('apps') for computers, tablets and mobile devices** are easy-to-use software programmes. In the context of zero pollution, they can be used, for example, to inform citizens about the pollution in air, water or soil around them. They can help encourage citizens to live, travel and/or consume more sustainably and also support them in data collection and analyses to support citizen science initiatives. Moreover, they can help to the compliance and enfocerment of EU laws, e.g. facilitating the detection and reporting by citizens of illegal waste disposal.

- **API (Application Programming Interface)** is a computing interface that allows applications to communicate with each other. APIs provide an access point for the server, allowing the sharing of data between different web, mobile and device applications. They are important, because otherwise applications would not be able to access and use data in other databases.

- An **Artificial intelligence (AI)** system is a machine-based system that can, for a given set of human-defined objectives, generate output such as content, predictions, recommendations, decisions or actions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy.[183] AI relies on (big) data, and enables the more efficient collection and processing of data to, for instance, improve pollution monitoring, analyse patterns of pollution to better identify sources and design cleaner and non-toxic products and services (e.g. through precision farming). The European Commission has set out its vision in the 2020 White Paper on Artificial Intelligence[184] and defined its policy through the recent Communication[185] 'Fostering a European approach to Artificial Intelligence' and the legislative proposal for a Regulation on a European approach for Artificial Intelligence[186] highlighting the benefits of using AI for achieving environmental objectives.

- **Blockchain (or distributed ledger technologies-DLT)** is a technology that makes it possible for people and organisations that may not know each other to reach agreement on and permanently record information in a transparent way, without need for a central authority to oversee the process. It has been recognised as an important

[182] A. Hedberg & S. Šipka: 'Towards a green, competitive and resilient EU economy: How can digitalisation help?' Policy paper published by the European Policy Centre (EPC) in June 2020.
[183] Annex of COM(2021) 205: Coordinated Plan on Artificial Intelligence 2021 (Review)
[184] COM(2020) 65
[185] COM(2021) 205
[186] COM(2021) 206

tool for building a fair, inclusive, secure and democratic digital economy. Blockchain can be used to support low pollution and toxic-free products and processes including e.g. labelling information or environmental permitting. It can help create ‘smart contracts’ contributing to ensure compliance as part of the next generation of pollution monitoring, reporting and verification. The EU has set up a European Blockchain Partnership and supports the setting up of a European Blockchain Service Infrastructure.[187]

- **Cloud computing** allows the storage of data on remote computing services, which can be accessed via the Internet. It is already used to manage data and enhance knowledge for pollution monitoring and control. A number of actions and significant investments in cloud infrastructure are promoted by the Commission’s European Data Strategy.[188]

- **Digital twins** are, traditionally, virtual models or digital replicas of physical objects. Such twins can be used, for example, to predict the operation life-cycle of a product. Building on this knowledge, the design and performance of the product can be improved. Digital twins can also be used to e.g. optimise waste management operations and production systems, making them more sustainable. However, specifically for the assessment of societal challenges due to environmental and socioeconomic pressures, Digital Twins can also represent digital replicas of complex interconnected natural and socio-economic systems that will give users not only passive access to high-quality information, services, models, scenarios, forecasts and visualisations, but enable them to actively interact with the system in order to test the efficiency and effectiveness of policy and/or technical measures against such pressures. This will result in the availability of real-time data and feedback to the physical asset, allowing real-time policy responses.

- **Earth observation, satellite imagery, sensors, cameras, drones or robots** can be used to gather data and monitor the environment. They can support greener practices to optimise production, using fewer resources. They can also enhance performance of and compliance with existing rules to ensure that, for example, farming practices are aligned with climate and environmental standards. Such data can be used either for pure data analytics or also for decision support approaches combining data and model analytics (digital twins).

[187] https://ec.europa.eu/digital-single-market/en/blockchain-technologies

[188] COM(2020) 66

- **Internet of things (IoT)** and connected devices merge physical and virtual worlds, creating smart environments. For example, everyday physical objects or devices can be connected to the IoT, where they can 'identify' themselves to other objects. The IoT can, for example, be used to predict when machines require maintenance or upgrades and thus prolong their lifetime or micromanage their operation to reduce pollution. Low-energy sensors or cameras are increasingly being deployed to collect and transmit real time data including pollution data, e.g. on air or noise emissions or plastic pollution. The Commission has aimed to unleash the innovation potential of IoT already since the 2015 Digital Single Market agenda[189] but the opportunities for environmental protection and pollution control have yet to be fully exploited.

