DISCUSSION PAPER

SUSTAINABLE PROSPERITY FOR EUROPE PROGRAMME

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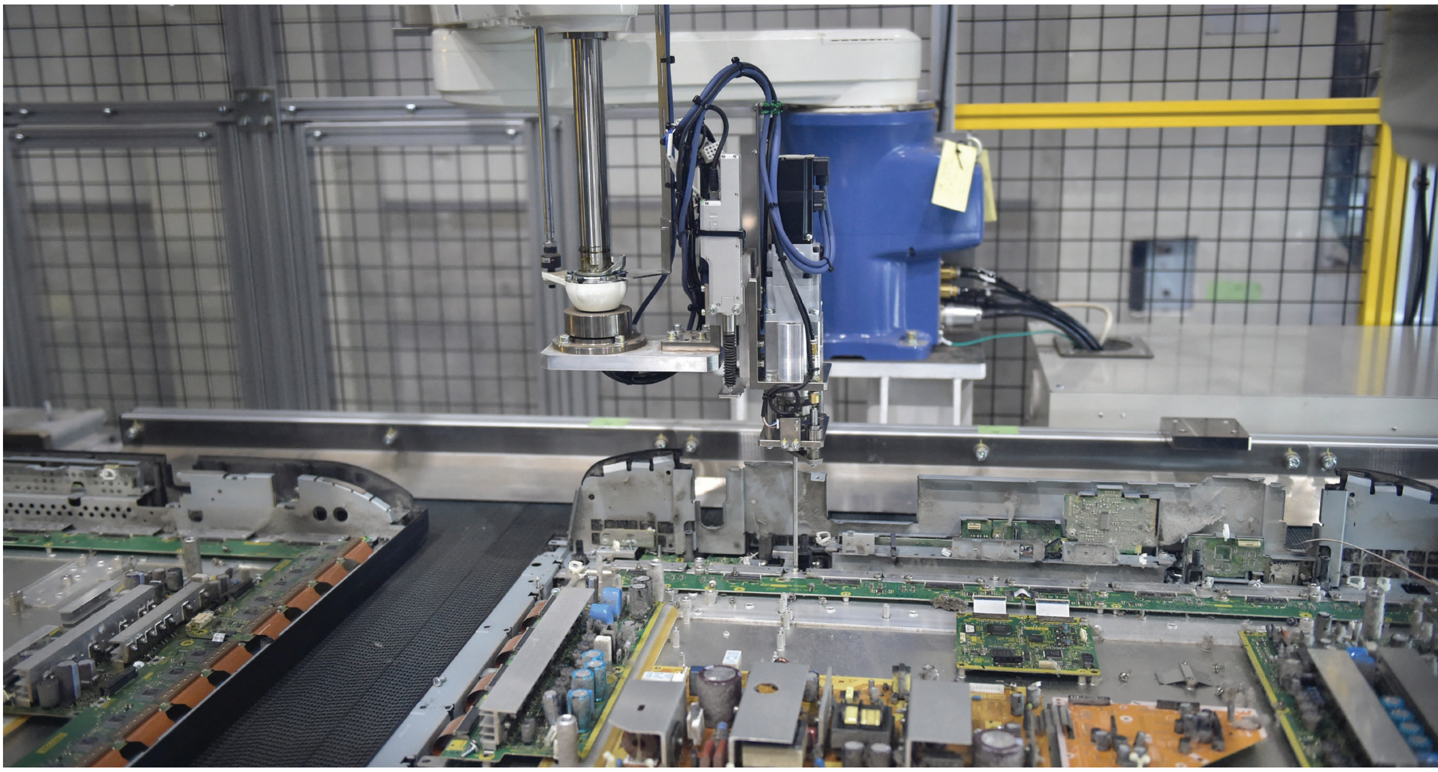
Towards circular e-waste management: How can digitalisation help?

Stefan Šipka



A picture taken on 21 February 2017 of a robot removing a screw from a flatscreen television at a Panasonic recycling factory in Inashiki, Japan. The factory collects and processes end-of-life home appliances with the latest recycling technologies to recover materials for reuse or repurposing. Credit: KAZUHIRO NOGI / AFP

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This Discussion Paper builds on the findings of "E-waste and the creation of a digital circular economy". Implemented by the European Policy Centre, supported by the WEEE Forum and funded by SENS eRecycling, this project was carried out between 2019 and 2021. It explored the role of digitalisation in improving the management of waste electrical and electronic equipment (WEEE), ways to make this management more circular in the EU and worldwide, and how these efforts could be better supported via policies. The project comprised a workshop and additional research activities, which led to this Discussion Paper.

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Visual created by Jon Wainwright.

Executive summary

E-waste is the fastest growing waste stream in the world. It contains valuable resources, including scarce and critical materials. The mishandling of e-waste results in avoidable pollution and greenhouse gas emissions. Even in the EU, which, as a whole, is the global leader in sustainable waste management, only one half of e-waste is reported as properly collected and treated. This sorry state of affairs must urgently change if we are to transition to a circular and sustainable economy.

Digitalisation can support the circular management of e-waste – including its prevention, collection and treatment – by enhancing information transfer, improving processes and connecting the relevant actors across the value chain. Artificial intelligence (AI) can improve the gathering and processing of information to enable the circular design of electronics. It can also improve waste sorting and strengthen law enforcement. Digital product passports (DPPs) can enable the tracking and tracing of electronics by producers and other actors in the value chain. Blockchain-enabled solutions can provide safe and transparent tools for sharing information about (used) electronics while safeguarding personal and business-sensitive data. Robots, sensors and digital twins can improve e-waste sorting and dismantling. 3D printing can provide spare parts to repair electronics, thereby extending their lifetime. Apps and online platforms can assist consumers' purchases of circular electronics and proper handling in the end-of-life phase.

Despite these existing good practices and prospects, challenges still remain regarding the use of data and digital solutions for a more circular e-waste management. While some digital solutions are already widely used (e.g. apps), others are yet to reach their full potential (e.g. robotics, blockchain, 3D printing). Some technologies, like AI and blockchain, are yet to be upscaled. The uptake of digital solutions by waste operators and producer responsibility organisations (PROs) are often hindered by costs and the EU's fragmented market for e-waste management. Concerns over data protection can create obstacles to accessing and sharing data of relevance to circular e-waste management. If not steered properly, digital transformation can also lead to negative side effects, such as *more* e-waste. For e-waste management to become more circular and digital, policy must back it up.

As the EU explores ways to promote the twin digital and green transition, improving e-waste management provides a timely and important case in practice. The EU should implement the following key policy recommendations:

- **Create a fully circular value chain for e-waste in the EU by 2030 and pursue the goal of establishing a circular e-waste system at the global level by 2050.** The EU should become a global leader in using digitalisation to improve waste prevention, collection and recycling and minimise exports. It must involve producers, PROs, waste operators, municipalities and non-governmental organisations when creating the enabling policy and investment framework for the transition.
- **Use regulation and soft law to develop rules and standards for data management**, to enable its sharing and processing to benefit the circular value chain for e-waste. This entails finalising the common European data space, developing common rules on using DPPs in electronics, and developing guidelines on how PROs and waste operators could manage their data.
- **Use EU financial instruments under the 2021-27 Multiannual Financial Framework and Next Generation EU recovery instrument to support the development and deployment of digital technologies** which enhance producers', PROs' and waste operators' management of e-waste.
- **Establish a single market for e-waste to incentivise private investments in the uptake of digital solutions for e-waste management.**
- **Use digital tools to enhance the enforcement of e-waste-related policies**, to end illegal waste shipments and other mishandlings of e-waste.

Introduction

Electrical and electronic equipment (EEE) is indispensable to our modern economy, lifestyle and society. Computers and smartphones optimise communication, data management and industrial processes, while electric home appliances make our daily tasks easier to handle. These products are central to the digital transformation. While the COVID-19 crisis and the consequential social distancing measures accelerate the digital transition further, it also highlights the importance of electronic devices in enabling teleworking and social connections. However, while they bring enormous benefits, their use is also coupled with challenges.

EEE comprises a diverse and complex range of products, with many components and materials, including hazardous substances (e.g. lead, mercury, flame retardants) and valuable assets (e.g. gold, copper, steel, aluminium). The latter category also includes critical raw materials (CRMs), such as cobalt, tantalum, indium and rare earth elements, sourced from only a handful of suppliers. Conversely, global actors, such as the EU, are highly dependent on foreign markets to access CRMs. That EU industry relies on a limited number of non-EU countries for CRMs undermines the security of supply and consequently the functioning and competitiveness of the EU's economy. The pandemic has demonstrated further the vulnerabilities of global value chains, which can hamper access to critical materials and undermine the resilience of both European and global economies.[1]

When computers, smartphones and other electronics become waste electrical and electronic equipment (WEEE) or 'e-waste', significant amounts of valuable resources are lost. This is economically costly. Moreover, if e-waste is not treated properly during its end-of-life phase, hazardous substances can pollute the environment and endanger public health.

The prevention and proper management of WEEE are also linked to climate mitigation. For example, in 2019, the inadequate treatment of fridges and air conditioners alone resulted in an estimated 98 metric tonnes (Mt) of carbon dioxide equivalents worldwide.[2]

E-waste is one of the fastest-growing waste streams in the world.

WEEE is one of the fastest-growing waste streams in the world. Multiple device ownership, the growth of cloud computing services and short replacement cycles pave the way for increased EEE consumption and waste.[3]

In 2019, around 53.6Mt of WEEE was generated worldwide, of which 12Mt is assigned to the EU. The secondary materials contained in this e-waste are estimated to be worth $57 billion.[4] WEEE stocks are increasing at an alarming rate of 2Mt per year. It is projected that the global generation of WEEE will exceed 74Mt by 2030.[5]

By sharp contrast, only 17.4% of the global e-waste generated in 2019 was reported as collected and recycled by official WEEE management schemes.[6] The situation is better in Europe: 42% of European WEEE is collected and recycled, and around one half in the EU.[7] Nonetheless, there is still great scope to improve the Union's treatment of already collected e-waste, recover more materials and components, and increase the share of repaired WEEE.

Huge amounts of e-waste are hoarded in households, handled inadequately (i.e. incorrect recovery of hazardous substances, unsafe working conditions), littered, incinerated, landfilled or shipped (illegally) to developing countries whose treatment standards and/or surveillance is likely to be substandard.[8] The generation and mishandling of WEEE come with great economic, social, environmental and climate-related costs.

The generation and mishandling of e-waste come with great economic, social, environmental and climate-related costs.

To counter resource depletion, emissions and waste, the EU is working towards a circular economy (CE) policy model which maintains the value of products and materials for as long as possible and minimises resource use and waste by increasing the repair, recovery, reuse and recycling of materials and products. The European Commission's proposal for a Circular Economy Action Plan (CEAP) – a key initiative under the European Green Deal – provides a policy framework and sets a global example. The EU's CE agenda feeds into the global Sustainable Development Goals on responsible consumption and production and contributes to climate aspirations under the Paris Agreement and the EU's 2050 climate neutrality objective.

