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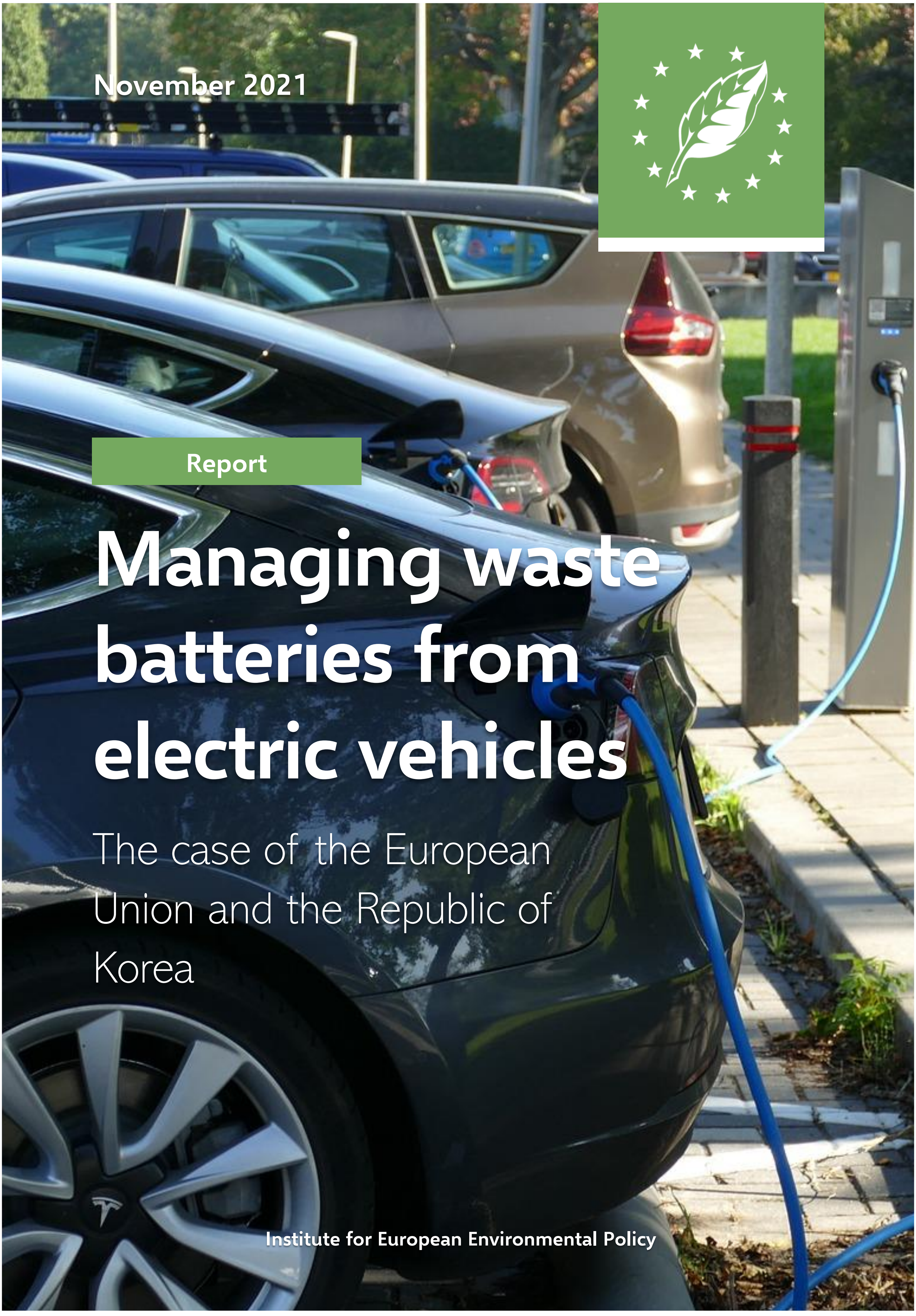

Report

Managing waste batteries from electric vehicles

The case of the European Union and the Republic of Korea

Institute for European Environmental Policy

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CONTENTS

List of abbreviations

BEV	Battery electric vehicle
ELV	End-of-life vehicle
EPR	Extended producer responsibility
ESS	Energy storage system
EU	European Union
EUR	Euro (currency)
EV	Electric vehicle
GBA	Global Battery Alliance
GHG	Greenhouse gas(es)
KARA	Korea Automotive Recyclers Association
KBRA	Korea Battery Recycling Association
KECO	Korea Environment Corporation
KRW	South Korean won (currency)
LFP	Lithium-iron-phosphate (battery type)
LIB	Lithium-ion battery
MOE	Ministry of Environment
NCA	Nickel-cobalt-aluminium oxide (battery type)
NDC	Nationally determined contribution (under the Paris Agreement)
NMC	Nickel-manganese-cobalt oxide (battery type)
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in hybrid electric vehicle
QR	Quick Response code
RFID	Radio Frequency Identification tag
ROK	Republic of Korea
UK	United Kingdom
UN	United Nations
US	United States
USD	US dollar (currency)
VAT	Value added tax
ZEV	Zero-emission vehicle

1. EXECUTIVE SUMMARY

This report explores the challenges related to the future management of waste batteries from electric vehicles (EVs), with a focus on how the Republic of Korea (ROK) and the European Union (EU) are dealing with the issue, and steps that may be taken in the future to improve the management of this type of waste. This comparison is beneficial both in relation to policy learning between the ROK and the EU, as well as considering the potential movement of EV batteries between the ROK and the EU.

