ANNEX I to D6.4 : Review of the relevant EU policy

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1. Introduction to policy applications relevant for electric car battery recycling

The analysis of D6.4 can demonstrate to a range of stakeholders (manufacturers, enforcing agencies, policy makers, final consumers) how environmental impacts can be influenced by design decisions.

The most prominent environmental impact is that of GHG emissions. The analysis of materials impacts from the criticality, circularity and thermo-economics points of view is of crucial interest to link energy transition objectives with recycling objectives at a policy level.

Policy applications will be researched for the four cases:

- Case 1: Lithium extraction and refining
- Case 2: Natural and synthetic graphite: trade-offs between carbon footprint and supply risk
- Case 3: Analysis and comparison of environmental impacts with circularity performance using Alkaline battery case study
- Case 4: Design for recyclability of electric vehicle batteries

First we will present the broader policy context for the four cases. Then we will describe policies and regulation of specific interest to this analysis. We will then perform a synthesis that explicitly links case studies to policy instruments. Finally, we will present recommendations and opportunities, thereby also using input from other relevant research.

2. The broader policy context

The EU wants to lead globally in making the economic system sustainable for the coming generations. This has resulted in policy context that aims to foster sustainable products. To look for policy relevant applications for Triple Link, we will first discuss the most relevant parts of the European broader policy context.

2.1 Policies interacting with major societal transitions

The adoption of agreements like the Paris agreement presents an unprecedented dynamic for public policies. The future of the European economy depends on an enormous, but predictable, increase in demand for certain civil/non-military products (such as those that shape the energy transition: PV panels, wind turbines, batteries etc.), best captured by the European Green Deal (European Commission 2019). Around the world, this package of policy initiatives is perceived as

among the most influential public ambition to tackle climate change. The recent “Fit for 55” (European Commission 2021c) is a package that aspires to deliver the EU's 2030 Climate Target on the way to climate neutrality.

The green transition aims to transform the EU into a more resource-efficient economy and covers not only the need to fight climate change but also to prevent environmental degradation in general. Furthermore, the interlinkages between the fighting climate change and stimulating the circular economy are widely recognized. In “A new Circular Economy Action Plan For a cleaner and more competitive Europe” (European Commission 2020e) targets are set to work towards a more circular economic system that is restorative by design and minimizes value destruction of materials.

Specific technologies are also spurred by policy objectives, especially in specific fields of the energy transition for which Europe wants to be a global leader in earlier stage of the innovation, such as “A hydrogen strategy for a climate-neutral Europe” (European Commission 2020d).

The twin transition underlines the need to embrace the revolutionary impact of the digital transition next to the green transition. In “Shaping Europe's digital future” (European Commission 2020f), the general principles that steer the digital innovations into desirable conditions are described. Although products and equipment that build the digital future will not undergo the same level of assessment in chapter 2 that products for decarbonization will, the implications of criticality assessment and raw materials stockpiling options relate just as much to the digital transition as they do to the green transition.

2.2 European Green Deal

European Green Deal (EGD), is one of the six priorities of the von der Leyen Commission, aiming to make the EU's growth sustainable, ensuring resource-efficiency and, by 2050, climate neutrality. It was adopted in 2019. The European Green Deal aims to transform the EU into a modern, resource-efficient and competitive economy. It sets ambitious targets for the reduction of green-house gas emissions, down by 55% compared to their 1990 level in 2030, and to net-zero by 2050.

2.3 New Circular Economy Action Plan

Published in March 2020, the New Circular Economy Action Plan for a leaner and more competitive Europe (CEAP 2.0), is one of the core building blocks of the Green Deal. The aim of the Action Plan is to reduce the EU's consumption footprint and double the EU's circular material use rate in the coming decade, while boosting economic growth. The 2020 Plan follows up on the 2015 EU action plan for the Circular Economy , Closing the loop, and the earlier 2011 Roadmap to a Resource Efficient Europe

The CEAP 2.0 presents initiatives to make sustainable products the norm in the EU; empower consumers; and decrease waste. It is driven by the ambition to make sustainable products that last.

Proposed initiatives address the entire life cycle of products: design, manufacturing, consumption, repair, reuse, recycling, and bring resources back into the economy. Initiatives should focus on high resource intensity sectors where the potential for circularity is highest: Electronics and ICT; batteries, vehicles; textiles; construction and buildings; packaging, plastics (including food packaging, single use tableware and cutlery) and food – along with selected high impact intermediary products. In this context the CEAP 2.0 present a range of Actions under seven headings covering:

A sustainable product policy framework covering notably (DDRN 2021):

- A legislative proposal for a sustainable product policy initiative;
- A legislative proposal empowering consumer in the green transition – including Legislative and non-legislative measures establishing a new "right to repair";
- A legislative proposal on substantiating green claims;
- Mandatory Green Public Procurement (GPP) criteria and targets in sectoral legislation and phasing-in mandatory reporting on GPP;
- Review of the Industrial Emissions Directive.

Key product value chains covering notably:

- Review of existing legislation covering the mentioned priority sectors;
- Development of new EU strategies for selected sectors (textiles, sustainable built environment) and other sector specific initiatives (e.g. as to substitute single-use packaging, tableware and cutlery).

Less waste, more value covering notably:

- Waste reduction targets for specific streams and other measures on waste prevention;
- Harmonised EU models for separate waste collection and labelling;
- Revision of the rules on waste shipments;
- New initiatives to track and minimise the presence of substances of concern in waste.