However, extending the CE vision to (W)EEE – not just in theory but also in practice – requires more effort. One less-explored solution for improving e-waste management is digitalisation.

THE ROLE OF DIGITALISATION

Better use of data and digitally enabled solutions can support a CE.[9] This includes more circular management of WEEE across the value chain, from preventing its occurrence to enhanced collection and treatment (e.g. sorting, dismantling, depollution). Digitalisation can improve connections and information transfer; make products, processes and services more circular; and influence and empower citizens and consumers to play a role in the transition. It can facilitate more sustainable design and production processes; extend the lifecycles of products; and encourage reuse, repair and recycling. Lastly, it can enhance WEEE-related policies, including law enforcement and the countering of illegal waste management practices.

The focus on the twin green and digital transition is inherent in the European Green Deal. The EU recognises it as central to its COVID-19 recovery efforts. As the EU explores ways to promote the twin digital and green transition, using data and digital solutions to enhance the CE and e-waste management marks a timely case study (see Figure 1).

However, digitalisation's negative side effects should not go unchecked. The information and communications technology (ICT) sector accounts for 5% to 9% of the total energy demand worldwide and could increase to 20% by 2030.[10] It accounts for 2% of global greenhouse gas (GHG) emissions, making it comparable to the aviation sector.[11] Modern technologies like data centres, artificial intelligence (AI), the Internet of things (IoT), blockchain and cloud-based software increase energy consumption. AI not only consumes energy but can cause other environmental impacts depending on the parameters on which it operates.[12] Introducing new, digitally enabled solutions, like radio-frequency identification (RFID) chips, into products can create new challenges for their end-of-life management.

The jury is still out on the exact balance between the benefits versus risks of digital transformation for climate action and environmental protection.[13] In any case, digitalisation offers many prospects to drive the green transition, which would become even more prominent if the negative side effects are resolved. This Discussion Paper investigates how digitalisation can enable more circular WEEE management and how policies can support synergies between the two agendas.

Fig. 1

ALIGNING THE GREEN AND DIGITAL TRANSITIONS CAN ENHANCE CIRCULAR ECONOMY AND GREENER ICT

METHODOLOGY AND SCOPE

The findings in this Discussion Paper build on:

- the discussions of the EPC "E-waste and the creation of a digital circular economy" workshop, held on 21 January 2020, gathering around 30 experts from EU institutions, industry, producer responsibility organisations (PROs),[14] EEE developers and civil society;
- desk research;
- a survey answered by 17 PROs that are members of the WEEE Forum;
- 18 additional interviews and written correspondence with representatives of PROs, EU institutions, industry and academia; and
- a webinar with 25 PRO representatives on 17 December 2020, hosted by the WEEE Forum.[15]

This Discussion Paper explores how digitalisation can improve the end-of-life phase of EEE across the value chain. In other words, how it can contribute to WEEE prevention, collection and treatment (i.e. sorting, dismantling). Other phases of the lifecycle (e.g. design, consumption) are covered when relevant to the end-of-life phase. Several illustrative cases of data and digital solutions being used for circular e-waste management are listed, as well examples that could be relevant for enhanced WEEE management.

This paper focuses on policy developments in the EU, given its advanced waste policy framework, comparatively high performance in WEEE management, and global status as a frontrunner in aligning the twin green and digital transitions. Nonetheless, it also takes stock of relevant developments globally and in other parts of the world.

1. Digitalisation as an enabler

1.1. PREVENTION

1.1.1. State of play

Preventing WEEE should be the starting point for action. Given that the design phase of a product determines up to 80% of its environmental impact,[16] designing more durable and repairable electronics would avert these impacts across the value chain and prevent WEEE.[17] Product-as-a-service (PaaS) business models, where producers retain ownership of their appliances and offer repair services, can extend the lifetime of products.[18] Prolonging EEE use and repairs can decrease the generation of e-waste.[19]

However, challenges still remain. Consumers and businesses may opt to buy new EEE instead of prolonging the use of the old one due to lifestyle choices, indifference, inconvenience and/or concerns over the reliability of repairs services. Repair shops, which are independent of manufacturers, may be unable to guarantee the quality of service due to a lack of necessary information.

1.2.2. The role of digitalisation

Designers can use **AI** to speed up and improve design processes by experimenting with numerous materials and structures and testing and refining design suggestions to make electronics more durable and reparable (see Infobox 1).[20]

Introducing **digital product passports** (DPPs) into electronics during the design phase would make valuable product information available to different stakeholders throughout the value chain (e.g. producers, consumers, waste operators). This would make products more durable and easier to repair and recycle.[21] DPPs could be supported, for example, by **digital tags**, such as RFID chips or quick response (QR) codes. Consumers could scan these to access information about hazardous substances or recycled materials, which would empower them to make more sustainable purchasing decisions. Consumers would know how to prolong a product's lifespan and what to do when it stops working; repairers would know how to repair a product. Via reverse feedback loops, product designers could learn about the lifecycle of their equipment and consequently improve its performance.

Going forward, **blockchain** – a distributed ledger that records and shares information securely – offers interesting prospects for information exchange between manufacturers, repairers, retailers, consumers and

INFOBOX 1: AI FOR IMPROVED DESIGN OF ELECTRONICS

The Accelerated Metallurgy project, funded under Horizon 2020 (H2020), identifies new metal alloys and creates new materials via AI. As AI can accelerate the navigation through the variables needed to create the materials, it helps reduce alloy development time from a handful of years to under one. Although not directly linked to EEE design, data and digitally enabled solutions could also be applied to the development of more sustainable materials and products, including electronics.

INFOBOX 2: DIGITAL TAGS AND BLOCKCHAIN FOR INFORMATION TRANSFER

Scan4Chem is an app developed under the AskREACH project. Consumers use it to scan a barcode and request information from the supplier about the presence of highly concerning substances in the product. Having access to such information can empower consumers to buy more circular products.

Circularise, a Dutch start-up, is improving transparency and communication across value chains via blockchain. Its smart questioning technology allows for secure exchanges of information between the information holder (e.g. producer) and requestor (e.g. repairer). A QR code enables the information exchange on a product. After the first audit, information about the product's content (e.g. presence of recycled plastics) is carried throughout the value chain instead of conducting live audits multiple times. This simplifies the verification of the content, bringing costs down and potentially incentivising a more circular design of a product. The application has been tested for plastics and electronics and is commercialised for certain apparel brands.

other actors in the value chain while also safeguarding business-sensitive information (see Infobox 2).

Online platforms can enable the sharing of and access to information on how to repair a product. They can also serve as online marketplaces of used electronics that can be repaired, remanufactured or refurbished. Moreover, online platforms and **IoT** can enable PaaS business models, monitor rented equipment and thus support predictive maintenance. **3D printing** can produce spare parts necessary to repair or remanufacture products, including electronics (see Infobox 3).

1.1.3. Challenges to address

- Sharing information about EEE characteristics across the value chain (e.g. via a DPP) is hampered by **manufacturers' concerns over data protection.**[22] While blockchain could enable secure data exchange and incentivise data sharing, producers may still restrict access to more sensitive data.
- E-waste may contain **user-related data**. Waste operators who could repair a device to be used further may opt to recycle it instead to avoid a risk of data leakage.
- Producers are on **different levels of digital transformation**. Not all companies have the know-how to use data or lack skills to use digital tools (e.g. using DPPs to trace their electronics).
- The application of advanced digital technologies (e.g. AI, 3D printing) to prevent e-waste is yet to reach full **technical capacity**. Without business cases that add value, it is unlikely that companies would invest in digital solutions for the sake of WEEE prevention.

1.2. COLLECTION

1.2.1. State of play

Collecting e-waste separately via compliance schemes is important to ensure the circular treatment and monitoring of e-waste. However, WEEE collection is currently hampered by a strong informal sector, including a complex transnational network of illegal shipments and management.[23] This informal sector operates separately from the official collection schemes established by, for example, producers or municipalities and may lead to the suboptimal handling of e-waste.[24] These collection practices hamper the functioning of official schemes. Weak law enforcement emboldens a strong informal sector (see section 2.3.).

Lack of convenience (e.g. low density of e-waste collection points), users' lack of knowledge on where and how to dispose WEEE and/or operator's improper treatment of waste can lead to hoarding and/or the inadequate disposal of e-waste (e.g. littering; mixing with metal, glass

INFOBOX 3: ONLINE PLATFORMS, IOT AND 3D PRINTING FOR PRODUCT REPAIRS

iFixit is an open-source online platform for repairing electronics and machinery. It contains repair guides, Q&A forums and user-generated updates on existing and prospective equipment.

Open Repair Alliance is an online platform that collects repair practices to develop repair standards.

Refurbed is an Austrian online platform that offers refurbished electronic devices obtained through a network of independent repairers.

ReBuy is a German online platform that buys old electronics before refurbishing and reselling them.

Bundles has an online platform that lends home appliances. Thanks to IoT and smart algorithms, the supplier can monitor machine performance and identify possible problems to predictive maintenance.

ThyssenKrupp gathers elevator data and uses IoT to enable predictive maintenance. Similar tools could be used for the predictive maintenance of electronics (e.g. printers, washing machines).

Bosch uses Zotrax M200 3D printers to produce spare parts for the machines and equipment on its production line.

or general waste).[25] As e-waste can contain user data, concerns over personal data can be a reason for users' hesitance to hand it over, especially if they do not know how to remove said data. This is also a potential problem for waste operators, as removing personal data requires resources and can lead to liability issues if the data ends up in the wrong hands (e.g. laptop or smartphone is stolen).

Lack of convenience can also be a problem in the business-to-business (B2B) sector. A company that uses a beverage fridge, for example, may lose sight of its obligations to return the equipment to the original supplier at the end of its lifecycle. This is especially challenging when paper contracts were signed long ago. A lack of coordination between the different actors involved in WEEE collection (e.g. producers, PROs, municipalities, waste operators) can result in the suboptimal handling of e-waste. Lack of transparency about collection plans can lead to 'cherry-picking': only picking up easily accessible and valuable e-waste.

INFOBOX 5: ONLINE PLATFORMS FOR E-WASTE COLLECTION

Amazon provides a pick-up service in the UK for WEEE weighing above 30 kilograms when a customer places an order for the delivery of a new, similarly large appliance.

Sustainability Victoria is a statutory authority established by the Australian Government to promote environmental sustainability and inform its citizens on how to handle e-waste.

The Urban Mine Platform database – developed by the WEEE Forum-led consortium and funded by H2020 – maps the whereabouts and structure of e-waste which can facilitate its efficient collection.

1.2.2. The role of digitalisation

Digitally enabled tools (e.g. entry cards, electronic payments) can improve the safety of collection points and prevent scavenging. They can help identify illegal WEEE management practices and act as a deterrent (see Infobox 4).