The **sale of EVs is growing significantly** in many countries, especially in the ROK, Japan, China and across Europe. Globally, EV sales are expected to reach around 6.4 million by the end of 2021, an increase of 98% from 2020. Estimates suggest that at the start of the 2030s there may be annual sales of 111 million EVs, or much more. A key driver for the expansion of EVs is the need to **reduce greenhouse gas (GHG) emissions**. Both the EU and the ROK have the target to become climate neutral, i.e. net-zero emission of GHGs, by 2050. Transport emissions are a major contributor to GHG emissions and **expansion of EVs is one approach to tackling this**. The EU has a target to have 13 million passenger zero-emission vehicles (ZEV) by 2025, and at least 30 million by 2030 and almost all vehicle stock by 2050. The ROK aims to have 430,000 EVs on the road by 2022 and has announced targets to have 3 million EVs in 2030. Korean vehicle manufacturers are working hard to produce more EVs to contribute to attaining these targets.

One essential component of EVs is the battery. Until now almost all have been produced in Asia (China, Japan and ROK) and the United States. The principal type of battery used in EVs is **lithium-ion batteries (LIBs)**. Globally, LIB production for EVs increased by 33% from 2019-2020. Whilst China accounted for around most LIB production in 2020, the ROK company LG Chem overtook Chinese producer CATL to lead the EV battery market, accounting for around 25% of the global market. ROK production capacity for EV batteries increased almost four-fold from 2016 to 2020 and the country has the ambition to continue to grow its EV battery industry, with Korean companies expanding and developing manufacturing facilities. In Europe there are announced new production facilities, but it has some way to go to catch up with East Asian production. Currently, therefore, the EU is a major net importer of EV batteries, at around 800,000 tonnes each year.

As EVs reach the **end of their life** in coming years, a new challenge will arise, namely how to manage the increasing number of old and waste batteries. The lifetime of a LIB is typically between 5 and 20 years, and it will typically outlive the EV it was built into. However, its performance diminishes over time with use. One estimate suggests that by 2020 around 102,000 tonnes of LIBs per year would be retired from EVs globally, potentially reaching 7.8 million tonnes per year by 2040. **The principles of waste management mean that all EV batteries should first be reused for their original purpose (where possible), then repurposed for a second-life use and, finally if that is not possible, then sent for recycling**.

With regards to **waste prevention**, the aim should be to **prolong the lifetime** of LIBs, with r**epair and maintenance** and r**efurbishment**. The next priority is then **repurposing or second-life use**, i.e. use other than in EVs, e.g. for stationary energy storage such as excess power from solar or wind energy. Repurposing could save around 63 million tonnes of carbon emissions compared with the manufacture of new batteries. Repurposing is only at the trial stage in the EU, but in the ROK Hyundai Motor Group entered into a partnership with Wärtsilä Energy Storage to use second-life EV batteries in the energy storage market.

Recycling recovers materials for further use, reducing the need for extraction of virgin raw materials and associated environmental damage. It also retains the economic value of those materials. Globally, the LIB recycling market is forecast to be worth US$ 31 billion per year by 2040, with over half of LIBs being recycled in China. In 2019, the EU had sufficient infrastructure capacity to recycle around 160,000 EV batteries annually, which would not be adequate to deal with the expected significant increase in the quantity of waste LIBs in the next few years. In the ROK, the SungEel HiTech company recycled 3,000 tonnes of LIBs from EVs in 2019, but failed to make a profit due to the reduced cobalt content of EV batteries. Recycling, therefore, has challenges for both the EU and ROK. The economic basis for recycling is critical for policy frameworks to promote it. If there is money to be made by the recycling sector from managing waste EV batteries, this will be a key driver. If the costs start to outweigh the value of the recovered materials, then policies will need to support recycling activities (such as costs to be borne by vehicle and/or battery manufacturers through producer responsibility schemes, etc.).

The relevant regulatory framework in the EU currently is the **Batteries Directive** (2006, revised 2013), which requires the separate collection and regulated storage or treatment of EV batteries. It has targets for the collection of waste batteries (45% of the amount placed on the market by 2016) and for recycling efficiencies for lead-acid (65%), nickel-cadmium (75%) and all other batteries (50%). Also, the Directive required the development of extended producer responsibility (EPR), whereby battery producers are made responsible for the collection and recycling of batteries when they become waste, and the associated costs. In 2020 the EU proposed a **new Batteries Regulation**. It would require EV batteries to be collected and recycled in full. It sets a **recycling target for LIBs** of 65% by average weight by 1 January 2025, and 70% by 1 January 2030. It would aim to facilitate the **repurposing** of EV batteries for a second life and require each EV battery to have a **'battery passport'.**

The ROK adopted a policy for **EPR** for battery recycling in 2003 under the 2002 Act on the Promotion of Saving and Recycling of Resources. In 2015, the collection target for recycling of primary lithium batteries was 329 tonnes, but only 173 tonnes were collected, and the collection rate was just over 34%. ROK has subsidised EVs and since December 2018, drivers of **subsidised EVs** who scrap their cars must return the spent batteries to the municipality that provided the subsidy. Until 2020 there was no regulation relating specifically to the **recycling** of end-of-life EV batteries. However, in July 2021, the Enforcement Decree on the Act on Resource Circulation of Electrical and Electronic Equipment and Vehicles was amended and this delegates to the Korea Environment Corporation the operation of four **EV battery collection centres** across the country. In November 2020, the Enforcement Rules of the Wastes Control Act were revised, adding used EV batteries to the waste type list and setting **standards** that must be met by facilities.

The report concludes that the ROK and EU should explore the following options to ensure effective management of end-of-life EV batteries. These are set out under four headings

Policy and legislation:

- Ensure policy and legislative frameworks for EV batteries are coherent and up-to-date, place a value on the sustainability throughout their lifecycle, and clarify that waste EV batteries should first be reused, then repurposed, then recycled.
- Ensure that legislation is clear with regard to its obligations and to whom they apply.
- Set targets for the recycling to incentivise collection and recycling and support the development of the recycling market.
- Provide guidance on secondary applications for EV batteries to facilitate their reuse and repurposing, including clear definitions and minimum quality standards.
- Ensure EPR is applied to LIBs from EVs, and also that it is clear regarding who is responsible for EV batteries when they are reused or repurposed.
- Consider setting targets for reuse and repurposing of EV batteries.
- Ensure stakeholders in the batteries value chain are engaged in policy-making.