2.4 Cohesion policy

The cohesion policy is an important tool for the EU to stimulate development in certain EU regions. Every six years, an extensive multi-billion EURO investment package is determined within the COHESION policy. Making the circular economy work for people, regions and cities covering policy and support initiatives to make cities and regions adjust – with associated funding opportunities for upskilling, regional and local development via ESF Plus Cohesion policy funds, the Just Transition Mechanism and urban initiatives

Efforts at global level (global agreement on plastics; Global Circular Economy Alliance, mainstreaming circular economy objectives in free trade agreements and other trade agreements)

2.5 Sustainable product Initiative

The sustainable product policy initiative (SPI) is one of the key initiatives of the CEAP 2.0. It aims to make goods and services fit for a climate neutral, resource efficient and circular economy, reduce waste and ensure that sustainability progressively becomes the norm. As such the initiative covers the broadest range of products possible. The Sustainable Products Initiative will revise the Ecodesign Directive (2009) and make products placed on the EU market more sustainable.

Accepting that there is already a body of EU legislation and other initiatives which already address sustainability aspects (see below), the CEAP specify that the core of the SPI will be "to widen the Ecodesign Directive beyond energy-related products so as to make the Ecodesign framework applicable to the broadest possible range of products and make it deliver on circularity". To this end the SPI is to build on criteria and rules established under the EU Ecolabel Regulation, the Product Environmental Footprint approach and the EU Green Public Procurement criteria, where appropriate. The Commission, furthermore, commits to consider the introduction of mandatory requirements to increase the sustainability not only of goods, but also of services.

In doing so, the Commission further committed to considering establishing "sustainability principles" in the context of the SPI to regulate:

- Product durability improvements, reusability, upgradability, and reparability, addressing the presence of hazardous chemicals in products, and increasing their energy and resource efficiency;
- Recycled content in products;
- Remanufacturing enabling and high-quality recycling;
- Reduction of carbon and environmental footprints;
- The restriction of single-use and countering premature obsolescence;
- The introduction of a ban of destruction of unsold durable goods;

- Incentives to develop product-as-a-service and other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle;
- Mobilising the potential of digitalisation of product information, including solutions such as digital passports, tagging and watermarks;
- Rewarding products based on their different sustainability performance, including by linking high performance levels to incentives.

These product sustainability principles are guide broader policy and legislative developments in the future.

3. Sustainable Product policy tools relevant for battery sustainable design

For the analytic tools developed in Triple Link to be applied, policy tools are needed that require specific environmental impact data and subsequently seek to strongly enforce the regulations that are the result of the policy tools. The Sustainable Product Initiative (SPI) offers a suite of specific instruments and regulations to do so. Complementary regulatory or voluntary approaches are to be developed in a way to improve the coherence of existing instruments regulating products along their life cycle.

There are many existing legislative instruments relevant to the SPI. To provide the background to the integrating initiative that the SPI is, we surveyed Climate, Energy, Circular Economy, Pollution, Consumer Protection, Product Safety, Single Market and other Environmental Horizontal Policies. We present key EU legislation relevant to the SPI below.

3.1 EU Ecodesign Directive 2009/125/EC and Energy Labelling

The Ecodesign of Energy-Related Products Directive 2009/125/EC is a framework directive that primarily focuses on the energy used by products during their lifetime. The Ecodesign directive sets mandatory minimum requirements on energy efficiency and other criteria on use of resources and environmental impacts for the products covered by the Directive's implementing measures.

Energy Labelling rules (which are to promote demand for energy efficient products),are designed to drive investment and innovation in a sustainable manner aiming to ensure that more energy-efficient products coming to the market,remain in demand by consumers, while delivering a levelled playing field in the internal market. The Ecodesign Directive provides consistent EU-wide minimum rules for improving the environmental performance of energy-related products through Ecodesign. It prevents disparate national legislation on the environmental performance of these products from becoming obstacles to intra-EU trade, which should benefit both businesses and consumers by enhancing product quality and environmental protection and by facilitating free movement of goods across the EU.

Products covered by the directive are those that have an impact on energy consumption during use which is placed on the market and/or put into service, and of which the environmental performance can be assessed independently.

The Directive further specify the following minimum requirements for products to be covered, see Table 1. Transport is not included in the scope of the directive.

Table 1: Categories of Products in the Ecodesign Directive.

Minimum requirements for certain energy-consuming products related to the following categories
Products that have a volume of sales that exceeds 200 000 units per year throughout the internal European market (a cumulative total and not one calculated on the basis of an individual producer)
Products that have a significant environmental impact within the internal market
Products that present significant potential for improvement in environmental impact without incurring excessive costs

The Ecodesign Directive is implemented through product-specific regulations, directly applicable in all EU countries. It follows multiannual Ecodesign and Energy Labelling Working Plans, the most recent published being the 2016-2019 Ecodesign Working Plan. There are currently 28 product groups covered by Ecodesign.

The objective is to reduce greenhouse-gas emissions and other adverse environmental impact throughout the life-cycle of a product with emphasis placed on its design and development stages with a view to improving its energy efficiency during consumption. However, Ecodesign and Energy Labelling measures for several products currently include rules on material efficiency requirements such as availability of spare parts, ease of repair, and facilitating end-of-life treatment in line with the 2015 EU action plan for the Circular Economy, and the implementation of the Ecodesign Working Plan 2016-2019.

In many of the regulations in force, the European Commission is looking into material recyclability through instructions for the end-of-life and requirements for products to be designed in a way that facilitates recyclable material recovery. For example, measures under the Ecodesign directive have included requirements on the disassembly of components for recycling and on the identification and accessibility of hazardous materials, with a view to facilitating recycling of the products at end of life. As stated in the Ecodesign work programme 2016 - 2019, the Commission is more systematically exploring the possibility of establishing product-specific requirements contributing to Circular Economy objectives, which will further contribute to better recycling of materials from products covered by Ecodesign measures. The Ecodesign and energy labelling framework has been one of the most effective policy instruments at EU level to promote energy efficiency, estimated to contribute around half of the energy savings target for 2020 .