Online platforms can serve many purposes across the value chain, such as better coordination and information sharing between waste collectors as well as law enforcement agencies. Online platforms can be data repositories for mapping and tracing WEEE. They can be used to inform consumers on how to dispose of e-waste. Online marketplaces can even provide take-back options for electronics bought online (see Infobox 5).

Sensors and **IoT** can support better logistics for official WEEE collection systems. For example, when installed in 'smart bins', they can increase the transparency and traceability of waste movements. Sensors detect when the bin is full and notify waste collectors automatically, hence saving time and costs. Adding extra features, like citizens entering data via consoles attached to the bins or recognising digital tags in discarded electronics, would provide information about WEEE characteristics to operators and facilitate analysis, future predictions and preparations for adequate treatment. Citizens inputting data about their e-waste would strengthen their sense of ownership over the process and increase transparency. This could help deter illegal WEEE management.

INFOBOX 4: DIGITAL TOOLS FOR THE SECURE HANDLING OF E-WASTE

In countries like Austria, the Netherlands and Switzerland, citizens have entry cards to access local collection points. This increases safety and reduces the need to keep personnel on the site all the time.

France has banned cash payments for scrap metal; electronic payment improves the monitoring of WEEE transfers and consequently law enforcement.

Similarly, sensors, IoT and other digital tools can enable 'smart trucks', connecting them with their surroundings and optimising their movement for better waste collection and transport. Fully autonomous vehicles are also being developed, although this technology is yet to be introduced on a wider scale (see Infobox 6).

DPPs offer interesting prospects for tracking and tracing e-waste across value chains. Greater transparency about WEEE's whereabouts and conditions is crucial to support the enforcement of e-waste rules, including by identifying illegal transfers. By scanning tags on items, competent authorities (e.g. custom officer, inspector) can determine its status and assess if the e-waste is being managed illegally (e.g. export or treatment by unauthorised persons). Moreover, DPPs could help producers locate and retrieve the equipment they have sold. This could incentivise a stronger role for producers when collecting e-waste and accessing valuable assets.

Using digitally enabled solutions, such as DPPs, to track and trace valuable EEE offers an interesting business case for e-waste collection, especially in B2B markets. Considering the higher value and relative ease of collecting B2B electronics compared to consumer electronics, business opportunities for retrieving, repairing, remanufacturing and ultimately reselling old, valuable B2B products can be created. Conversely, better access to information about e-waste (e.g. content, lifespan, damages, reparability) could incentivise producers to design more circular electronics and encourage the repairing and recycling of electronics in its end-of-life phase.

Algorithms and **AI** can support law enforcement since they can screen the web for traces of illegal activities that may warrant investigation. Digital tools can also analyse big data and help predict the generation of e-waste and facilitate its collection (see Infobox 7).

INFOBOX 6: SENSORS, APPS AND DIGITAL TAGS FOR E-WASTE COLLECTION

InnoWEEE was a project developed by EIT Climate-KIC, with Italian PRO Erion's involvement. It tested the use of smart bins for enhanced WEEE collection. Citizens could enter information about the discarded device via a screen attached to the bin; while smart bins could read the digital tag on the equipment.

Van Happen uses IoT and sensors on waste containers to track the movements of WEEE. This enables more efficient WEEE management.

OPEN, a Dutch PRO, is testing smart bins equipped with sensors that automatically inform WEEE operators when waste can be picked up.

Elektrowin, a Czech PRO, uses an app where waste collector upload information about WEEE loaded from collection points to kerbside trucks. The app uses the Global Positioning System (GPS) to determine the location of the WEEE loading.

Smart Recycling has developed cloud-supported sensors that are placed on waste containers to monitor and determine when they are ready to be emptied. This solution optimises waste collection routes, which cuts time, costs and emissions. The sensors are in use in the collection of waste glass, metal, paper and plastic in Sweden and Norway.

Conundra has developed an algorithm that optimises truck routes. Similar solutions can be applied to WEEE collection trucks.

Fleetmind has developed smart truck technologies that are based on electronic information sharing to enhance waste collection. These solutions include on-demand pick-ups via electronic scheduling, the automatic sharing of this information with available trucks, and real-time fleet tracking.

Ashbee has developed smart trucks for waste collection. The vehicles are equipped with sensors, GPS technology and RFID readers and are supported by digital platform which optimises the use of trucks.

Chalmers University, Volvo and Renova are in the early phase of testing robots supported by drones in collecting and emptying refuse bins automatically. Volvo and Renova are researching and testing the use of autonomous trucks in collecting and transporting waste. This research builds on Volvo's experience in using autonomous trucks in mining activities in Northern Sweden.

1.2.3. Challenges to address

- Applying DPPs to electronics is an opportunity for producers to retrieve valuable assets from e-waste. However, it could also hamper a **company's competitiveness** if sensitive product information would be made accessible to third parties. There is still no consensus between producers on the use of DPPs. The voluntary adoption of DPPs will likely depend on producers' case-by-case assessments.
- DPPs could be used to determine the location of an electronics user, which raises concerns over **personal data protection**.
- DPPs cannot be applied to **already existing e-waste**.
- Some digital solutions, such as smart bins, are technically feasible but are **not yet cost-effective**. In principle, smart bins cost more than regular ones, especially for waste operators that are small and medium-sized enterprises (SMEs).
- Collaboration and digital tools (e.g. online platforms) for better management of WEEE can be undermined by a **lack of skills, perceived costs or indifference** by competent authorities, consumers, producers and waste operators.

INFOBOX 7: ALGORITHMS AND AI FOR MONITORING GENERATION AND MOVEMENTS OF E-WASTE

Web crawler spiderbots and AI can be used to collect and process online data about producers and their products. Likewise, these tools could be used to search for any sign of illegal handling of e-waste.

OPEN uses modern algorithms to process historical data about EEE sales and advertising campaigns. This predicts the generation of waste and facilitate its collection.

1.3. TREATMENT

1.3.1. State of play

Once e-waste is collected by the designated operators, its circular treatment (e.g. sorting, dismantling, depollution, repair, recycling) must be ensured. E-waste is a diverse and complex waste stream. The continuous development of new electronics (e.g. e-bikes) adds additional burdens to the recycling process. Small WEEE (e.g. LEDs), can be difficult to manage. Accessing CRMs or depolluting the equipment can be complicated. These challenges are related to limited access to information about WEEE content and its proper treatment.[26]

INFOBOX 8: BLOCKCHAIN AND DIGITAL TAGS FOR IMPROVED INFORMATION TRANSFER

Circularise's blockchain-based smart questioning can share information about EEE content in a secure way and help facilitate WEEE treatment. For example, an operator can scan QR codes and ask if certain e-waste items contain hazardous chemicals. The information arrives from the producer and can facilitate e-waste handling. Circularise is also involved in the H2020 C-SERVEES project, in partnership with the WEEE Forum. The project seeks to make washing machines, televisions, printers and telecom components more circular by developing, testing, validating and sharing information on new circular business models.

FiliGrade is a Dutch company that has developed a system of imprinting watermarks onto plastic products, which can be scanned via a smartphone to, for example, retrieve valuable information on the product. Filigrade's watermarks can also be used to make waste sorting and thus recycling much more efficient.

The absence of a truly harmonised single market for e-waste is hindering WEEE treatment in the EU. Market fragmentation is linked to the current legislation (see section 2.3). A fragmented waste market hinders economies of scale for secondary raw materials. Limited supplies of e-waste make treating it more costly and the final output more expensive. They hamper investments and innovation. This undermines the competitiveness of secondary materials versus virgin materials and reinforces a linear economy. Moreover, a fragmented e-waste market may disincentivise producers from setting up their own e-waste management schemes. A gap between the producer and its electronics hampers the circular design of new electronics, which can exacerbate its management in the end-of-life phase.

The absence of a truly harmonised single market for e-waste is hindering e-waste treatment in the EU.

1.3.2. The role of digitalisation

Digital data platforms allow for simpler fast-track procedures for shipments of e-waste. They can enable electronic pre-notification and check upcoming WEEE shipments, and hence replace hard copy documentation. E-waste could be treated to recover valuable assets. Illegal practices could also be prevented (e.g. dumping, burning, dangerous working conditions).

DPPs, digital tags, and **IoT coupled with blockchain** for a secure exchange of information can help waste operators access WEEE content information and how to dismantle or repair it.[27] Otherwise, if a waste operator cannot determine a *priori* the presence of hazardous substances in e-waste, the equipment would need to be disassembled manually to determine the content. This costs money and time (see Infobox 8).

AI solutions can also offer possibilities for improving WEEE treatment by supporting access to information on sorting or dismantling e-waste. Using cameras with AI-supported image recognition technology to compare the devices on a treatment line with countless e-waste images in a database can help identify products, automatise the sorting process, and help workers dismantle or repair items (see Infobox 9).

Applying **robotics** to e-waste management can improve waste sorting and disassembly. Robots can act alone or collaborate with humans, completing more dangerous or tedious tasks where human attention and performance diminishes over time. Robots can also be combined with other digital tools, such as AI, to automatise WEEE management (see Infobox 10).

Digital twin technology and **sensors** can optimise waste sorting and recycling processes. While digital twins can create digital replicas of physical processes before they are implemented in real life, sensors can support the continuous monitoring and gathering of information on the performance of waste treatment (see Infobox 11).

INFOBOX 9: AI FOR E-WASTE SORTING

Recupel, a Belgian PRO, has developed an AI-enabled solution that helps sort small WEEE via product image recognition. It uses AI for basic device recognition and is developing advanced functions for enhanced device recognition and identification of hazardous materials.

OPEN is developing AI for WEEE sorting, especially to separate mercury- from non-mercury-containing display screens. E-waste which contains mercury is more costly to treat. Early separation from the rest of WEEE can reduce the costs of its treatment.

SENS eRecycling, the biggest Swiss PRO, is developing AI which recognises different e-waste on a conveyor belt based on image recognition.

The EIBA project, led by Fraunhofer Institute for Production Systems and Design Technology, is developing an AI solution that identifies and assesses the conditions of used equipment, namely automotive components. This information would help workers remanufacture a piece of machinery and could be relevant for electronics, too.

INFOBOX 10: ROBOTICS FOR E-WASTE SORTING AND DISMANTLING

Apple uses robotics to dismantle end-of-life iPhones. Its robot can dismantle 15 different iPhone models at a pace of 200 devices per hour (i.e. 1.2 million per year).

HR-Recycler is a H2020 project developing a collaborative human-robot system to enhance WEEE management (e.g. categorising e-waste, disassembling equipment, sorting device components).

Votechnik developed an automated dismantling system and robots to manage waste liquid-crystal display (LCD) screens. ReVolv is a project run by Votechnik that upscales and commercialises its automated technology for disassembling and depolluting LCD panels.

AMP Robotics developed an AI-powered robotics system for WEEE sorting in Japan. Robotic arms, supported by cameras, sort waste with 99% accuracy and at a speed of 80 items per minute (i.e. four times faster than manual sorting).