Battery design and information:

- Ensure EV batteries are designed with the end of their first life in mind, to enable their reuse, repurposing, disassembly, sorting and recycling.
- Consider setting eco-design requirements, e.g. composition and disassembly.
- Ensure that adequate and accurate information about batteries, e.g. through labelling.
- Consider the introduction of product passports for EV batteries and seek harmonisation of such passports globally to ensure ease of trade.

Economic and financial considerations:

- Provide funding for R&D for the development of circular business models and recycling technologies.
- Consider use of financial incentives to encourage investment in EV battery circularity.

International considerations:

- Ensure there are appropriate requirements, controls and quality standards placed on the export of used EV batteries, to reduce impacts on importing countries.
- Ensure compliance with EV battery-related policy and regulation in export markets.
- Consider alignment of legislation between trading partners (e,g, EU and ROK).
- Consider the introduction of certification schemes for EV batteries based on international standards, to facilitate trade.
- Create platforms to share best practices and lessons learned from national initiatives.

2. INTRODUCTION

The sale of electric vehicles (EVs) is growing significantly in many countries across the world, especially in the Republic of Korea (ROK), Japan, China and across Europe. Globally, 2.65 million new EVs were purchased during the first half of 2021 alone, with growth in sales of EVs 3 to 8 times higher than growth in overall light vehicles sales (EV Volumes, 2021). The share of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) increased from 3% in the first half of 2020 to 6.3% in the first half of 2021 (EV Volumes, 2021), suggesting a true shift towards EVs.

One essential component of EVs is the battery required to power the vehicle. These batteries have until now almost all been produced in Asia (China, Japan and ROK) and the United States (US), though there are now new production facilities in Europe (and further announced). Whilst there are some regulations and procedures in place to manage the disposal of end-of-life vehicles (ELVs) in Asia and in Europe, only a rather limited number of EVs have been disposed of to date compared to the number in use, since they are a relatively recent development. As EVs begin to reach the end of their life in the coming years, a new challenge will arise, namely how to manage the increasing number of old and waste batteries. This challenge will have consequences not only for waste management, but also potentially for the production of EVs and batteries, and global trade in these products (either as separate batteries or for the vehicles that contain them).

This report explores some of the challenges related to the future management of waste batteries from electric cars, with a focus on how the ROK and the European Union (EU) are currently dealing with the issue, and steps that may be taken in the future to improve the management of this type of waste. This comparison is beneficial both in relation to policy learning between the ROK and the EU, but also in considering the potential movement of EV batteries between the ROK and the EU.

The report firstly looks at the state of play on EV batteries, including the types of batteries in use, the volume of batteries being used, and the current approaches available for the management of waste batteries from EVs.

It then includes a summary of the existing legal and policy framework in both the EU and the ROK that is relevant to the management of used and waste batteries from EVs.

Finally, the report includes a discussion of the current approach to the management of waste EV batteries in both the EU and the ROK, presenting some options to improve policy in the future.

3. STATE OF PLAY ON ELECTRIC VEHICLE BATTERIES

This chapter provides an overview of some of the key elements regarding the current state of play on electric vehicle (EV) batteries. It outlines the most common types of battery in use in EVs, trends in the quantity of EVs and their batteries and the policies underpinning those trends, and the different approaches available for the management of end-of-life/waste EV batteries.

3.1 Types of EV battery

The principal type of battery used in EVs is **lithium-ion batteries (LIBs)**, with nickel-manganese-cobalt oxide (NMC) and nickel-cobalt-aluminium oxide (NCA) materials being the main cathode types currently in use, accounting for 95% of new electric passenger cars sold in 2019 (IDTechEx, n.d. e). NMC had a 71% sales share in 2020, with NCA making up most of the remainder and lithium-iron-phosphate (LFP) accounting for under 4% of the electric car market (IEA, 2021b). BMW, Hyundai and Renault all use NMC types of battery, with Tesla and Chinese manufacturers preferring NCA types.

The composition of LIBs means they contain several high impact, and high value, materials. Nickel can comprise up to 60-80% of the metallic content of current LIBs. Higher nickel content increases the reversible capacity and energy density of batteries, which is beneficial for EV batteries. It can also replace some of the cobalt (which is more expensive than nickel and also a scarce material). As a result, the future trend is likely to be towards higher nickel content, and lower cobalt content, batteries. The use of NMC batteries with a nickel content of over 60% is expected to increase significantly between 2020 and 2030 (IDTechEx, n.d. c). As well as NMC and NCA batteries, this may also include LFP batteries which are well-suited for use in short-range EVs such as electric buses and two-wheeled vehicles, as well as for some stationary applications.

After 2030, other potential technologies may be developed that exceed the performance constraints of LIBs, such as lithium-metal solid state batteries, lithium-sulphur, sodium-ion or lithium-air. These technologies may prove cheaper, more energy dense, with longer life-cycles and would have the additional benefit of using more widely available materials than existing LIB technologies; however such technologies will require extensive testing before they can be scaled up enough to compete with LIBs. (IEA, 2020)

3.2 Trends in EVs, their batteries and the policies driving them

This section first includes a brief summary of the overarching policies in the EU and ROK related to climate change and greenhouse gas (GHG) emissions reductions, which are key drivers for the shift towards EVs with lower GHG emissions. The transport sector is one of the largest contributors to global GHG emissions, so vehicle manufacturers and governments are increasingly taking steps to reduce vehicle emissions as a core contribution to meeting targets in climate-related policies.