Within the possibilities of the existing EU Ecodesign rules and in synergy with the focus on energy efficiency, this working plan strengthens the focus on the circularity aspects of Ecodesign, following the example set in the previous working plan and in line with the 2020 Circular Economy Action Plan. New product-specific requirements on material efficiency aspects are set to be explored, ahead of the adoption of a proposed Ecodesign for Sustainable Products Regulation.

3.2 European Ecolabel

Whereas the Ecodesign Directive sets out mandatory minimum requirements for a limited set of products, the European Ecolabel Regulation is a voluntary environmental labelling scheme, aiming to support innovation, and encourage the development of new and more sustainable products and services for a wider set of products.

Products and services have to meet specific, identified criteria (depending on the product groups), which reduce overall environmental impact (from product development to disposal) compared to other products in the same group. It covers a wide range of product and service groups from manufacturing to tourist accommodation. Criteria has currently been established for 25 goods and service groups , and three additional Products Groups are under Development.

The EU Ecolabel fits the International Organization for Standardization definition for a Type 1 Ecolabel. This means the EU Ecolabel is voluntary, based on multiple criteria, where a third party awards the use of the label to indicate overall environmental preference within a particular product category based on life-cycle assessment.

Launched in 1992, the EU Ecolabel scheme promotes the production and consumption of products that have a reduced environmental impact in comparison to existing products on the market. Because the scheme works on a European level, it goes beyond the pre-existing national ecolabels that are often only known within national borders.

The European Commission manages the scheme at the EU level to ensure that the Ecolabel Regulation is implemented correctly. Even if the development or revision of EU Ecolabel criteria can be initiated and lead by parties other than the European Commission (States, Competent Bodies and other stakeholders), the Commission is in any case responsible for preparing the final draft of the criteria documents that have to take into account the comments from the European Union Eco-Labelling Board. The Commission adopts EU Ecolabel criteria for each product group as “Commission decisions” after the Ecolabel Regulatory Committee supports the criteria by a qualified majority.

Every four years, on average, the criteria are revised to reflect technical innovations such as evolution of materials or production processes, as well as factors like emission reduction and changes in the market.

3.3 Green Public Procurement

Green Public Procurement (GPP) is (IDS Water 2021) a process whereby public authorities seek to “procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured. "

GPP is mostly a voluntary instrument . However, it has an important role to play in the EU's efforts to become a more resource-efficient economy. Public authorities spend approximately, 1.8 trillion euro annually, representing in the range of 14 % of the EU's gross domestic product .

Key to the GPP is a, verifiable and ambitious environmental criteria for products and services, which needs to be based on a life-cycle approach and scientific evidence base, for inclusion in the public procurement process. Working with expert groups the Commission has over the last two decades, published 20 criteria – covering as wide as procurement of waste water Infrastructure, to cleaning products, office building design and construction and to data centres, server rooms and cloud services. The GPP criteria are based on data from an evidence base, on existing ecolabel criteria and on information collected from stakeholders of industry, civil society and Member States. While both Commission and European countries have developed guidance in this area (in the form of national GPP criteria), consistency is key as to avoid a distortion of the single market and a reduction of competition.

The EU GPP criteria are developed to facilitate the inclusion of green requirements in public tender documents. While the adopted EU GPP criteria aim to reach a good balance between environmental performance, cost considerations, market availability and ease of verification, procuring authorities may choose, according to their needs and ambition level, to include all or only certain requirements in their tender documents.

3.4 Extended producer responsibility

Extended Producer Responsibility (EPR) is an approach to ensure that producers contribute financially to the costs of waste management. EPR can be defined as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (From CEAP 2.0, see §2.3). It is an economic instrument to stimulate waste reduction in design to reduce such costs. EPR schemes form an essential part of efficient waste management. ERP requirements are included in most EU waste related directives, including the Waste framework directive, the Directive on Waste of Electrical and Electronic Equipment, End-of-Life Vehicles Directive, the Batteries Directives, the Single use Plastic Directive and the Packaging Directive.

The revised Waste Framework Directive, which has a transposition deadline for mid-2020, also sets new general minimum requirements for EPR schemes to improve their effectiveness and performance across the EU – including costs that should be covered by producers (including costs of separate waste collection, its transport and treatment, as well as costs of providing information to the waste holders and the costs of monitoring and reporting).

3.5 Waste and recycling regulations and measures

The EU has elaborated legislation on waste that in many aspects relates to recycling. Beyond sectoral legislation (see below) the key horizontal instruments in place, are the Waste Framework Directive (WFD) (amended in 2018) and the Directive on Landfilling of Waste. Overall, the EU Waste Shipment Regulation (EC No. 1013/2006) (the EWSR) is effective, relevant and coherent, and adds value at the EU level European Commission (2019. Further measures with similar aims are included in sectoral legislation such as the directives on Waste Electrical and Electronic Equipment (WEEE), End-of-life Vehicles (ELV), Packaging and Packaging Waste and Batteries.

These instruments set targets for reducing the amount of waste going to landfill and recycling and recovery targets to increase the amount of waste being recycled. The WFD sets the basic concepts and definitions related to waste management, and the binding waste management hierarchy for all waste prevention . The WFD introduces the "polluter pays principle". It incorporates provisions on hazardous waste and waste oils and sets recycling and recovery targets to be achieved. The Directive also requires that Member States adopt waste management plans and waste prevention programmes.

Further measures with similar aims are included in sectoral legislation such as the directives on Waste Electrical and Electronic Equipment (WEEE), End-of-life Vehicles (ELV), Packaging and Packaging Waste and Batteries.

The WFD was amended in 2018. Key amendments related to more stringent targets for preparation for re-use and recycling of municipality waste; minimum requirements for extended producer responsibility schemes, new conditions on By-Products and End-of-Waste and establishment of bio-waste separation household, hazardous waste collection and collection of textile waste.