Refind developed waste-sorting technology based on cameras and machine-learning software to help sort out WEEE more efficiently and identify valuable components and hazardous items.

ZenRobotics uses AI-supported robots for fast and precise waste sorting.

Online platforms can support information sharing between producers and waste operators. This can facilitate better WEEE treatment and help inform producers about the fate of end-of-life products. Digital platforms can support online trading in secondary raw materials, boosting investments and innovation in e-waste treatment (see Infobox 12, page 12)).

1.3.3. Challenges to address

- As in the case of e-waste collection (see section 1.2.), **data protection** issues (e.g. personal data, intellectual property rights) hinder the uptake of digital tags and DPPs.
- The development of **adequate tracking and tracing tools** is hampered by the complexity and variety of e-waste. Digital tags could also be damaged during an EEE lifecycle and be less practical in small WEEE when huge amounts need to be sorted out and dismantled quickly.
- Many WEEE operators are SMEs that lack substantial **funds and capacities to modernise their infrastructure and processes** (e.g. introducing AI, robotics). Lower-income countries and/or regions may not be able to automatise WEEE treatment due to low labour costs that incentivise manual operations. If a waste operator is *not* using modern digital tools, the PRO that coordinates its work must adjust to the 'weakest link'. This is an administratively burdensome task.
- Waste operators traditionally do not have **experience with digital tools**. Moreover, their focus has been on material recovery (i.e. recycling) rather than repairing or remanufacturing. This hampers the use of digital tools for practices later on.
- **Many digital solutions are still under development and need to be technically** improved for them to become efficient and reliable tools for treating e-waste (e.g. sorting by brand, analysing content).
- **The application of robotics is currently limited** to a certain type of e-waste (e.g. only dismantling smartphones).
- **A fragmented e-waste market** limits access to e-waste, which hampers innovation, including introducing new digital technologies. For example, robotics is costly and requires sufficient WEEE supply to justify its deployment.

INFOBOX 11: SENSORS FOR E-WASTE SORTING AND TREATMENT

TOMRA developed a set of cutting-edge sensors-based technologies to help automatise the sorting of different kinds of waste and make the entire process more efficient.

Novamet applies digital twin technology to model and simulate the aluminium melting processes which also pertains to its recycling. Sensory equipment monitors the melting process in furnaces and sends the data for more precise planning and decision-making on future aluminium melting.

SUEZ uses advanced waste characterisation with multi-sensor data to improve its waste sorting and recycling. Infrared technologies enhance waste sorting, while digital twin technology enables sorting machines to learn from its digital images of waste items. SUEZ is also experimenting with blockchain technology to ensure the real-time traceability of waste flows.

INFOBOX 12: ONLINE PLATFORMS FOR ENHANCED TREATMENT OF E-WASTE

Recykal is an Indian company that develops digital solutions to help waste operators better manage end-of-life products, including WEEE. Examples include online platforms for producers to buy and sell WEEE from waste operators and a consumer app to help dispose of WEEE.

I4R is an online platform where waste operators can access information provided by producers on preparing for the reuse and treatment of WEEE. I4R has been designed and developed by APPLiA and DIGITALEUROPE, equipment manufacturing associations, and is maintained and hosted by the WEEE Forum.

Cobat, an Italian PRO, is involved in the H2020 project DigiPrime (2020-23), which the Polytechnic University of Milan manages. It aims to establish a model for interoperable digital platforms for CE. These platforms would support cross-business exchanges of data on EEE conditions and guide its remanufacturing.

SeconTrade is a digital platform managed by UFH, an Austrian PRO. It facilitates the trade in secondary raw materials, therefore enhancing the business case for recycling and incentivising investments into WEEE treatment.

SCIP is the European Chemicals Agency's database on substances of very high concern in products, including electronics. It aims to ensure that the information is available throughout EEE lifecycles, including the end-of-life phase, and accessible to recyclers to enhance e-waste management.

CircularBrain is developing Digital Hub, a data ecosystem, to share information on, for example, secondary material flows and recycling of complex products (i.e. electronics).

Europe is at the forefront of the transition to a CE, including e-waste management. However, there is still a long way ahead before reaching full circularity across the value chain and realising prospects of digitalisation to that end. This calls for effective policies to help enable the use of digital tools for a more circular WEEE management.

2. The EU policy framework

2.1. THE CIRCULAR ECONOMY ACTION PLAN

The CEAP – put forward by the European Commission in 2020 – outlines a policy framework for the future, building on the previous CE agenda (2015) and sectorial policies, including on WEEE. The CEAP is a spin-off of the European Green Deal, the EU's overarching green growth strategy for a climate-neutral and resource-efficient economy.

The CEAP lays out a "regenerative growth model" which "gives back to the planet more than it takes".[28] It also recognises the opportunities a CE provides for industry and entrepreneurship. The CEAP envisages a myriad of initiatives, including a sustainable product policy framework and an enhanced waste policy framework, while also focusing on key value chains, including electronics.

The CEAP recognises the prospects of digitalisation as an enabler for the CE. It acknowledges the importance of a common European data space in supporting the CE; a governing framework to drive the application of concrete digital solutions (e.g. DPPs). The common European data space may prove crucial in overcoming barriers to data sharing (see section 1). It is linked to a wider initiative under the EU's Data Strategy. The CEAP also considers adopting regulatory measures to mobilise the potential of DPPs and tags. The Commission envisages the development of systems that track and manage the information on substances that hamper waste recovery operations.

The Circular Economy Action Plan recognises the prospects of digitalisation as an enabler for the circular economy. It acknowledges the importance of a common European data space in supporting the circular economy; a governing framework to drive the application of concrete digital solutions.

On top of the aforementioned references to data and digital solutions, CEAP could have stressed more the prospects of AI, robotics and 3D printing in supporting circular design, waste sorting and repairs. Furthermore, as it was adopted before the COVID-19 crisis escalated, the CEAP does not fully reflect the acceleration of the digital transition (e.g. e-commerce, teleworking) nor recognise the vulnerability of global supply chains. Lastly, concrete instruments for implementing the CEAP and aligning circular and digital agendas are still under development.

2.2. PRODUCT POLICY

2.2.1. Ecodesign framework

The Ecodesign Directive 2009/125/EC established "a framework for the setting of Community ecodesign requirements for energy-related products".[29] The 'requirements' are defined in specific implementing measures (i.e. regulations)[30] and supported by harmonised standards.[31] Until recently, the Ecodesign Directive only considered energy efficiency aspects. However, the EU has started introducing circularity requirements for electronics as of 2019.[32] The CEAP now extends this ambition to mobile phones, tablets and laptops to improve their energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling.

Producers are not yet required to introduce DPPs into their electronics. Their willingness to do so voluntarily varies, especially due to concerns over data protection (see section 1). However, the CEAP's Sustainable Products Initiative, which will feature new ecodesign requirements, could push the development and uptake of DPPs.[33]

The Sustainable Products Initiative, which will feature new ecodesign requirements, could push the development and uptake of digital product passports.

In 2020, the Commission proposed the Batteries Regulation, which would make the introduction of DPPs into large batteries for electric vehicles and industrial purposes mandatory. This proposal complements the Global Battery Alliance's similar, ongoing work on introducing DPPs into batteries. If adopted, this legislation could make information on the content of batteries accessible and facilitate their end-of-life treatment. The ongoing work under the proposed Regulation could also be considered a pilot case for introducing the requirements on DPPs into electronics.

Nevertheless, the road ahead is long. Integrating DPPs into highly valuable supplies of large batteries is different from using them in the EEE value chain, which features a wide range of appliances and components. Also, it may be easier to initially limit their use for B2B EEE, making it easier to consider the business case and minimise costs and administrative burden. However, potential trade-offs should not be neglected: inserting DPPs in certain electronics (e.g. LED lamps) could bring environmental benefits without tangible economic gains.

2.2.2. Green public procurement

Public procurement (PP) accounts for 14% of EU GDP. Green public procurement (GPP) could stimulate the development of digital, circular EEE and PaaS. The EU's Public Procurement Directive 2014/24/EU envisages voluntary GPP and has developed criteria for certain office EEE. The CEAP envisages developing and introducing mandatory GPP criteria. At this point, however, member states' GPP implementation has been limited, and links between the EU's GPP rules and digitalisation are missing.

2.2.3. Consumer law

The EU's consumer policies are well-developed and include some environment-related rules (on e.g. voluntary ecolabels, mandatory energy efficiency labels). Still, a strong link with the CE is missing, risking an increase in the unsustainable use of electronics. The CEAP envisages revising consumer law to "ensure that consumers receive trustworthy and relevant information on products at the point of sale, including on their lifespan and on the availability of repair services, spare parts and repair manuals."[34] The European Commission is currently considering introducing amendments to the existing consumer legislation or a separate instrument. However, the digital tools for informing consumers (via e.g. online platforms, DPPs) could be improved.[35]

2.3. WASTE POLICY FRAMEWORK

2.3.1. E-waste legislation

General rules on waste management are set out in the Waste Framework Directive 2008/98/EC, while WEEE Directive 2012/19/EU sets specific rules for e-waste management. Both directives introduced extended producer responsibility (EPR) to cases where, in principle, producers take care of their end-of-life products. In the WEEE Directive, producers must finance e-waste collection and treatment. Producers can also manage their e-waste or establish a PRO to do that instead. The latter option is more popular.[36] Producers must provide relevant information on e-waste handling to waste operators. Member states can introduce a similar responsibility to inform the users.

The WEEE Directive sets e-waste collection and treatment targets that are also linked to the EPR. As of 2019, member states' annual collection target is 65% of the national average weight of electronics placed on the market in the three preceding years.[37] The treatment targets are set as percentages of recovered (i.e. reused, recycled) pieces of e-waste. Given the CEAP's focus on repair and/or remanufacturing, it remains to be seen if these targets will be revised by, for example, separating recycling targets from preparation-for-reuse targets. Lastly, to ensure EPR fulfilment, producers must register in their country of operation and report on collected and treated e-waste via a common format.[38]

The WEEE Directive leaves a huge margin of discretion for member states to regulate their own e-waste management systems. This hampers the Directive's implementation and achievement of its objectives. EPR was meant to incentivise changes in producers' behaviour, notably to design more sustainable products.[39] Instead, e-waste is managed by multiple stakeholders (i.e. producers, PROs, municipalities, repairers, other operators) without always having a clear delineation of responsibilities. The ongoing discussion on improving the existing policy framework ranges from enforcing the EPR principle to formally assigning responsibility to all the stakeholders involved in e-waste management (i.e. the All Actors Approach).[40] In any case, assigning clear responsibility for e-waste management, coupled with strong law enforcement, would improve waste handling. It could also arguably incentivise the deployment of digital solutions for e-waste management because they would help responsible actors achieve objectives under the WEEE Directive.

The WEEE Directive leaves a huge margin of discretion for member states to regulate their own e-waste management systems.