3.2.1 Policies driving the shift towards EVs

Both the **EU** and the **ROK** have the overarching target to become climate neutral, i.e. net-zero emission of GHGs, by 2050 (IEA, 2021b).

The **EU**'s nationally determined contribution (NDC) under the Paris Agreement, last updated in December 2020, commits the bloc to reduce its GHG emissions by at least 55% by 2030 (compared to 1990 levels) (Climate Action Tracker, 2021b). In 2019 the transport sector represented 23% of total emissions (Climate Action Tracker, 2021a). It is estimated that EU transport emissions must be reduced by 90% for the bloc to meet its 2050 climate goals (European Commission, 2020c). From 2020, new cars in the EU must meet an emissions standard of 95g CO_2/km. CO_2 emissions from cars must be reduced by 15% from 2021-2025 and by 37.5% from 2021-2030 (by 15% and 31% for vans) (EEA, 2020). From 2025, 15% of new passenger cars and light commercial vehicles must be zero- or low-emission (emitting less than 50g CO_2/km), rising to 35% for cars and 30% for light commercial vehicles from 2030 (Regulation EU/2019/631).

The EU has announced a target to have 13 million passenger zero-emission vehicle (ZEV) stock by 2025, and a further ambition to have at least 30 million passenger ZEV stock by 2030 and almost all passenger light-duty vehicle (LDV) and heavy commercial vehicle stock by 2050 (IEA, 2021b). Several individual European countries have pledged that 100% of vehicle sales will be ZEVs in the coming decades[1] (IEA, 2021b). Many individual European countries[2] also have purchase incentives in place for EVs, including purchase subsidies ranging from EUR 750-6,000 (USD 800-6,800) (typically increasing with the purchase value of the car)

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[1] Norway by 2025; Denmark, Iceland, Ireland, the Netherlands, Slovenia and Sweden by 2030; the UK by 2035; France, Portugal and Spain by 2040; and Germany by 2050.

[2] Including Austria, Belgium, France, Germany, Italy, Portugal, Spain, Sweden and the UK. See (IEA, 2021b) for details.

and/or tax reductions (no registration/ownership tax in Italy and some regions of France, and exemption from VAT and BEV exempt from VAT (25%) and weight-, CO_2 and NOx-based purchase taxes in Norway) (IEA, 2021b).

The **ROK**'s nationally determined contribution (NDC) under the Paris Agreement, last updated in December 2020, commits the country to reducing its total GHG emissions by 24.4% by 2030 (compared to 2017 levels) (European Parliament, 2021). In 2017 the transport sector represented 17% of CO_2 emissions from fuel combustion in the ROK (Climate Action Tracker, 2021c). From 2020, the emissions standard for light-duty vehicles is 97g CO_2/km (Climate Action Tracker, 2021c), similar to the EU standard. Supported by subsidies and tax rebates, the country aimed to have 430,000 EVs on the road by 2022 (Climate Action Tracker, 2021c), and has also announced targets to have 1.13 million passenger BEVs (and 200,000 passenger fuel-cell/hydrogen vehicles) by 2025 (IEA, 2021b), and 3 million EVs in 2030 (Climate Action Tracker, 2021c). The ROK also offers a purchase subsidy of KRW 8 million (USD 6,700) for BEVs (IEA, 2021b) (and KRW 22.5 million (USD 18,800) for fuel-cell EVs (IEA, 2021b), together with a national car tax exemption, and discounted parking and road toll fees (Choi & Rhee, 2020).

Such policies demonstrate the key role of EVs in achieving global climate goals, since they serve to decarbonise the transportation and mobility sector, which is one of the main contributors to greenhouse gas emissions. It is also important to note that GHG are not the only emissions of concern with vehicles. Air pollution from nitrogen oxides and particulates is a concern in urban areas around the world and the World Health Organisation has stressed the need for tougher air quality standards. Vehicles that emit low levels of these pollutants are one route to tackling this problem and EVs certainly contribute.

In addition, technological improvements such as increases in battery energy density (leading to improved performance and longer ranges for EVs), increased availability of charging infrastructures, faster charging speeds, and significant reductions in the price of EV batteries, are all contributing to the rollout of EVs around the world. For example, average battery energy density is currently increasing at 7% per year, whilst LIB prices fell by 89% between 2010 and 2020 (BloombergNEF, 2021).

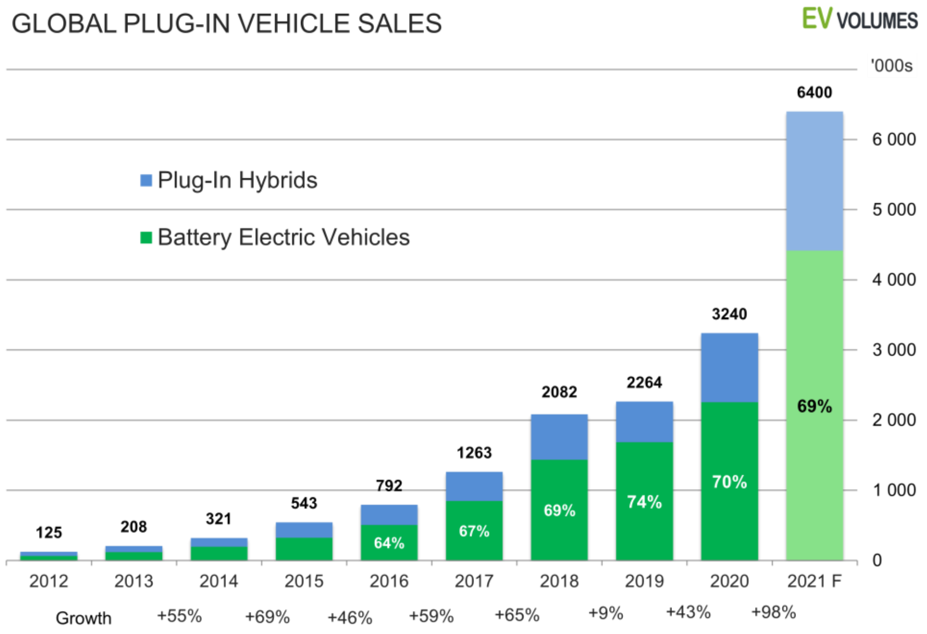
Combined with the policies outlined above, these drivers help to explain the significant increase in global sales of EVs in recent years. The trends in both EVs and their batteries are discussed further in the following sections.