In many of the regulations in force, the European Commission is looking into material recyclability through instructions for the end-of-life and requirements for products to be designed in a way that facilitates recyclable material recovery. For example, measures under the Ecodesign directive have included requirements on the disassembly of components for recycling and on the identification and accessibility of hazardous materials, with a view to facilitating recycling of the products at end of life. As stated in the Ecodesign work programme 2016 - 2019, the Commission is more systematically exploring the possibility of establishing product-specific requirements contributing to Circular Economy objectives, which will further contribute to better recycling of materials from products covered by Ecodesign measures.

Also, EU Ecolabel and GPP tools promote the recyclability of products and material.

3.6 REACH

Comprehensive EU policy is in place addressing chemicals safety. The REACH Regulation is the EU's key instrument to improve the protection of human health and the environment from the risks that can be posed by chemicals. REACH operates through early identification and registration of the

properties of chemical substances. In principle, REACH applies to all chemical substances, including chemical use in the high resource intensity products to be covered by the SPI (textile, furniture, packaging, plastics, vehicles, and chemical etc.)

REACH places the burden of proof on companies. To comply with the regulation, companies must identify and manage the risks linked to the substances they manufacture and market in the EU. They have to demonstrate how the substance can be safely used, and they must communicate the risk management measures. Identification is done by the four processes of REACH: registration, evaluation, authorisation, and restriction of chemicals. As such the REACH Regulation places responsibility on Manufacturers and importers to manage the risks from chemicals and provide safety information on the substances.

3.7 Market consultation revision RoHS

A recent market consultation by Steptoe was conducted (Steptoe 2020). Electronics and Electrical Equipment (EEE) is equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current". This open scope of RoHS (with narrow exceptions and exemptions) includes items such as household appliances, IT and telecommunications equipment, lighting equipment, electrical and electronic tools, toys, leisure and sports equipment, medical devices, and monitoring and control instruments including industrial monitoring and control instruments. Both consumer and professional EEE is covered.

The RoHS Directive currently restricts the use of 10 substances at maximum concentration values for each (set by weight in homogeneous materials): lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP). All products with an electrical and electronic component, unless benefitting from a specific exclusion, must comply with these restrictions. By restricting the use of those substances, the RoHS Directive facilitates recycling of waste EEE (WEEE) covered by Directive 2012/19/EU."

3.8 General Product Safety Directive (GPSD)

The General Product Safety Directive (DPDS) complements sector specific legislation covering among other the key product groups furniture, textiles, and electrical and electronic equipment.

The GPSD imposes general safety requirements for any product put on the market for consumers or for any product that is likely to be used by them. This also includes all products that provide a service.

4. Electric Vehicle Battery Sector Specific Policy Instruments

For the analytic tools developed in Triple Link to be applied, other specific policy instruments beyond the Sustainable Product Initiative will reshape the current opportunities for circular design.

Beyond the measures outlined earlier, the EU has put in place a number of sector specific policy instruments, which covers the priority product groups identified in the new circular economy action plan. In a headline overview, key sectoral EU policy tools addressing different aspects of circular economy are:

4.1 Electronics and electrical equipment

For electronics, ICT and batteries several instruments are of relevance:

- The Directive on Waste of Electrical and Electronic Equipment (WEEE) which primary objective is the prevention of WEEE. In addition, the directive aims at the reuse, recycling and other forms of recovery of such wastes so as to reduce their disposal and to contribute to the efficient use of resources and the retrieval of valuable secondary raw materials. It also seeks to improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, e.g., producers, distributors and consumers, and, in particular, those operators directly involved in the collection and treatment of WEEE. The WEEE Directive includes guidelines that aim to promote the repair and preparation for reuse of products through their design as well as sets ambitious targets for the collection and preparation for reuse/recycling of WEEE. It also incorporates extended producer responsibility requirements so as to incentivise EEE producers to design their products in a way which reduces the amount of material ending up as waste;
- The Directive on Restriction of certain hazardous substances in electrical and electronic equipment (RoHS) ( ) which aims to eliminate substances used in EEE products that could be hazardous to human health and the environment, including substances that could hamper recycling;
- The Batteries Directive which addresses aspects relating to the life cycle of batteries, i.e. the design, placing on the market, end of life, collection, treatment and recycling of spent batteries. The directive defines objectives and sets targets, identifies corresponding actions and outputs. It has recently been evaluated;
- Other relevant acts include the Radio Equipment Directive (RED) which provides a regulatory framework for placing radio equipment on the market and which sets essential requirements for safety and health. It is relevant for battery recyclability since several radiographic products contain batteries

4.2 Battery Directive

This directive prescribes that manufacturers or importers of batteries and accumulators are responsible for the management of that product in the waste phase. To this end, the manufacturers or importers must either:

- set up an intake and processing structure individually or collectively;
- submit a communication on the collection and treatment of batteries and accumulators in the waste phase.

More stringent applications of the Battery Directive occur periodically. At the end of 2020, the EP already voted in favour of EU policy to improve battery recycling. That proposal has now been tightened up. The Parliament wants to increase the recycling rate of scarce raw materials such as nickel, lithium and cobalt in Europe. The aim is to be able to recycle 90 percent of the battery by 2026. From 2024, it must be prohibited for manufacturers to glue or melt batteries to electronics. This is now happening with many devices such as telephones, laptops, electric toothbrushes and headphones. Ultimately, consumers should be able to replace all batteries themselves with materials available on the market.

The battery passport will also address recycling of outdated batteries taken off the market. Currently, almost all cars contain a lead-acid battery. These batteries are easy to recycle, which means that many companies are responding to this. The separate collection of lead batteries is not only mandatory because it is a hazardous type of waste, but also pays off because it generates money. After collection, the batteries are sent to a specialized processing company.