In an attempt to enhance EPR, in 2018, the Waste Framework Directive introduced rules on the eco-modulation of the EPR fee, where producers would pay less for circular products. However, it is yet to be implemented across the EU.[41] The EU has defined six WEEE categories upon which producers must report. Since they are broad and do not reflect the complexity of e-waste, member states introduced their own subcategories for reporting. These vary across member states,[42] and producers often need to report to multiple authorities (i.e. customs, PROs, environment agencies) across different countries. This complicates the reporting and makes it prone to errors, although there are good practices, too (see Infobox 13).

Weak law enforcement is a major problem when implementing the WEEE Directive. Limited resources and a lack of planning and coordination between authorities (e.g. customs, inspectorates) and the relevant stakeholders (e.g. PROs, non-governmental organisations) make it difficult to tackle the informal sector, counter 'free riders' (e.g. producers not partaking in EPR schemes) and ensure accurate reporting.[43] This problem is magnified in several non-EU countries which import EU e-waste. For example, Nigeria is a destination of much of the EU's WEEE, and while the legislative framework is in place (including EPR), it is not fully implemented. 20 EU member states have recently formed the European WEEE Enforcement Network, composed of national enforcement agencies, to counter free riders. Nevertheless, more should be done to counter the illegal e-waste management sector, especially by building on existing initiatives (see Infobox 13).

These shortcomings explain, to a great extent, the practical problems of WEEE management (see sections 1.2 and 1.3) and are manifested in a lack of compliance with the set targets. While the WEEE Directive's *treatment* targets have mostly been met, most member states did not reach the 2019 *collection* targets.[44] Moreover, there are serious concerns over the accuracy of the data on collected and treated e-waste due to complex reporting and/or lack of surveillance.

Furthermore, the WEEE Directive does not establish a link between e-waste management and the use of data and digital solutions, except in relation to rules for producers on providing information to waste operators. The I4R Platform is an example of such information transfer (see section 1.3.). However, the Directive's references regarding the means of informing the waste operators are somewhat vague or outdated.[45]

INFOBOX 13: DIGITAL TOOLS FOR REGISTRATION, REPORTING AND LAW ENFORCEMENT IN THE ELECTRONICS SECTOR

Digital producer registration is already implemented by some governments (e.g. Italy, Austria). PROs are also using online platforms for producer registration (e.g. Salesforce, Blackbox, tailor-made). Dutch PRO Wecycle pre-fills registration forms for producers and generates electronic invoices automatically, reducing human error and removing unnecessary work. WEEE Ireland automated contract signing with their producers and certification to avoid paper contracts. WF-RepTool is a database app developed by the WEEE Forum to determine the recovery and recycling rates of e-waste treatment in a transparent and traceable manner, to obtain comparable results. PROs and waste operators use the app in their reporting on recycling, recovery and depollution.

The European Commission has developed the Information and Communication System for Market Surveillance to facilitate information sharing between national authorities. The Commission is also running a dedicated EEPLIANT (Energy Efficiency Compliant Products) project to improve the market surveillance over ecodesign rules.

2.3.2. Rules on waste shipments

There is no real EU single market for secondary materials. This undermines the economy of scale for secondary raw materials and disincentivises producers from investing in digital solutions for circular WEEE management. The Basel Convention and Waste Shipment Regulation 1013/2006 heavily restrict the shipping of e-waste across the world and the EU, respectively. The Organisation for Economic Co-operation and Development's (OECD) Control System for Waste Recovery distinguishes between green (i.e. low risk for human health, e.g. e-waste) and amber control procedures for waste (i.e. higher risk, stricter control).

Shipping used products and materials for recycling across EU borders is challenging, time-consuming and costly. Navigating through member states' fragmented regulatory landscapes is also complicated. There are good reasons for these restrictions, given the strong informal (i.e. illegal) waste management sector, lack of harmonised standards and presence of hazardous and valuable materials in e-waste. However, these restrictions also hamper the movement of e-waste to certified treatment facilities that can support the CE. Inefficient, paper-based administrative procedures still burden these waste shipments.[46]

Adopting EU-level mandatory standards on WEEE management, coupled with stronger law enforcement to counter illegal operations, would help address some of these hurdles. Positively, the Commission is looking into possibilities of introducing mandatory standards for WEEE management, building on the existing voluntary CENELEC and WEEELABEX standards.[47]

2.4. THE DIGITAL AGENDA

2.4.1. State of play

In 2020, the Commission adopted a new Digital Agenda, including the European Digital Strategy, the European Data Strategy and the White Paper on Artificial Intelligence. The Digital Agenda, together with the relevant international developments, can boost the use of data and digital solutions and, as such, support the modernisation of WEEE management across the value chain.

The new Digital Agenda aims to establish a single market for data. It envisages a common European data space so that Europe can benefit from sharing industrial data, unlocking new business opportunities and achieving common objectives, such as the transition to a CE. The EU's Intellectual Property Rights strategy recognises Europe's need for "a solid framework to allow businesses to create, access, share and use data" to "facilitate repairs".[48] To that end, the Commission is evaluating the intellectual property rules to ensure a balance between information transfer and data protection.

The new Digital Agenda envisages a common European data space so that Europe can benefit from sharing industrial data, unlocking new business opportunities and achieving common objectives.

2.4.2. Information transfer

A starting point for establishing common European data space is the Commission's proposal for a Data Governance Act. It would facilitate different stakeholders' (i.e. businesses, citizens, researchers) access to information held by public authorities and help intermediary organisations manage data on behalf of data providers and users. It would facilitate data sharing for 'altruistic purposes', including the common good, and therefore be relevant to the green agenda and the CE. The Commission is also expected to propose a Data Act by the end of 2022; the legislation will aim to facilitate access to and use of data in B2B and business-to-government (B2G) situations. Another initiative relevant for information transfer is the GAIA-X project to develop common requirements for a European open data infrastructure. It is a collaborative effort between seven European countries and led by Germany and France, and involves policymakers, industry and the scientific community. Nonetheless, the rules on information transfer remain far from complete, and a smooth flow of data is yet to be attained.[49] Consequently, information transfer of relevance to the WEEE management is also affected.

Lastly, global developments on standardising, notably on electronic data interchange (EDI), exist. These standards are being developed within the EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport) and EDIFICE (Global Network for B2B Integration in High Tech Industries) regulatory frameworks. The European Parliament has recently highlighted the relevance of EDI standards for monitoring waste (shipment) flows.[50] GS1 is another global initiative on developing standards to identify, capture and share product-related information. The standards could potentially include circular management of W(EEE).[51]

2.4.3. Digitally enabled solutions and infrastructure

Blockchain can provide a secure and transparent channel for transferring information relevant for enhanced WEEE management (see section 1). The European Blockchain Partnership is a joint effort of all 27 EU member states, Norway, Liechtenstein and the European Commission. It aims to create a European Blockchain Services Infrastructure that supports the delivery of cross-border digital services by public and eventually private actors. The EU supports European and global standardisation of blockchain (e.g. under the International Organization for

Standardization, European Telecommunications Standards Institute, CEN-CENELEC, Institute of Electrical and Electronics Engineers, International Telecommunication Union's Telecommunication Standardization Sector). It is also involved in the International Association for Trusted Blockchain Applications, which aims to facilitate interaction between blockchain developers and regulators. The EU Blockchain Observatory & Forum maps key initiatives, monitors developments and inspires common actions on blockchain.

AI is one of the most transformative technologies to emerge and can improve the design processes of electronics and enhance e-waste sorting.

AI is one of the most transformative technologies to emerge and can improve EEE design processes and enhance e-waste sorting (see section 1). The EU's Digital Agenda emphasises its development strongly. The EU is expected to invest €1 billion per year in AI under the 2021-27 Multiannual Financial Framework (MFF) and help mobilise additional private investments to reach €20 billion per year.[52] The European Commission's White Paper includes a list of possibilities for developing ethical or trustworthy AI. It notes that "[d]igital technologies such as AI are a critical enabler for attaining the goals of the Green Deal".[53] Moreover, it suggests exploring with member states how to promote sustainable AI solutions that make environment-friendly choices. Building on the White Paper, the Commission proposed a regulation on AI. It would establish a framework for adopting codes of conduct "to foster the voluntary application to AI systems of requirements related [...] to environmental sustainability".[54] It would also facilitate the use of personal data for developing innovative AI, which improves the quality of the environment.

At the global level, the Institute of Electrical and Electronics Engineers has developed standards for the ethical use of AI (i.e. P7000). Standards on ethical AI are also relevant to solve sustainability-related challenges.

Modern digital infrastructure (i.e. data centres, internet coverage with high-speed broadband, 5G) is the basic foundation for the connectivity and high performance of tools like AI and robotics, including better WEEE management. Initiatives on WiFi4EU, high-performance computing, a European Cloud, eGovernment and 5G all play a role in bettering European connectivity. However, the modernisation of EU infrastructure is still ongoing. The EU is also involved in international standardisation initiatives on IoT (oneM2M) and 5G (3GPP).

Modern digital infrastructure is the basic foundation for the connectivity and high performance of tools like AI and robotics, including better e-waste management. However, the modernisation of EU infrastructure is still ongoing.

2.5. E-COMMERCE

2.5.1. Scope of the challenge

E-commerce introduces new actors in the supply chain, broadly classified as operators of online marketplaces and fulfilment service providers.[55] E-commerce stretches across member states and beyond the EU, potentially hindering compliance with EPR rules on e-waste, notably when non-EU producers sell electronics online to EU buyers without complying with EU law.[56]

The challenge of businesses' non-compliance is significant. Around 5% to 10% of electronics placed on the OECD market via e-commerce are not covered by EPR (i.e. 460,000 to 920,000 tonnes in EU alone).[57] Additional challenges remain as to the online marketing of products; ecolabels not being visible on online platforms makes it difficult for consumers to buy sustainably.

2.5.2. E-commerce legislation and extended producer responsibility

The e-Commerce Directive 2000/31/EC breaks down the online barriers to consumers accessing goods and services across the Union. These rules are being updated via the recently proposed Digital Services Act (DSA). It recognises the significant role online marketplaces play in the EU's economy and sets minimum obligations for all online intermediaries and e-commerce platforms. Nonetheless, a direct link to the green agenda is missing. The European Parliament suggests making online marketplace operators responsible for promoting eco-friendly products and fighting against false green claims in the DSA.

Concerning the e-commerce and EPR, the WEEE Directive defines producers inter alia as "any natural or legal person who [...] sells EEE by means of distance communication directly to private households or to users other than private households in a Member State, and is established in another Member State or in a third country."[58] Although this definition is vaguely related to e-commerce, it fails to define the roles of online marketplace operators or fulfilment service providers.