3.2.2 Trends in EVs

There are two main types of EVs: **battery electric vehicles (BEVs)** and **plug-in hybrid electric vehicles (PHEVs)**. BEVs are the most environmentally advantageous, since they have zero emissions at the point of use, though overall emissions depend on the means of electricity production. Emissions from PHEVs depend on the drivers' charging and driving habits, as well as the means of electricity generation, but they provide a short- to mid-term solution by offering more sceptical consumers a longer distance range due to their hybrid propulsion options.

Globally, 2.65 million new EVs were purchased during the first half of 2021, representing a 168% increase from 2020, although it should be noted that sales during the first half of 2020 were 14% lower than during the first half of 2019, suppressed by the first wave of the Covid pandemic (EV Volumes, 2021). Sales growth for EVs during the first half of 2021 was 3 to 8 times higher than for light vehicle markets overall, with the share of BEVs and PHEVs increasing from 3% in the first half of 2020 to 6.3% in the first half of 2021 (EV Volumes, 2021), suggesting a true shift towards EVs. Including a rebound in the popularity of mini-EVs in China, EV sales are expected to reach around 6.4 million (4 million BEVs and 2.4 million PHEVs) by the end of 2021, an increase of 98% from 2020 (EV Volumes, 2021). This would see over 16 million EVs (two thirds BEVs and one third PHEVs) in operation globally by the end of 2021 (EV Volumes, 2021), an increase from the 8.1 million plug-in EVs (BEVs and PHEVs) estimated to be on the road by the end of 2019 (IDTechEx (n.d. b) and 10 million in 2020 (IEA, 2021c). The figure below gives an overview of the global increase in plug-in EV sales from 2012-2021 (EV Volumes, 2021).

Various longer-term estimates suggest that at the start of the 2030s there may be 111 million (IDTechEx, n.d. b), 145 million (The Guardian, 2021a) or even 300 million (IEA, 2021a) EVs in use globally, and that by 2040 anywhere between 150 and 900 million EVs could be on the road (Tsiropoulos et al., 2018), depending on the policies pursued by different governments around the world. EV sales are predicted to reach almost 15 million in 2025 and over 25 million in 2030, which represents 10% and 15% of road vehicle sales respectively (IEA, 2021b).

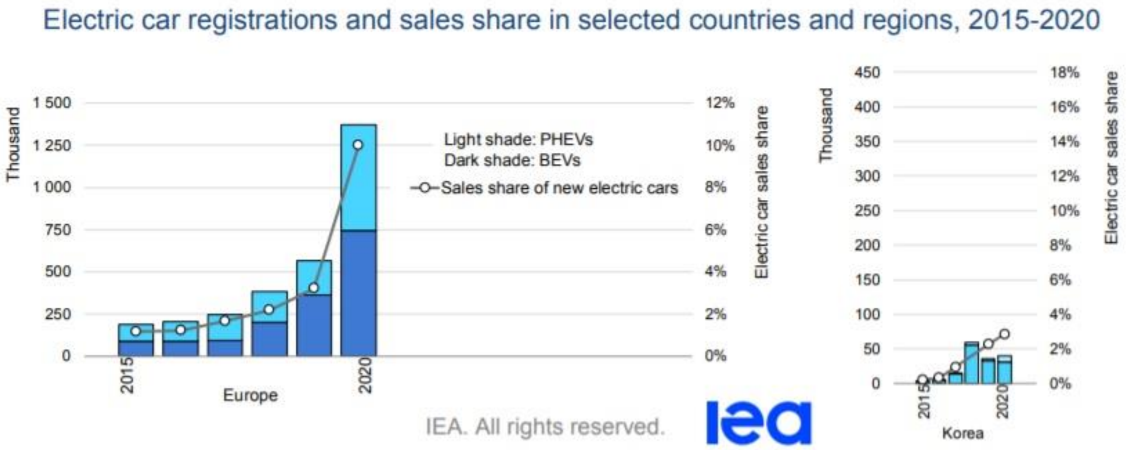


In the **EU** (plus Iceland, Norway and the UK), new registrations of electric cars (including both BEVs and PHEVs) rose from only 700 units in 2010 to around 550,000 in 2019, accounting for a market share of around 3.5% of newly registered passenger vehicles (EEA, 2020). BEVs specifically accounted for around two-thirds of electric car sales, and 2% of total new car registrations, with Germany, Norway and the Netherlands alone accounting for around half of BEV registrations (EEA, 2020). PHEVs accounted for around 1% of total registrations (EEA, 2020). In addition, over 20,000 electric vans (mostly BEVs) were sold in the EU in 2019, representing a market share of 1.3% and an increase of around 0.5% from the previous year. In 2020, EVs accounted for around 10% of new vehicles (52% of which were BEVs, compared to 64% in 2019). In the first half of 2021, EVs accounted for 14% of European vehicle sales, with around 44% of those sales being BEVs (EV Volumes, 2021). EVs had a 40% share in Sweden, 28% in Finland and 27% in Denmark, whilst in several other countries (including Poland, Estonia, Slovakia, Slovenia, Croatia, Romania, Cyprus and Lithuania) they had less than a 3% share (Climate Action Tracker, 2021a). Demand for EVs is being driven by a mix of subsidies, falling costs and growth in EV charging infrastructure (Climate Action Tracker, 2021a). Looking to the future, it has been estimated that there will be 28 million EVs on the road in the EU in 2030, comprising 31% of the vehicle fleet (Engle et al., 2018).