- **Online platforms** are digital services that facilitate online interactions between interdependent users. Examples of online platforms include online marketplaces, content crowdsourcing platforms and data harvesting platforms. They support information exchange and decision-making. They allow managing large amounts of cross-domain data and involving stakeholders.

- **3D printing or additive manufacturing** are computer processes which create a three-dimensional object. These processes often use less material than traditional manufacturing methods. These technologies allow the on-site production of components on the basis of a digital template, and can thus help reduce pollution by reducing transport and storage of spare parts. Moreover, the components produced may be lighter or more durable which can reduce the environmental footprint of products.

[189] https://ec.europa.eu/digital-single-market/en/internet-of-things

Annex II: Funding and investment opportunities

The new financing instruments under the Multi-Annual Financial Framework (MFF) have been agreed in the end of 2020 and the programming for each instrument is still ongoing. The examples and information below are based on the situation at the moment of drafting. More information will be available at the references provided below.

- **European Regional Development Fund (ERDF)**

The ERDF provides financial support for the development and structural adjustment of regional economies, economic change, enhanced competitiveness as well as territorial cooperation throughout the EU. The key priority areas of ERDF investments are innovation and research, the digital agenda, support for small and medium-sized enterprises (SMEs) and low-carbon economy. These priority areas could have potential applications in the area of digital solutions for zero pollution. More information here.

- **Common Agricultural Policy (CAP)**

The new CAP highlights the importance of greater use of knowledge and innovation as well as aiming for higher environmental and climate action. Applications in the area of digital solutions for zero pollution in the agricultural sector could find funding from the CAP. More information here.

- **European Maritime Fisheries and Aquaculture Fund (EMFAF)**

EMFAF funding can provide opportunities for digital solutions in zero pollution in the marine environment. These potential applications could relate to e.g. sustainable fisheries management and aquaculture, marine environment protection and sustainable blue economy. More information here.

- **Horizon Europe**

Horizon Europe is the EU's next funding programme for research and innovation and it will offer funding opportunities for research and innovation projects, which could include projects with applications related to digital solutions in zero pollution. More information here.

- **Connecting Europe Facility (CEF)**

The CEF supports trans-European networks and infrastructures in the sectors of transport, telecommunications and energy. Especially the CEF Telecom could have relevant applications for digital solutions in zero pollution. More information here.

- **Digital Europe Programme**

The Digital Europe Programme will build the digital capacities of the EU and facilitate the wide deployment of digital technologies. Various sections of Digital Europe could provide opportunities for funding of digital solutions for zero pollution, including in the context of smart cities and communities. More information here.

- **LIFE Programme**

The LIFE programme is dedicated to environmental and climate objectives. The next LIFE will contribute to the protection and improvement of the quality of the environment, the shift to a circular economy and halting biodiversity loss. As LIFE funds green technologies, applications in the area of zero pollution could also be available. More information here.

- **European Solidarity Fund Plus (ESF+)**

The ESF+ aims at supporting Member States to tackle the crisis caused by the coronavirus pandemic, achieve high employment levels, fair social protection and a skilled and resilient workforce ready for the transition to a green and digital economy. More information here.

- **Neighbourhood, Development and International Cooperation Instrument (NDICI)**

The NDICI can help create business opportunities for EU and foreign companies on the twin green and digital transition, connect Europeans and foreigners to advance it. More information here.

In addition to the MFF, the **Recovery and Resilience Facility** offers many opportunities to implement the application of digital solutions in national programmes and projects. Member States are currently preparing their national Recovery and Resilience Plans with the objective to allocate at least 20% and 37% of their expenditures to reforms and investments that support the digital and green transition respectively. These can include investments into research and development, the greening of the digital sector, as well as investments into green and digital skills that can accelerate the transition.

Finally, the **private investments** triggered by the **EU's Sustainable Finance policy** can be an important driver for innovation and harvesting business opportunities resulting from applying digital solutions.