Some member states are considering complementing EU-level legislation with additional green regulatory measures, be it at the EU or national level. For example, Germany is considering possible responsibilities for new e-commerce actors. They range from ensuring that producers fulfil EPR responsibility (or else online marketplace operators refuse access to the online market) to assigning producer responsibility to online marketplace operators fully or in cases where producers fail to comply with EPR rules.[59] PROs involved in e-waste management back these policy considerations.[60]

2.5.3. E-commerce and market surveillance

The new Market Surveillance Regulation 2019/1020 (fully in force as of mid-2021) assigns responsibilities to market surveillance authorities and economic operators to ensure compliance of products placed on the market with the EU law. It recognises fulfilment service providers as economic operators under certain conditions and assigns responsibilities to online marketplaces ("information society service providers") to collaborate with competent authorities. Nonetheless, according to the German Environment Agency, "control powers [...] remain merely selective, concerning individual cases, and only allow an ex-post procedure" and "does not imply a nationwide, comprehensive preventive compliance-check".[61] While certain progress is still to be expected regarding the enforcement of technical requirements for products (i.e. product ecodesign), it is unlikely that the Market Surveillance Regulation will make a difference regarding the fulfilment of EPR obligations.[62]

2.6. FUNDING INSTRUMENTS

The EU's funding instruments can support the necessary collection and analysis of data and facilitate the development and deployment of sustainable technologies, practices and business models that enable a more circular e-waste management. In December 2020, the EU adopted the new 2021-27 MFF (€1.074 trillion), together with the EU's COVID-19 recovery plan, Next Generation EU (NGEU; €750 billion). The package also includes InvestEU, a public-private instrument expected to trigger hundreds of billions of euros of additional investments.[63] Following the adoption of MFF and NGEU, individual instruments have been or remain to be adopted.

2.6.1. Digital Europe and Horizon Europe

The **Digital Europe Programme** (DEP) will play a key role in the deployment and uptake of digital technologies, with an overall budget of €7.5 billion. It will focus on five areas: supercomputers, AI, cybersecurity, digital skills, and the deployment and best use of digital capacity and interoperability. While the Programme only establishes broader linkages between envisaged support to digitalisation and the environment, its draft work programme for 2021-22 is more explicit. It will aim at the "large-scale roll-out of AI-driven services [...] in [...] waste and secondary resource management, industry and (re)manufacturing, healthcare, e-government, and more."[64] Pertinent funds will also be used to support industrial pilot projects, "such as smart automated waste treatments and smart disassembly factories for electronic products."[65]

Horizon Europe succeeded H2020 (2014-20) with an overall budget of €95.5 billion. Although it does not establish a link between the two agendas, Horizon Europe will support digitalisation and the CE transition. Nonetheless, Horizon Europe will also feature a multiannual Strategic Plan to prepare the more specific work programmes. The draft Strategic Plan makes several references to using the funds for research and innovation to support the CE, including "new automated technologies to sort, dismantle and remanufacture or recycle products" (including electronics).[66]

2.6.2. InvestEU and the Recovery and Resilience Facility

InvestEU and the **Recovery and Resilience Facility** (RRF) will contribute 16% and 20% of their funds to the Digital Agenda, respectively. While they make broad references to the green and digital transitions, more specific ones, including the role of digitalisation in supporting CE, are lacking. Since member states must prepare Recovery and Resilience Plans (RRPs) to access the funds, it remains to be seen if and how the RRF funds will foster the circular and digital transition regarding e-waste management.

InvestEU and the Recovery and Resilience Facility will contribute 16% and 20% of their funds to the Digital Agenda, respectively.

2.6.3. Structural funds

The Commission's proposal for the **Cohesion Fund** (CF) and **European Regional Development Fund** (ERDF) – totalling almost €234 billion – refers to the CE and digitalisation, albeit without linking the two. The **Smart Specialisation** (S3) **Platform**, supported by the EU's Cohesion Policy – is a particularly useful tool for supporting regional development. The proposed €88 billion-worth **European Social Fund Plus** (ESF+) contains references to both digital and green skills. The EU's **Skills Agenda**, which is to be mainly funded by the ESF+, contains stronger cross-references between the CE and digitalisation. The **Pact for Skills**, a multi-stakeholder engagement model for skills development in Europe, is the first initiative launched under the European Skills Agenda. The ESF+, CF and ERDF are relevant for the digitalisation of the WEEE management sector. Given these funds' heavier focus on lower-income areas, they can support the just transition in the EU's more vulnerable regions.

3. EU policy recommendations

These recommendations are targeted at the EU – namely, the European Commission, member states and the European Parliament – unless specified otherwise. However, most are also applicable to non-EU countries.

STRATEGIC DIRECTION

- The twin green and digital transitions are setting the stage to make our economy more efficient, resilient and sustainable. Recognising the economic, environmental, climate-related and societal impacts of consuming electronics and increasing WEEE, as well as the possibilities that digitalisation offers for improving WEEE management, EU and national authorities must align WEEE management with the ongoing twin transitions. The EU should create a fully circular value chain for e-waste management by 2030 and pursue the goal of establishing a circular e-waste system at the global level by 2050. The EU should become a global leader in using digitalisation to improve e-waste prevention, collection and recycling while minimising exports.

The EU should create a fully circular value chain for e-waste management by 2030 and pursue the goal of establishing a circular e-waste system at the global level by 2050. The EU should become a global leader in using digitalisation to improve e-waste prevention, collection and recycling while minimising exports.

- The EU must use its Digital Agenda to speed up the deployment of digital infrastructure (i.e. 5G, broadband, data centres) and solutions that can enhance data sharing and information transfer (i.e. blockchain, AI, IoT, cloud, DPPs).

- Public authorities must recognise the power of data and digital solutions to enhance WEEE prevention, collection and treatment. They must use the CE agenda to facilitate the use of data and digital solutions for circular WEEE management. They must recognise the accelerated pace of digitalisation brought by COVID-19 and ensure that digitalisation is supportive of a CE, including in the electronics sector.

- Public authorities must consider and prevent or reduce the negative side effects of digitalisation on the climate, environment and society at large. They must develop rules and standards for and invest in digital solutions that are energy- and resource-efficient and enable the circular management of WEEE.

- Public authorities must recognise the importance of the just transition in ensuring that different regions have access to advanced digital solutions to enhance WEEE management.

- Industry, PROs and waste operators must be brought on board to boost the use of data and digital solutions for circular e-waste management. To that end, it is important to listen to their needs and concerns and create an enabling policy framework for all relevant stakeholders to join the transition. Conversely, organisations involved in e-waste management must take a proactive approach and collaborate with the decision-makers. Current industry-led initiatives and several measures taken by the PROs (see parts 1 and 2) exemplify such actions.

OBJECTIVE 1: IMPROVE INFORMATION TRANSFER FOR CIRCULAR E-WASTE MANAGEMENT

- **Create a common European data space, a data governance framework that incentivises and enables the fair access to and sharing of data and information for CE.** It would help create the conditions to share information about products, materials and substances between producers, consumers and waste operators while recognising their needs and ensuring a balance between sharing information and protecting confidential data.

- Start by identifying the data and information needed for the circular management of WEEE; in collaboration with member states, producers, consumer associations, PROs, waste operators, municipalities and non-governmental organisations (NGOs). For example, what information do PROs and waste operators need to depollute or repair used electronics most effectively? What data and information are needed to use AI-enabled solutions to design more sustainable EEE or robotics to sort out or dismantle WEEE? What information do consumers need to prolong the lifespan of electronics and dispose of them correctly? What data and information are needed for DPPs?

- Help set the technical standards for data to enable efficient data and information transfer for WEEE prevention, collection and treatment. The EU should closely involve member states, producers, PROs, waste operators, municipal associations and consumers in setting these standards. For this purpose, it could establish a separate stakeholder platform. Based on stakeholders' inputs, the EU should determine on a case-by-case basis if guidelines are sufficient or if mandatory harmonised rules are necessary.

- Set the rules that would enable the secure transfer of WEEE-related information between relevant stakeholders (i.e. producers, waste operators, consumers).

- Start by establishing voluntary schemes (i.e. 'coalitions of the willing') to enable information sharing, building on existing initiatives (e.g. I4R). In doing so, the EU should consider how data sharing could add value to businesses while safeguarding confidential data and supporting circular WEEE management simultaneously.

- Building on the lessons learned from the voluntary schemes, assess the possibilities of establishing mandatory requirements on data accessibility and information transfer to support WEEE collection and enable access to information on repairing and depolluting WEEE.

- Develop guidelines for PROs and waste operators to establish management systems that would be interoperable with platforms and databases of competent authorities, producers, and other PROs and waste operators.

► **Assess how EU policy can support the introduction of DPPs in electronics during their design phase** to help reduce the environmental footprint of electronics throughout their lifecycle. Such impact assessment would need to estimate the economic and environmental benefits and costs, especially the effects of voluntary versus mandatory rules.

- The rules on DPPs must be developed in close collaboration with all relevant stakeholders and entail assessments on a case-by-case basis (i.e. for each product type). The goal should be to provide the needed information to waste operators, repairers and consumers. Information transfer should be user-friendly while avoiding unnecessary costs and administrative burdens for producers while safeguarding confidential business information and personal data.

- Build on the proposed pilot for DPPs in large batteries, as envisaged in the proposed Batteries Regulation, when developing information transfer further in circular value chains. Consider supporting voluntary schemes for DPPs where they could become business opportunities (i.e. locating and retrieving valuable electronics) before moving on to mandatory requirements.

- Consider introducing mandatory rules on DPPs in B2B and for more valuable WEEE. Starting with more valuable (W)EEE could help bring industry on board and gather valuable experience needed to extend the legal requirements on DPPs at a later stage.

► **Consider adjusting the rules on EPR under the WEEE Directive**, to require producers to provide information to consumers and waste operators via DPPs and online platforms.

► **Consider introducing requirements for producers to inform consumers about the sustainability aspects of products with digital tools** (e.g. platforms, DPPs) as part of the upcoming consumer-related rules. Consumers would be informed about EEE content, and how to repair (supporting the 'right to repair' initiative under CEAP) and where to dispose of it. The EU should also introduce obligations for online marketplaces to inform consumers about sustainability aspects of the electronics sold. This requirement could be introduced via the upcoming DSA and/or the new consumer law.

► **Encourage the development of global guidelines on sharing data and information across value chains** (e.g. World Trade Organization, OECD, Group of Seven). It should promote international collaboration between governments and industries to develop a common set of standards on data sharing, which could also support DPPs.

OBJECTIVE 2: ENABLE THE UPTAKE OF DIGITAL SOLUTIONS FOR CIRCULAR E-WASTE MANAGEMENT

► **Develop EPR guidelines and assess the prospects of requiring producers to invest in the development and deployment of digital solutions for WEEE management** (e.g. smart bins, AI-enabled solutions and robotics) as part of their financial responsibility. These developments should build on voluntary practices (e.g. I4R). When developing the guidelines, PROs and waste operators must be involved in order to learn from their experience.