In contrast with the majority of European sales being PHEVs, around 80% of EVs sold outside of Europe are BEVs (EV Volumes, 2021). In the **ROK**, the government aims to have 430,000 BEVs on the road in 2022 (IEA, 2020), to have 1.13 million passenger BEVs stock by 2025 (plus 200,000 fuel-cell EVs) (IEA, 2021b), and for

33% of vehicle sales to be BEVs or fuel-cell EVs by 2030 (IEA, 2020). Korean vehicle manufacturers are also working hard to produce more EVs to contribute to attaining these targets. For example, the Hyundai Motor Group has planned to release 44 new greener cars by 2025, including 23 all-electric models, with the goal of selling 560,000 BEVs globally in 2025, to challenge market leaders such as Tesla (US), BYD (China) and Volkswagen (Germany) (Pulse News, 2020).

The figure below gives an overview of the registrations and sales share of electric cars in **Europe** and the **ROK** from 2015-2020 (amended from IEA, 2021b).



Regarding **trade in vehicles**, in 2020 the **EU** exported around 5.2 million cars, 725,000 (around 14%) of which were EVs or hybrid. Of these, 27% were electric, 24% plug-in hybrid and 49% non-plug-in hybrid. In the same year, the EU imported around 3 million cars, 892,000 (around 30%) of which were EVs or hybrid. Of these, 34% were electric, 16% plug-in hybrid and 50% non-plug-in hybrid. These trade figures showed an increase in spite of COVID-19; EU exports rose five-fold from 2017 (when 150,000 cars were exported) and imports tripled (from 301,000 in 2017). The main destinations for EU exports in 2020 were the UK (39%), US (16%), Norway (10%) and China (9%), whilst the main imports came from Japan (23%), the US (23%), **ROK** (15%), the UK (14%), Turkey (10%) and China (9%) (Eurostat, 2021).

3.3 Trends in batteries for EVs

Globally, LIB production for EVs increased by 33% from 2019-2020 (IEA, 2021b). Whilst China accounted for around 77% of overall LIB production in 2020 (S&P Global, 2021), the **ROK** company LG Chem overtook Chinese producer CATL to lead the EV battery market, accounting for around 25% of the global market (Financial Times, 2020). Global demand for **batteries** has been predicted to increase

14-fold between 2018 and 2030, driven largely by the increase in EVs (European Commission, 2020c). The market for EV batteries is predicted to increase to be worth US$304.7 billion by 2030 (Financial Times, 2021), with the market for LIB cells in EVs alone forecast to reach US$ 70 billion by 2026 (IDTechEx, n.d. a).

One estimate suggests that the **global** material demand for EV batteries sold in 2019 was around 19 kt of cobalt, 17 kt of lithium, 22 kt of manganese and 65 kt of nickel, and that demand will increase to 180 kt per year for cobalt, 185 kt for lithium, 177 kt for manganese, and 925 kt for nickel (these figures are based on existing stated policies, but demand could be more than twice as high if additional policies are introduced) (IEA, 2020). Important countries for the raw materials contained in LIBs include: China (80% of global refining capacity for the relevant raw materials, 60% of global graphite production), Australia (around 50% of global lithium production, second largest reserves of nickel), Brazil, Chile and Argentina (together accounting for around 58% of global lithium reserves), Indonesia (largest nickel producer globally), the Democratic Republic of the Congo (around 68% of global cobalt mining) and South Africa (28% of global manganese production, largest manganese reserves) (Bhutada, 2021). This emphasises the importance of global trade for LIB production.

Around 800,000 tonnes of automotive batteries enter the **EU** each year (European Commission, n.d.). EV batteries account for around 80% by weight of industrial lithium batteries placed on the EU market, and around 41% by weight of all lithium batteries placed on the market (European Commission, 2019). In terms of production, the EU produces battery packs for EVs using imported cells (mostly from East Asia), but also wishes to increase its production capacity (European Commission, 2019). In 2016, the EU produced over EUR 1 billion worth of nickel cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel iron and other electric batteries, imported EUR 5.5 billion worth, and exported over EUR 2.5 billion worth (European Commission, 2019). In 2019 it was estimated that the EU produced around 5% of the global volume of NiCd, NiMH and lithium batteries (European Commission, 2019). Demand for batteries in 2020 exceeded domestic European production capacity, with capacity at roughly 35 GWh per year, but with potential future capacity of up to 400 GWh by 2025 thanks to the construction of new battery plants (IEA, 2021b). Over the next 10 years, it has been estimated that Europe may serve between 7% and 25% of global demand for LIBs (with notable production capacity in Sweden, Germany, Poland and Hungary) (Oeko-Institut et al., 2021).

The **ROK** is home to some of the largest global EV battery manufacturers. ROK production capacity for EV batteries increased almost four-fold from 2016 to 2020 (Bloomberg, 2021) and Korean manufacturers represented around a third of the total global market in the first five months of 2021 (Bloomberg, 2021). The country has the ambition to continue to grow its EV battery industry, with Korean companies expanding and developing manufacturing facilities (some of this production to take place in other countries), to meet the growth in EV demand (Bloomberg, 2021). The aim is to compete with market leaders from China (the Chinese Contemporary Amperex Technology Co. Ltd. accounted for 31% of EV battery sales in the first half of 2021 (Bloomberg, 2021)) and Japan. At the end of 2019, Hyundai Motor Group agreed a 10 trillion won (US$8.2 billion) deal to purchase batteries for 500,000 EVs from SK Innovation over the coming five years (Yonhap News Agency, 2020). In 2020, the two companies signed a memorandum of understanding to collaborate on future mobility solutions and EV batteries, to strengthen their competitiveness and promote the uptake of EVs in Korea (Yonhap News Agency, 2020). In July 2021, the ROK government announced a 40.6 trillion won (US$ 35 billion) investment in the country's EV battery industry by the end of the 2020s, including support for SMEs to provide materials and components for EV batteries (Bloomberg, 2021). LG Energy Solution, SK Innovation and Samsung SDI will be key producers investing in R&D and battery production. For example, LG Energy plans to invest 15.1 trillion won by 2030, including 9.7 trillion won for R&D activities and the construction by 2023 of an institute for training in battery technology (Bloomberg, 2021).