The Nickel Metal Hydride (NIMH) batteries represent an intermediate phase. Nickel-metal hydride batteries, which are common in hybrid cars, can also be recycled well. These batteries mainly contain the materials nickel, cobalt and iron. These raw materials are valuable for new production processes, including new batteries and for the production of stainless steel. The true anticipation is for the recycling of lithium-ion batteries. The lithium-ion (Li-ion) batteries used in hybrid and fully electric cars are a different story. These batteries have a longer lifespan and more capacity, but are difficult to recycle.

Li-ion batteries are complex and contain many different materials, see section 3.1. Electric vehicle NMC battery in the main report. Battery recycling is currently very focused on the recovery of aluminium, copper, nickel and cobalt. These materials can also be recovered from li-ion batteries, but that is a much more laborious and therefore more expensive process. Lithium demands a dedicated process to allow its recovery. The lithium-ion batteries and batteries in general currently have a negative residual value, because the costs of dismantling are much higher than the revenue from the secondary materials produced. Unfortunately, this means that important raw materials are lost and driving electric cars remains less sustainable than hoped. Currently, approximately 5%

of all lithium batteries and batteries worldwide would be recycled according to the EU lithium factsheet(JRC 2020).

The latest development in the battery directive will be the battery passport (Global Battery 2021). The Battery Passport is a digital representation of a battery that conveys information about all applicable ESG (Environment Social Governance) aspects and lifecycle requirements based on a comprehensive definition of a sustainable battery. Each Battery Passport will be a digital twin of its physical battery enabled by the digital Battery Passport platform, which offers a global solution for securely sharing information and data. This platform aims to go beyond enabling the performance management of just one battery to that of all batteries across the full industry value chain.

It is expected that battery passports will feed into a corporate administrative "rulebook". The specific objectives of these rulebooks are to set globally harmonized rules that make "cradle to gate" Battery Carbon Footprints transparent; and to allow decisions to be driven by reliable, accessible, and trusted data. The Rulebook aims to provide a sound method by which process-specific data is generated and collected in a homogeneous way and Battery Carbon Footprints across vendors in the battery value chain are comparable.

4.3 European strategy for critical raw materials

In 2008, the EU already recognized fundamental changes in global raw material markets, resulting in the first Raw Material Initiative (European Commission 2008a). The latest major policy document that testifies the relevance of managing CRM (Critical Raw Material) supply to the EU is the Action Plan on Critical Raw Materials from September 2020 (European Commission 2020a). It concludes that EU institutions, national and sub-national authorities as well as companies should become much more agile and effective in securing a sustainable supply of critical raw materials. The related report from the Joint Research Center (European Commission 2020b) clearly showed the relation between key-products/key-technology fields and the raw materials that are critical to these technologies. Another crucial contribution of this report was an estimate of demand for CRM in 2030 and 2050, acknowledging that foresight studies were essential for effective CRM policy and needed to be done frequently and periodically. Future demand will be implemented in the next version of the Study on the EU's list of Critical Raw Materials (European Commission 2020c). In 2020, the 4th version of the study was published. The methodology is globally renowned.

The latest development in CRM research is represented by the Raw Material Act, offered for public consultation on October 5th 2022 (European Commission 2022) . It will specifically aim to support industries that use metals in designs that enable circular use. Market interventions, like subsidies and public procurement tools, are explicitly mentioned.

4.4 Industrial policy

Although among the more contested responsibilities of the European Union, green industrial policy is widely regarded as a justified course of action. The objective of Industrial policy aims to secure framework conditions favourable to industrial competitiveness. It interacts with other EU policies such as those relating to trade, the internal market, research and innovation, employment, environmental protection and public health and aims for horizontal (i.e. not sector-specific) structural improvements. Furthermore, the relevance and pertinence of industrial policies are acknowledged by mainstream economists and political leaders from all sides of the ideological spectrum (Stiglitz et al. 2013).

The latest EU industrial strategy was launched in March 2020 and discussed CRM supply in the context of sustainability and strategic goals for 2030 and later. The 2020 strategy was provided with an update (European Commission 2021a) a year later to adapt to a world that had witnessed the effects of a COVID pandemic on global supply chains. The Commission proposed public policy measures that can support industry's efforts to address these dependencies and to develop strategic capacity needs: diversifying supply and demand relying on different trading partners whenever possible, but also stockpiling. The update also referred to identifying measures to reinforce the EU position in global value chains. Lastly, the update featured an analysis of strategic dependency (European Commission 2021b). The analysis was done at a high level of detail (a "granulation" of over 5000 product groups) and identified 137 product groups with a higher risk of supply disruption. It also exemplified the necessary outreach for public decision makers to support supply-chain decisions in a corporate setting.

A draft report on the Implementation of the Updated New Industrial Strategy has been developed by the ITRE committee (ITRE 2022), with a focus on aligning spending to policy. Therein it claims that the EU should not be dependent on non-EU countries for products and technologies that are essential to the EU economy of the future. The report stresses that the EU needs to regain a strong position in crucial global value chains and secure the supply of critical materials in times of crisis (ITRE 2022). It states that public procurement is an essential instrument for national and economic security and for supporting the uptake of and demand for clean products. It suggests a legitimate basis for the Commission to review public procurement and competition rules where needed. Interestingly, it suggests adapted public procurement rules. Moreover, it names key elements of the Single Market Emergency Instrument, such as enhanced market surveillance procedures, reinforced information sharing and targeted measures for speedier product availability.

The European Fund for Strategic Investment (EFIS), established under the Investment Plan for Europe enabled additional investment between 2015 and 2017 in digital infrastructure, energy, research, etc. The total investment was set at 315 billion EUR. The current European structural and investment funds (ESIF) has (among others) investment funds for European regional development and Cohesion funds. The Important Projects of Common European Interest (IPCEIs) provide a State

aid compatibility basis under Art. 107(3)(b) TFEU under which Member States can jointly design large cross-border projects to pursue EU strategic goals. Then there is the InvestEU Programme, that is designed to give an additional boost to investment, innovation and job creation in Europe over the period 2021-27. It stems partly from the sizeable NextGeneration EU economic recovery package to support the EU member states. It will be added to the regular multiannual investment schemes. The NextGeneration EU package is expected to amount to €750 billion between 2021 to 2026.