► **Assess if establishing a single market for e-waste could drive the digitalisation of the WEEE management.** Such a policy move should consider the prospects of a single WEEE market to increase the quantities of e-waste available for treatment – thanks to increased waste shipments across the continent. Consequently, more e-waste could justify deploying advanced technologies (e.g. robotics, AI) to manage WEEE. This can be achieved by developing mandatory standards on the collection, transport and treatment of WEEE and relaxing the restrictions for shipments designated to go to treatment facilities that comply with the EU's standards.

► **Use the financial instruments MFF and NGEU** to boost the development and deployment of digital solutions for circular WEEE management.

- Horizon Europe and DEP should spearhead the research, development and roll-out of digital solutions for WEEE management.

- InvestEU and NGEU should support the scale-up of digital solutions for WEEE management. Member states should use their national RRPs to direct funds towards the uptake of digital solutions for e-waste management.

- Structural funds (i.e. ESF+, CF, ERDF) and the related S3 Platform and Skills Agenda should support the scale-up of digital solutions while supporting the digitisation of WEEE management, and upskilling of the workforce to use digital tools in underdeveloped regions and support the just transition. This support should be targeted to the actors and regions lagging the most to help reduce disparities and enable an EU-wide just transition.

► **Tailor EU financial support to waste operators and PROs**, given that they are the ones who usually handle e-waste, and producers who fulfil their EPR individually. This can include for, example, support for the research, development and testing of data management systems and new technologies like AI and robotics.

► **Consider introducing GPP criteria** that would require procurement of electronics, especially within PaaS business models, coupled with supplementary digital services (DPPs, IoT connection with producer or supplier). GPP can help create demand for green digital electronics, which could help prevent e-waste. The EU could start with voluntary GPP criteria, and consider introducing mandatory GPP criteria after assessing the effectiveness of the voluntary criteria.

► **Assess the options for making online marketplace operators responsible for waste arising from the EEE sold on their platforms.** For example, e-commerce actors could be requested to inform producers about EPR commitments and ensure they fulfil their obligations before selling their products on the online marketplace. Alternatively, online marketplace operators could become producers themselves and be assigned EPR for the electronics sold via their platforms. The EPR should be assigned to fulfilment service operators by redefining *producer*.

► **Develop monitoring mechanisms and metrics to assess the transition** toward sustainable, digitally enabled WEEE management. The EU should establish an observatory to monitor European and national efforts to link digitalisation to a CE, including WEEE management.

OBJECTIVE 3: USE DIGITALISATION TO ENHANCE E-WASTE-RELATED POLICIES

► **Explore the possibilities of using AI to improve the EU's ecodesign framework.** Namely, to conduct faster and more systematic collection and processing of data needed to research and develop circular electronics. The EU should use its financial instruments (i.e. Horizon Europe, DEP) to develop and deploy AI solutions that speed up the development of new ecodesign requirements.

► **Use digital tools to support law enforcement.**

- Assess how the introduction of DPPs could support law enforcement efforts.

- Invest in developing and deploying smart algorithms to monitor the internet for illegal activities and fraudulent behaviour, such as informal e-waste management or placing the product on the market without paying an EPR fee.

- Develop rules for interoperable databases on facilitating the exchange of data and information between competent authorities within and across national borders.

- Support existing initiatives (e.g. European WEEE Enforcement Network) and encourage the use of digital tools (e.g. online platforms) to enhance its performance. In doing so, it is important to encourage the exchange of information between the competent authorities, producers, consumers, PROs, waste operators and environmental NGOs.

- The Market Surveillance Regulation should be more closely aligned with EPR requirements to detect and counter free riders (i.e. producers not participating in EPR schemes). Online marketplaces operators should have an active role to ensure that non-EU producers meet their EPR obligations or otherwise deny them access to the online market.

- Promote the sharing of information at the global level and establish platforms to collaborate between EU- and non-EU-based law enforcement agencies to ensure that free riders outside the EU are brought to justice.

► **Facilitate WEEE shipments by using electronic notifications.** The EU should amend the Waste Shipment Regulation and link the e-notification requirement with global EDIFACT and European EDIFICE rules on EDI.

► **Use its structural funds to strengthen the capacities of member states and subnational authorities.** For instance, EU funds can be used to digitise national environment agencies and customs offices and support municipalities to develop more secure local collection points (e.g. having entry cards to enter the site).

► **Create guidelines for member states on digitising EPR registrations and reporting on collected and treated WEEE in member states.** The goal should be to establish interoperable databases where the producer provides information on the amounts of electronics placed on the market and of WEEE collected and treated only once, and which builds on past information. Guidelines could also entail provisions on the establishment of smart contracts between producers, PROs and waste operators to improve the data accuracy, transparency and quality of WEEE statistics.

► **Adopt an action plan to introduce electronic payments for WEEE transfers.** Member states should ban cash payments for WEEE transfers as soon as possible.

Conclusion

The increasing consumption of electronics results in emissions, the depletion of critical raw materials, and huge amounts of e-waste, which cause additional environmental and socio-economic concerns. Low WEEE collection rates and its suboptimal treatment lead to pollution, GHG emissions, resource depletion, loss of valuable assets and even concerns over labour rights if managed illegally.

As this Discussion Paper demonstrates, there are many examples of how digitalisation is already contributing to a more circular WEEE management across the value chain. Tools such as online platforms, digital product passports, blockchain and Internet of Things can support sharing of data throughout the value chain. Tools such as robotics, AI and 3D printing can make electronics more circular in different stages of its lifecycle. The key is to use data and digital solutions to prevent e-waste and enhance its collection and treatment. Digitalisation can also improve WEEE-related policies and support law enforcement.

Going forward, data and digital solutions must support the green transition, including the circular management of e-waste.

Going forward, data and digital solutions must support the green transition, including the circular management of e-waste. Challenges like the lack of information transfer, as well as the maturity, costs and scalability of digital solutions, persist and must be addressed. Creating a framework for action that addresses these challenges and turns digitalisation into an enabler for improved WEEE management and a CE requires regulations, investments and soft law. At the same time, the EU cannot do this alone. Global value chains warrant international collaboration to exploit the synergies and avoid loopholes in policy design and law enforcement.

The EU has been at the forefront of using digitalisation as an enabler for the green transition. Going forward, the negative side effects of digitalisation, such as the generation of e-waste and increased energy consumption and GHG emissions, must be taken into account. And the green and digital transitions must not neglect underdeveloped regions and stakeholders that may lag further behind. Improving WEEE management is central to transitioning towards the digital, circular, competitive and resilient economy of the future.

1 See European Commission (2021a), Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery, COM(2021) 350 final, Brussels; European Commission (2020a), Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability, COM(2020) 474 final, Brussels.

2 Forti, Vanessa; Cornelis Peter Baldé; Ruediger Kuehr; and Garam Bel (2020), "The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential", Bonn/Geneva/Rotterdam: United Nations University, United Nations Institute for Training and Research/International Telecommunication Union/International Solid Waste Association, p.60.

3 Baldé, Cornelis Peter; Vanessa Forti; Vanessa Gray; Ruediger Kuehr; and Paul Stegmann (2017), "The Global E-waste Monitor 2017: Quantities, flows and resources", Bonn/Geneva/Vienna: United Nations University, International Telecommunication Union/International Solid Waste Association, pp.19, 38. McDonald, Rosie (2020), "Internet Waste", International Telecommunication Union/WEEE Forum.

4 Forti *et al.* (2020), *op.cit.*, pp.23, 25, 59. Furthermore, second-hand electrical and electronic equipment, in principle, retains even more economic value than recovered secondary materials. This stresses the importance of longer product lifespans and repairs. See Baldé *et al.* (2017), *op.cit.*, pp.54-56.

5 Forti *et al.* (2020), *op.cit.*, p.23.

6 *Ibid.*, p.23.

7 Haarman, Arthur; Federico Magalini; and Joséphine Courtois (2020), "Study on the Impacts of Brominated Flame Retardants on the Recycling of WEEE plastics in Europe", Sofies, p.18. Baldé, Cornelis Peter; Michelle Wagner; Giulia Iattoni; and Ruediger Kuehr (2020), "In-depth review of the WEEE Collection Rates and Targets in the EU-28, Norway, Switzerland, and Iceland", United Nations University/United Nations Institute for Training and Research, p.27.

8 Baldé *et al.* (2020), *op.cit.*, p.27. See also Platform for Accelerating the Circular Economy & World Economic Forum (2019), "A New Circular Vision for Electronics: Time for a Global Reboot", Geneva, pp. 13-14. Huisman, Jaco; Ioana Botezatu; Lucía Herreras-Martínez; Mary Liddane; Juha Hintsa; Vittoria Luda di Cortemiglia; Pascal Leroy; Elise Vermeersch; Sangeeta Mohanty; Susan van den Brink; Bogdan Ghenciu; Denitsa Dimitrova; Emily Nash; Therese Shryane; Melanie Wieting; James Kehoe; Cornelis Peter Baldé; Federico Magalini; Alessandro Zanasi; Fabio Ruini; Toni Männistö; and Alessandro Bonzio (2015), "Countering WEEE Illegal Trade: Summary Report", Lyon: CWIT Consortium.

9 See Hedberg, Annika and Stefan Šipka (2020), *The circular economy: Going digital*, Brussels: European Policy Centre.

10 Avgerinou, Bertoldi, and Castellazzi (2017), op.cit., p.1470. Enerdata (2018), "Between 10 and 20% of electricity consumption from the ICT sector in 2030?". Baldé *et al.* (2017), *op.cit.*, p.19.

11 Avgerinou, Bertoldi, and Castellazzi (2017), *op.cit.*

12 Villani, Cédric (2018), "For a meaningful artificial intelligence: Towards a French and European Strategy", AI for Humanity.

13 E.g. a study conducted by the Global Enabling Sustainability Initiative shows that there is a negative correlation between digitalisation and the efforts to achieve Sustainable Development Goal 12 (i.e. responsible consumption and production). Other studies show that carbon abatement from mobile communication technology (e.g. machine-to-machine technologies in buildings, transportation and energy sectors; smartphones) was approximately ten times greater in 2019 than the carbon dioxide emitted from mobile networks. *Global Enabling Sustainability Initiative*, "#DigitalAccessIndex > A strong and positive link" (accessed 27 August 2020). Lange, Steffen; Johanna Pohl; and Tilman Santarius (2020), "Digitalization and energy consumption. Does ICT reduce energy demand?", *Ecological Economics,* Volume 176. Stephens, Andie; Marta Iglesias; and Jamie Plotnek (2015), "GeSI Mobile Carbon Impact: How mobile communications technology is enabling carbon emissions reduction", Brussels: Global Enabling Sustainability Initiative, p.5. GSMA (2019), "The Enablement Effect: The impact of mobile communications technologies on carbon emission reductions", London, p.9.