3.4 Management of end-of-life/waste EV batteries

In general terms, waste should be managed in the following order of priority: waste prevention, then reuse (including preparation for reuse), then recycling, then energy recovery, with disposal as a final resort once the other options have been exhausted (see for example the EU Waste Framework Directive, 2008/98/EC, but these principles form the basis of circular economy thinking in many countries and in the UN). This order should therefore also be applied to the management of waste EV batteries. This means that, in practice, all EV batteries should first be **reused** for their original purpose (where possible), then **repurposed** for a second-life use, then sent for **recycling**.

The lifetime of a LIB is typically between 5 and 20 years, depending on the purpose they are used for and how they are used (Oeko-Institut et al., 2021). Indeed, a EV LIB today will typically outlive the EV it was built into (Castelvecchi, 2021). The performance of LIBs does however diminish over time with use. An EV battery can no longer perform to an adequate level for its intended purpose once it reaches 70-80% of its original capacity (for example because it begins to restrict the range of the EV). It therefore reaches the end life for its intended purpose. Its remaining capacity may still be sufficient for less demanding second-life applications such as stationary energy storage. The alternative, and indeed the next step following any period of second-life reuse, is to send the battery for recycling to recover as much of the useful material it contains as possible.

One estimate suggests that by 2020 around 102,000 tonnes of LIBs per year would be retired from EVs **globally**, potentially reaching 7.8 million tonnes per year by 2040 (IDTechEx, n.d. d). Another estimate suggests that 12.85 million tons of LIBs from EVs will reach the end of their life between 2021 and 2030 (Greenpeace East Asia, 2020). In **Europe** in 2020, it was expected that almost 40,000 tonnes of waste LIBs (from energy storage systems, traction batteries and portable batteries) would be generated, with estimates increasing to around 75,000 tonnes per year in 2025 and 240,000 tonnes per year by 2030 (Oeko-Institut et al., 2021). In the **ROK**, it is expected that 8,300 EV batteries will reach the end of their life in 2025 (Choi & Rhee, 2020).

3.4.1 Waste prevention, reuse and repurposing

With regards to **waste prevention**, one recent study suggested that efforts should focus on **prolonging the lifetime** of LIBs, thereby lengthening their first use phase (Oeko-Institut et al., 2021). Battery design options to achieve a longer lifespan (predicted to become available by 2025) include: making improvements to the Battery Management System and sensoring of the cells (for example by measuring more than one physical range to improve cell management); using sensor-less measurement to reduce wiring and improve energy density; or improving the thermal management to homogenise the cell temperature (VITO and Fraunhofer ISI, 2019). **Repair and maintenance** can also prolong an EV battery's life, for example through repair or replacement of faulty components, as long as the battery is designed to enable repair (Andersen et al, 2021). **Refurbishment** may also be an option to allow **reuse** (use of the battery or components for the original purpose as an EV battery). Not all customers need the maximum capacity of an LIB, meaning that refurbished, but slightly less efficient batteries, can still be acceptable to some consumers (Andersen et al, 2021) and can, therefore, be reused. A recent paper identified six examples of repair, five of refurbishment, and one of remanufacturing amongst battery manufacturers in the EU (Andersen et al, 2021).

Increasing the lifespan of EV batteries in these ways has the associated benefit of delaying batteries' end-of-life, giving more time to develop the necessary processes and infrastructure for the waste treatment and recycling of LIBs (Oeko-Institut et al., 2021). As noted above, however, the challenge for increasing the lifespan of EV batteries is to ensure they retain sufficient charge to deliver journey times to drivers. However, all EV batteries eventually reach a point where they cannot continue to be used for their primary purpose. Therefore, reuse and recycling are also important.

Reuse of an EV battery can take two routes. The first is the complete reuse of the battery as a whole. The second is the reuse of components of the battery. The latter, like repair/maintenance, requires battery design that allows for easy disassembly (note that this is different from recycling).

As mentioned above, reuse for the original purpose as an EV battery is technically feasible, but only until the battery loses a certain amount of its original capacity. The next option is then **repurposing or second-life use**, i.e. use in applications other than use in EVs. This can include residential, commercial or even grid-scale applications, e.g. for stationary energy storage (for example temporarily storing excess power from solar or wind energy, or use in 5G infrastructure or data centres (Greenpeace East Asia, 2020)), or to provide energy back-up/mitigate fluctuations in (renewable) energy generation (Bobba et al., 2018). Indeed, some global EV manufacturers such as Nissan, Renault, BMW and Volkswagen have begun to explore second-life options for EV batteries. LFP batteries may be particularly suited to second-life use, since they tend to have a longer lifespan and also be safer than LIBs, which is a key consideration for stationary storage. Other repurposing options include applications such as use in forklifts, street lighting, refrigerated vehicles, or hybrid and electric propulsion ships (Andersen et al, 2021). One recent report estimated that repurposed EV LIBs could potentially meet global energy storage needs by 2030, with EVs decommissioned from passenger cars having a value of US$15 billion by the same year (Greenpeace East Asia, 2020).