4.5 Internal Market and Consumer Protection (IMCO)

The Annual Single Market (ASM) report of 2021 (European Commission 2020g) was among the first evaluations of the turbulent developments of the public response to the outbreak of the COVID19 pandemic. The report reiterates the importance of measures already identified in the March 2020 Industrial Strategy package. One of the significant findings in the report was that existing EU crisis governance mechanisms are not fully effective at coordinating national responses. The emergency situations proved able to distort trade, innovation, exacerbate product shortages in other Member States, and more generally weaken the collective bargaining power of the EU.

There are a number of possibilities for Member States to provide equity support under national support schemes to strengthen the solvency and growth of innovative SMEs and mid-caps in line with State aid rules, including the State aid Temporary Framework.

Another policy initiative that neatly combines the functioning of the internal market and consumer protection is the proposal for a new regulatory framework on batteries (COM 2020/798). It aims to ensure that there are robust sustainability, safety and performance requirements for all batteries placed on the EU market. Noteworthy, this document demonstrates a traditional focus on safety but not on strategic aspects that will improve the security of supply of all kinds of batteries relevant for the EU green transition.

4.6 Safeguarding strategic autonomy

The concept of strategic autonomy has gained momentum in European politics in the wake of the COVID19 pandemic. Some argue that being strategically autonomous would enable a region such as the EU to be a global leader in sustainability and to be assertive against unfair and coercive practices (EPRS 2022). The prefix “open” is intended to point at the will to maintain the principles of globalisation and to remain open to global trade and investment for the EU economy.

The information revolution provides a first example of the relevance of strategic autonomy. For instance the establishment of the European Alliance for Industrial Data, Edge and Cloud. One of the EU's headline policy initiatives aimed at strategic autonomy in the digital domain is the European Chip Acts. As part of the overall Chips Act funding package, it is set up ton gather €11 billion of public and private investments up to 2030, funded by the EU and MS. It is expected to leverage

considerable private investments. This is set to be complemented by other member states projects with the ambition to lead to an overall funding of €43bn.

The energy market is another focal point for strategic autonomy. The geopolitical powerplay following the outbreak of the Ukraine war prompted the EU to launch REPowerEU. It is about the EC ambition to make Europe independent from (Russian) energy carriers well before 2030. Additional investments of €210 billion are assembled until 2027 to make Europe independent from the Russian energy supply. European consumers pay nearly 100 billion euros per year for Russian energy. A clear reference in RePower is made to the industrial eco-system: *Achieving the REPowerEU goals will require diversifying the supply of renewable energy equipment and of critical raw materials, reducing sectoral dependencies, overcoming supply chain bottlenecks and expanding the EU's clean energy technology manufacturing capacity*.

An "Observatory of critical technologies" is being prepared by the Commission in line with the Action Plan on synergies. This Action Plan (the 'Three-Point Belt Plan') has three objectives, namely enhancing complementarity between relevant EU programmes, promoting spin-offs from investments in investments in manufacturing space & defence products and promoting "spin-ins" where civil research can infuse defence & space (European Commission 2021e). The Observatory will monitor critical technologies for space, defence and related civil sectors, as well as their potential applications and related value chains that need to be securitized. The Commission, based on data of the Observatory, will present a classified report on critical technologies. It is remarkable as well as logical that such a monitor on risks associated with strategic dependencies affecting security, space and defence will not be available in the public sphere, but it should be available to several decision makers and representatives. The first edition should be ready by the end of 2022, to be continued every two years thereafter.

The latest annual "Strategic foresight report" was presented in 2021. It focused on resilience across four dimensions: green, digital, social and economic, and geopolitical. Building on the previous editions, the 2021 report focused on the EU's open strategic autonomy as part of the geopolitical dimension of resilience. The Commission wants to build close foresight cooperation and alliances with other EU institutions, notably in the context of the critical technology observation that will be founded by the JRC (JRC 2021) . Some of the ten areas of the monitor touch on the scope of this report, such as securing decarbonised and affordable energy, strengthening capacity in data management, building a resilience and future-proof economics and financial systems, developing and retaining skills and talent matching EU ambitions. Most of all, the foresight report aspires to monitor securing and diversifying supply of critical raw materials.

A final example of expressions of strategic autonomy is exemplified by a speech by Vice-President Šefčovič to the European Battery Alliance (23 February 2022). He said "*I am not overstating it when I say that securing supplies of critical raw materials is a strategic security question for Europe. I*

would say it is now or never. Europe has close to 260 deposits of key battery materials as well as the state-of-the-art technologies and expertise necessary for their responsible and sustainable exploration. It is necessary to urgently: [...] enhance our capacities to monitor global supply chains, helping us anticipate potential crises and to act, for instance through stockpiling." The statement suggests that strategic autonomy is prioritised over cost-efficiency.

4.7 Revision of CLP-regulation

According to the CLP review study (European Comission 2021), as many as 12,000 substances could potentially be in the scope of the two upcoming legislative proposals alone – the changes to Classification, Packaging and Labelling Regulation (CLP) and the application of a Generic Risk Approach (GRA). The study found that these substances could cover up to 43% of the European chemical industry's total turnover.

The companies consulted indicated that around one third of this most likely affected portfolio of 28% could potentially be substituted or reformulated. However, the ability of companies to substitute potentially affected products will largely depend on the details of the upcoming regulations, on what might be technically and economically feasible, and especially on how customers will react to the substitutes or reformulated products. The most significantly impacted downstream sectors are expected to be adhesives and sealants, paints, washing and cleaning products.