14 Producer responsibility organisations take care of e-waste on behalf of the electronics industry (see section 2.3).

15 The organisations that contributed to the research efforts include Agoria, Apple, APPLiA, Asociatia ECOTIC, Circularise, COBAT, COCIR, Collaborating Centre for Sustainable Consumption and Production (CSCP), Dell, DIGITALEUROPE, Ecodom (now Erion), Ecologic SAS, Ecosystem, Ecotrel, EES-Ringlus, EIT Raw Materials, Electrão – Associação de Gestão de Resíduos, ELEKTROWIN, EPRON, EucoLight, European Commission, European Environment Agency, European Environmental Bureau, Federation of the German Waste, Water and Raw Materials Management Industry, Green Mt, International Institute for Industrial Environmental Economics (Lund University), OPEN, Orgalim, Oslo Region European Office, Pfane Scientific, Recupel, RENAS, SENS eRecyling, Siemens Healthineers, The German Broadband Association, UFH, VšĮ Elektronikos gamintojų ir importuotojų organizacija (EGIO), WEEE Forum, ZEOS.

16 European Commission (2012), Ecodesign your future: How Ecodesign can help the environment by making products smarter, p.3.

17 See Wilson, Simon, "Let's design out waste for a real Circular Economy", *EURACTIV*, 23 June 2016. See also European Commission (2020b), Circular Economy Action Plan: For a cleaner and more competitive Europe.

18 E.g. reduced personal ownership could lead to less (e-)waste if the appliance (e.g. washing machine) serves multiple users.

19 Bachér, John; Yoko Dams; Tom Duhoux; Yang Deng; Tuuli Teittinen; and Lars Fogh Mortensen (2020), "Electronic products and obsolescence in a circular economy", Copenhagen: European Environment Agency.

20 See e.g. Ellen MacArthur Foundation (2019), "Artificial Intelligence and the Circular Economy AI as a Tool to Accelerate the Transition", Cowes.

21 In this Discussion Paper, the author refers to *digital product passports* as digital solutions that entail a tag (e.g. radio-frequency identification or quick response code) which, when scanned, enables access to information stored on an online database (e.g. via an app) or provided on request by the owner of said information (e.g. a producer).

22 Orgalim (2020a), "Orgalim views and recommendations on the Sustainable Products Initiative", Brussels. See also Orgalim (2020b), "Orgalim recommendations on the New Circular Economy Action Plan", Brussels.

23 Bisschop, Lieselot, (2014), "How e-Waste Challenges Environmental Governance", *International Journal for Crime, Justice and Social Democracy*, Volume 3, Number 2, pp.82-96.

24 Lack of transparency in the informal sector of e-waste collection means that e.g. the operator can only focus on recovering valuable materials while discarding other components in a potentially harmful way to the environment and public health, safe working conditions are not guaranteed, or e-waste could be illegally exported to countries that do not treat it properly.

25 Citizens are largely aware of the *importance* of WEEE recycling and appropriate disposal but require more information on how to do it properly. EucoLight, "EucoLight research confirms European citizens are aware of the need to recycle lighting and all WEEE", 01 July 2020a.

26 Kling, Maximilian; Ferdinand Zotz; and Dana Huranova (2018), WEEE compliance promotion exercise, Brussels: European Commission.

27 See also Long, Euan; Saskia Kokke Saskia; Donald Lundie; Nicola Shaw; Winifred Ijomah; and Chih-Chuan Kao (2016), "Technical solutions to improve global sustainable management of waste electrical and electronic equipment (WEEE) in the EU and China", *Journal of Remanufacturing*, Volume 6, Number 1.

28 European Commission (2020b), *op.cit.*, p.4.

29 Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products (recast), Art.1(1).

30 For the list of implementing measures for specific product groups developed so far, see *European Commission*, "List of energy efficient products Regulations: by product group" (accessed 28 August 2020).

31 See *European Commission*, "Ecodesign and Energy Labelling" (accessed 28 August 2020).

32 See *European Commission*, New rules make household appliances more sustainable, 01 October 2019a, Brussels. See also European Commission (2019b), Sustainable products in a circular economy – Towards an EU Product Policy Framework contributing to the Circular Economy, SWD(2019) 91 final, Brussels, pp.28-32.

[33] Council of the European Union, "Digitalisation for the benefit of the environment: Council approves conclusion", 17 December 2020; European Parliament (2021), Report on the New Circular Economy Action Plan, 2020/2077(INI), Strasbourg. Moreover, Digital tags (e.g. QR codes) already accompany new, mandatory energy labels of electronics linked to the ecodesign framework's technical requirements. These digital tags are linked to the European Product Database for Energy Labelling (EPREL).

[34] European Commission (2020b), *op.cit.*, p.8.

[35] European Commission (2020c), Inception impact assessment: Empowering the consumer for the green transition, Brussels.

[36] Producers may consider individual producer responsibility impractical due to complex reverse logistics and pertinent costs or legislative barriers. See van Rossem, Chris (2008), "Individual Producer Responsibility in the WEEE Directive – From Theory to Practice?", Lund: International Institute for Industrial Environmental Economics, p.310. Dempsey, Mark; Chris van Rossem; Reid Lifset; Jason Linnell; Jeremy Gregory; Atalay Atasu; Jonathon Perry; Anders Sverkman; Luk N. Van Wassenhove; Martin Therkelsen; Viktor Sundberg; Kieran Mayers; and Harri Kalimo (2010), "Individual Producer Responsibility: A Review of Practical Approaches to Implementing Individual Producer Responsibility for the WEEE Directive", INSEAD, pp.69-70.

[37] Ascertaining how much e-waste is generated annually or setting waste collection targets require complex calculations due to diverse range of electronic and different lifespans (e.g. photovoltaic panels versus smartphones). A common approach is to look at the number of electronics placed on a national market in the three preceding years and approximating how it corresponds to the annual amount of e-waste.

[38] European Commission (2019c), Commission Implementing Regulation (EU) 2019/290 of 19 February 2019 establishing the format for registration and reporting of producers of electrical and electronic equipment to the register.

[39] Organisation for Economic Co-operation and Development (2001), *Extended Producer Responsibility: A Guidance Manual for Governments*, Paris, p.9; Lindhqvist, Thomas (2000), "Extended Producer Responsibility in Cleaner Production: Policy Principle to Promote Environmental Improvements of Product System", Lund: Lund University.

[40] The ongoing discussion ranges from enforcing the extended producer responsibility principle to assigning responsibility to all the stakeholders involved. WEEE Forum (2020), "An enhanced definition of EPR and the role of all actors", Brussels; Orgalim (2020b), *op.cit.* Sander, Knut; Stephanie Schilling Naoko Tojo; Chris van Rossem; Carolyn George; and Jan Vernon (2007), The Producer Responsibility Principle of the WEEE Directive: Final Report, European Commission.

[41] The exact rules on eco-modulation are yet to be laid out. The entire scheme would still benefit from an impact assessment prior to its application.

[42] Nonetheless, some member states', such as Germany, Austria, and Denmark, use more efficient systems with fewer subcategories for registration and reporting on e-waste.

[43] Bisschop (2014), *op.cit.*

[44] This is unsurprising given that, in 2017, only 15 out of 27 EU member states managed to reach the collection targets, which were lower at that time.

[45] E.g. Directive 2002/96/EC contains a provision that producers should provide information to reuse centres and treatment and recycling facilities "in the form of manuals or by means of electronic media (e.g. CD-ROM, online services)." Directive 2002/96/EC on waste electrical and electronic equipment (WEEE), Art.11(1). The wording has remained the same since the adoption of the Directive.

[46] European Commission (2020d), Evaluation of Regulation (EC) No 1013 /2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste, SWD(2020) 26 final, Brussels, p.47.

[47] European Commission, (2020), Study on quality standards for the treatment of waste electrical and electronic equipment (WEEE). Reference: ENV.B.3/ETU/2018/0014. Final Report. CENELEC (European Committee for Electrotechnical Standardization) standards are the EU standards for the collections, logistics and treatment of e-waste. WEEELABEX, or the WEEE label of excellence, was initiated in 2009 to develop standards for e-waste management and establish a harmonised certification scheme for audits of WEEE treatment facilities. In the course of the project, WEEE management standards have been established, although they have mostly given place to standards developed by CENELEC. Moreover, the WEEELABEX certification body, based in Prague, is currently the world's only organisation that provides certificates for audits of WEEE treatment facilities. It therefore contributed to the harmonisation of rules on auditing.

[48] European Commission (2020e), Making the most of the EU's innovative potential: An intellectual property action plan to support the EU's recovery and resilience, COM(2020) 760 final, Brussels, p.13.

[49] Bjerkem, Johan and Marta Pilati (2019), "An Industry Action Plan for a more competitive, sustainable and strategic European Union", Brussels: European Policy Centre, p.31.

[50] European Parliament (2021), *op.cit.*

[51] The European Commission is also already involved in the GS1 project. See GS1 (2019), "Be ready for UDI in the EU!", Brussels.

[52] European Commission (2019d), A European approach to Artificial Intelligence.

[53] European Commission (2020f), White Paper on Artificial Intelligence – A European approach to excellence and trust, COM(2020) 65 final, Brussels, p.2.

[54] European Commission (2021b), Proposal for a Regulation laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) and amending certain Union legislative acts, COM(2021) 206 final, Brussels, Art69(2).

[55] A *fulfilment service provider* is "any natural or legal person offering, in the course of commercial activity, at least two of the following services: warehousing, packaging, addressing and dispatching, without having ownership of the products involved". Regulation (EU) 2019/1020 on market surveillance and compliance of products and amending Directive 2004/42/EC and Regulations (EC) No 765/2008 and (EU) No 305/2011, Art.3(11).

[56] Hermann, Andreas; Peter Gailhofer; and Thomas Schomerus (2020), "Producer responsibility of third-country producers in e-commerce", Dessau-Roßlau: German Environment Agency, p.13.

[57] Organisation for Economic Co-operation and Development (2018), "Extended producer responsibility (EPR) and the impact of online sales", Paris, p.6.

[58] Directive 2012/19/EU on waste electrical and electronic equipment (WEEE), Art.3(1).

[59] Hermann, Gailhofer and Schomerus (2020), *op.cit.*

[60] See e.g. EucoLight, "EucoLight, Eucobat and EXPRA call for a more sustainable Digital Services Act", 30 October 2020b; WEEE Forum (2019), "Successfully countering online free-riders Response to the consultation regarding the study to support the preparation of the Commission's guidance for extended producer responsibility schemes", Brussels.

[61] Hermann, Gailhofer and Schomerus (2020), *op.cit.*, p.55.

[62] *Ibid.*, pp.53-55.

[63] This will be achieved by providing an EU guarantee that would allow the European Investment Bank and other financial partners to invest in more and higher-risk environment-related projects.

[64] European Commission (2019e), Digital Europe: Draft Orientations for the preparation of the work programme(s) 2021-2022, Brussels, p.2.

[65] *Ibid.*, p.18.

[66] European Commission (2019f), Orientations towards the first Strategic Plan for Horizon Europe, Brussels, p.81.

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