4.8 Product and Organisation Environmental Footprint Methods (PEF and OEF) (Regulation)

The final methods, called Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF), were published as an Annex to the Commission Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. The two methods are tightly interlinked and will have many elements in common.

This version was developed taking into account the results of 2011 road test, the results of the invited expert consultation and of a consultation between Commission services.

4.9 Right to repair

This is a proposal for a directive. This initiative promotes a more sustainable use of goods throughout their useful life. It will encourage consumers to make more sustainable choices by providing incentives and tools to use goods for a longer time, including by repairing defective goods. It will also:

- encourage producers to design goods that last longer and are easily reparable;

- help reduce unsustainable consumption and its negative impact on the global environment and climate;
- help build a circular economy.

4.10 Reports on development of EU sustainability reporting standards

The EU Green Taxonomy and the Non-Financial Reporting Directive (NFRD) are the latest examples to enforce accountancy standards that support decision making that is sustainable.

These reports, which were prepared at the request of the Commission following an invitation from the Economic and Financial Affairs Council, are an important step in the development of corporate sustainability reporting across the EU.

Both reports recognise the importance of coordinating the development of EU sustainability reporting standards with existing and emerging global initiatives. EU sustainability standards are necessary to meet the political ambition and urgent timetable of the European Green Deal.

They are also necessary to ensure consistency of reporting rules at the heart of the EU's sustainable finance agenda , especially the existing Sustainable Finance Disclosure Regulation, the Non-Financial Reporting Directive (NFRD), the Taxonomy Regulation, as well as with the requirements of forthcoming legislation on sustainable corporate governance and due diligence.

The EU Green Taxonomy is especially expected to have an impact in the coming years. In order to meet the EU's climate and energy targets for 2030 and reach the objectives of the European green deal, it is vital that we direct investments towards sustainable projects and activities.

The current COVID-19 pandemic has reinforced the need to redirect money towards sustainable projects in order to make our economies, businesses and societies – in particular health systems, more resilient against climate and environmental shocks.

To achieve this, a common language and a clear definition of what is 'sustainable' is needed. This is why the action plan on financing sustainable growth called for the creation of a common classification system for sustainable economic activities, or an "EU taxonomy".

It was reported (Bergensia 2021) that the Member States expert group on sustainable finance (E03603): The European Commission adopted its "Action Plan on Financing Sustainable Growth" on 8 March 2018 which proposes concrete actions that will help achieve the Sustainable Development Goals and the objectives set in the Paris Agreement on Climate Change drawing on the recommendations of the High-Level Expert Group on Sustainable Finance.

In its Action Plan, the European Commission has called on other players, such as EU Member States, to support implementing sustainable finance actions and promote the transformation in their territories.

For this purpose, the European Commission is creating a dedicated EU Member States expert group on sustainable finance. Delegated regulation: This initiative will establish an EU 'taxonomy' (classification) of environmentally sustainable economic activities. Potential investors can be certain that these activities substantially contribute to the EU's environmental objectives of:

- sustainable use and protection of water and marine resources
- transition to a circular economy ('re-use, repair, recycle')
- pollution prevention and control
- protection and restoration of biodiversity and ecosystems.

It can be easily observed that the EU taxonomy relies heavily on the objectives of the CEAP.

5. Synthesis

When matching the relevance of sector specific policy tools to the four Triple Link case studies, one can see that relevant cross-references are more often present than not. See Table 2

The generic policy instruments from Ecodesign and ecolabel self-evidently apply, as well as policies that are investment related, waste related, safety/consumer protection related or CRM related. The emphasis on separating key components make that all product make the case studies relevant for batteries or electronic directives.

Table 2: Relevant cross-references between specific policy instruments and Triple Link case studies (denoted by " √ ")

	EU Ecodesign directive	Ecolabel	Green Public Procurement	Extended Producer Responsibility	Waste and recycling regulations (e.g. WEE directive)	REACH and market consultation RoHS	General Product Safety Directive	Electronics	Battery directive	Critical Raw Materials act and strategic autonomy	The New EU Industrial policy	Internal Market and Consumer Protection	PEF and organisational footprint	Right to repair	EU Taxonomy and sustainable investment
Lithium extraction and refining	√			√		√		√	√	√	√				√
Natural and synthetic graphite: trade-offs between carbon footprint and supply risk	√			√	√	√		√	√	√	√		√		√
Alkaline battery case study	√		√	√	√		√	√	√	√	√	√	√	√	√
Design for recyclability of electric vehicle batteries	√	√	√	√	√		√	√	√	√	√	√	√		√

The abundance of relevant intersections between product cases and recommendations are discussed further in the next section.

6. Recommendations and opportunities

Based on structures from Tang et al. (2021) and Park (2021), we can identify the following recommendations and opportunities. The recommendations are written by taking the view from a start-up company.

Recycling and a circular economy approach are an indispensable part of future supply and lowering the environmental impact of batteries. This is also acknowledged by the EU, as they state that by 2050 the EU wants to achieve a fully circular economy. Even though recycling batteries has a promising future, it is expected that recycling will not eliminate the need for mined battery metals. Even with a high end-of-life recycling rate, the expected increase in the annual use of primary resources is estimated to be 5-10% for copper, 20-30% for nickel, 45-55% for cobalt, and 80-90% for lithium, compared to the estimated annual use of these metals in case there would be no energy transition. Under ideal circumstances, recycling could provide around 50% of the global demand for lithium by 2040 (Dunn et al., 2021). However, other projections are less optimistic and foresee that by 2040 metal recycling could reduce demand by only 5% (IEA, 2021). The future impact of this development is still very uncertain, and it is most likely that the EU will continue to rely heavily on primary mining.

The open-loop recycling rates would be greatly improved in the coming years by better design of products i.e. better use of metals. Moreover, a high collection rate of the discarded batteries is paramount to ensure minor leakages from the recycling process. Policies should therefore strive towards establishing a comprehensive system for tracking and tracing the end-of-life EV batteries to guarantee the quality and composition of these wastes, as they represent a strategic stock for potential urban mining. At the same time, an efficient end-of-life battery management system and recycling infrastructure needs to be well-established to ensure that discarded EV batteries are appropriately processed and that their secondary metals can be reused for sustainable manufacturing production in the future (Tang et al. 2010).

The conclusion is therefore that battery design on the level of chemical elements can boost these recycling rates and increase the quality level of secondary metal.

6.1 E-waste sector

In addition to analysing the context of and problems in the e-waste sector, there are also opportunities for new business development. These opportunities are based on an analysis of expected e-waste streams, technological and organisational innovations.

Opportunities provided by expected e-waste streams relate to EEE streams that are new on the market and still growing. Hence, these kind of EEE streams do not create large e-waste streams yet, if at all.

However, it is expected this will be the case in the (near) future, which is why these streams are relevant to look at. It provides the opportunity to anticipate on a future e-waste problem. Targeting one or more of these lacking or insufficiently developed technologies (battery designs that were discarded for purely price-based reasons in markets that have changed permanently) might be a relevant angle to base the start-up on.

The last section gives an outline of non-technical opportunities that were identified as a potentially relevant basis for start-up creation. To acquire information about the specific opportunities every source that has been spoken to was asked to provide their views on the valuable resources, expected streams and technologies that require further development.

Lastly they were asked to give their ideas about organisational structures for the start-up that might be relevant. Furthermore, academic and governmental literature were reviewed. The opportunities as listed below are not yet tested for their feasibility. In this report the different leads we encountered are only mentioned, to give an overview of what potential exists in the current e-waste sector.

In the next phase analysis on the characteristics of the different opportunities and a first analysis of their feasibility will be done.

6.2 Expected waste streams

The following list shows expected streams as communicated by stakholder conversations around the Triple Link project, as well as leads deduced from the analysed literature. These streams are potentially interesting foundations for the business model.

- 3D printers. This is seen as a 'transformative technology': a development that will change will be of huge influence to society. It is expected to grow tremendously in the coming fifteen years, not only for industrial or medical purposes, but also for consumer use (Campbell et. al, 2011; Yeh, 2014);
- Lithium batteries. This is a rapidly growing stream, due to the rise of the electric car and the expanding use of lithium batteries in consumer electronics
- Photovoltaic solar panels (PV). Attractive stream to focus on because it grows rapidly. Large enough volumes for economically viable recycling are expected in 2025/ 2030. Moreover, PVs contain a lot of valuable metals like gallium, and many hazardous components like cadmium and flame retardants, for which proper recycling technologies are essential (Cucchiella et al., 2015; Dubey et.al, 2013);
- Laptop batteries. This is currently a very small e-waste stream, but this will become a very large and important stream in the future.

Additionally, we have asked several other participants for their input on expected e-waste streams. They provided us with the following potentially interesting streams, some of which are also deemed relevant in the literature:

- Tablets;
- Smart watches;
- E-readers;
- Board computers from cars;
- External hard disks (and USBs);
- Chargers;
- Cameras.

6.3 Technical innovations

Next to finding streams that might become a large e-waste stream, it is relevant to look at the discrepancy between currently available and necessary technology. This discrepancy might provide relevant leads to focus on with the start-up. Every stakeholder has thus been asked whether or not they have ideas about innovations that are currently lacking or insufficiently mature, that would have a positive impact on e-waste recycling if developed (further). Several suggestions were made:

- There is a lack in technologies that target urban mining specifically. Now mainly technologies are used that are fit for natural ore mining. However, more specific urban mining technologies are needed for more eco-efficient e-waste recycling;
- Technologies for effective solar panel disassembly are lacking;
- There are many possibilities for improvements with regards to informal manual dismantling. Currently not only very dangerous rudimentary technologies are being used, but also a very low recovery rate is acquired leading to high loss of resources. Basic technological innovations that could assist informal manual disassembly practices are necessary (StEP, 2014).
- Lithium batteries are currently difficult and very expensive to recycle. Improvements in recycling technologies (automated dismantling using machinery), would be relevant;
- Plastic is a huge part of electronics, but currently recycling schemes are underdeveloped and economically not viable. Further developments are needed;
- Currently more and more electronics and cars are made of composites. However, feasible technologies to effectively recycle composites are lacking.

6.4 Options for Organisational innovation

The past research phase has provided us with different options and leads for the direction of the start-up with regards to e-waste streams and technologies. Additionally, four ideas with regards to the structure and/or organisation of the start-up (or even the structure of the chain in which the start-up would operate) became apparent. These ideas are listed below:

- Almost every stakeholder expressed the importance of securing sufficient volumes for economically viable recycling. But to ensure sufficient volumes, collection rates have increase greatly. It has been suggested multiple times, that providing solutions to increase collection rates instead of developing recycling technologies might be a relevant focus point for the start-up (NVMP 2021);
- Adopt a Best-of-both-Worlds-approach. This approach provides the opportunity of having impact in both the Netherlands as well as the developing world;
- When the focus would be re-use, the products that are collected should be mainly high-end products which are returned by first users before the end of the technology cycle. This mainly regards ICT-products like computers and telecom products. These are products that are developing very quickly into new products and newer versions, resulting in disposal early in their lifecycle. Products for which this is not the case, like washing machines, have much less potential for re-use;

- When the start-up would be aimed at refurbishing rather than recycling, the highest potential lies in attracting company electronics instead of consumer electronics. Company electronics are available frequently in relatively large volumes and good states, while consumer electronics often have been used much longer and therefore have lower value for refurbishment. Moreover, although private households need to be able to dispose their e-waste free of charge, this is not the case for e-waste generated in a non-private context,

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