Whilst repurposing is not currently widespread in the **EU**, some small-scale examples and trials do exist (Oeko-Institut et al., 2021, Andersen et al, 2021). In some countries such as France, Finland and Germany, enterprises have reached agreements with large EV manufacturers (e.g. Renault, Hyundai, VW, BMW and Daimler) to use their still-functioning batteries in second-life applications such as storage for solar energy or 'spare parts stores' for corporate vehicle fleets (Oeko-Institut et al., 2021). The Enel Group energy company is using 90 batteries previously used in Nissan cars at an energy storage facility in the off-grid town of Melilla in Spain (The Guardian, 2021b). Reneos is network of five national battery collection systems (Bebat, Belgium; GRS, Germany; Cobat, Italy; BatteriRetur, Norway; and Stibat, The Netherlands) which arrange legal cross-border take-back and provide recycling or second-life uses for LIBs (Reneos, n.d.). In Belgium, Watt4Ever collects LIBs from vehicles and remanufactures them into new battery packs where possible (Watt4Ever, n.d.).

In the **ROK**, in 2018 Hyundai Motor Group entered into a partnership with Wärtsilä Energy Storage to use second-life EV batteries in the energy storage market. Hyundai also had plans to develop a 1MWh-level Energy Storage System (ESS) using Hyundai IONIQ Electric's and Kia Soul EV's second-life battery, firstly implementing a demonstration project in a Hyundai Steel factory (Inside EVs, 2018). The ROK also has plans to further develop its used battery industry (Bloomberg, 2021). For example in 2020, Hyundai and SK Group discussed cooperation on next-generation EV battery technologies and the battery-as-a-service (Baas) platform, a new business model aimed mainly at EV battery rental and replacement services (Yonhap News Agency, 2020).

One recent report estimated that repurposing of batteries could save around 63 million tonnes of carbon emissions compared with the manufacture of new batteries (Greenpeace East Asia, 2020). This is a clear indication that reuse and repurposing of EV batteries can make an important contribution to emissions reductions as well as circularity of the materials contained within the batteries themselves.

3.4.2 Recycling

After reuse and repurposing options have been exhausted, the final destination of EV batteries should be **recycling.** Recycling has multiple potential benefits. It recovers materials for further use, reducing the need for extraction of virgin raw materials and associated environmental damage. It also retains the economic value of those materials.

The recovery of materials such as nickel, lithium and cobalt through recycling is typically less environmentally harmful than producing the same materials through mining/extractive activities, which can emit hazardous substances to the environment (Recharge, 2018). Nickel is usually mined from ores with a very small nickel content, resulting in a large amount of waste. The Philippines government suspended nearly half of its nickel mines in 2017 for environmental reasons, and recently it was suggested that two nickel mining companies in Indonesia were planning to use deep-sea disposal for millions of tonnes of raw material waste each year. Current methods for extracting lithium rely on significant energy or water consumption (for extraction from rock and water respectively), although more modern techniques that extract lithium from geothermal water, using geothermal energy, are less resource intensive (Castelvecchi, 2021). Two thirds of global cobalt supply is currently mined in the Democratic Republic of the Congo, where there are concerns over workers' rights and health, and alternative sources such as deep-sea mining also come with environmental risks (Castelvecchi, 2021).

Use of secondary raw materials from the recycling sector can also reduce the need for imports/exports and the risk of changes in supply, as well as shielding manufacturers from price fluctuations.

Globally, the LIB recycling market is forecast to be worth US$ 31 billion per year by 2040, with over half of LIBs (4.3 million tonnes) being recycled in China (IDTechEx, n.d. d). From 2025 onwards, it is estimated that end-of-life EV batteries will dominate the recycling market for LIBs, exceeding batteries from consumer electronics (IDTechEx, n.d. d).

However, the recycling market for EV batteries still needs to adapt to manage the expected increase in the number of waste batteries (Oeko-Institut et al., 2021). In 2019, the **EU** had sufficient infrastructure capacity to recycle around 160,000 EV batteries annually (Alves Dias et al., 2018), which would not be adequate to deal with the expected significant increase in the quantity of waste LIBs in the next few years (Oeko-Institut et al., 2021). This capacity may however expand in the future, attracting imports of waste EVs from other countries for recycling (Alves Dias et al., 2018).

In the **ROK**, the SungEel HiTech company reported recycling 3,000 tonnes of LIBs from EVs in 2019, but failed to make a profit due to the reduced cobalt content of EV batteries (Korea Herald, 2020).

In the **EU**, the current Batteries Directive only has a recycling efficiency target for 'other' batteries (which includes lithium-based batteries) of 50%; there is not currently a specific target for lithium-based batteries, nor are there specific treatment or recycling provisions for these batteries (although a new Batteries Regulation proposed in 2020 would introduce new targets for lithium batteries, if adopted – see section 4.1). This means there is not a sufficient incentive to make significant efforts to recover them (European Commission, 2019).

The value of the materials in batteries is an important factor in determining whether recycling is economically efficient. If material values are not high enough, and/or waste battery volumes are not high enough, recycling will not be profitable. One study has suggested that for cells that do not contain cobalt or nickel, the value of the recovered materials may never cover the costs of the recycling process (Oeko-Institut et al., 2021). Lithium battery recycling typically focuses on the most valuable components (mainly cobalt and nickel) and recycling of lithium was not profitable in the **EU** until 2016, although some recycling of lithium from slags has begun since then. For example, a Li-ion battery recycling plant opened by Accurec in 2016 with an annual treatment capacity of 5,000 tonnes, and with a recycling efficiency of 59.3% (potentially up to 70.6% if by-product slag is also used for other purposes) (European Commission, 2019). In 2019, LIB recycling in the EU was concentrated in Germany, Belgium and France (European Commission, 2019). Estimates suggest that if 65% of industrial lithium-based batteries were collected, and 57% recycling efficiency for lithium achieved, by 2030 the value of recovered materials (lithium, cobalt, nickel and aluminium) in the EU could reach EUR 408 million, as well as creating 2,618 jobs (European Commission, 2019).

There is ongoing research into new battery technologies to reduce or even entirely remove cobalt from EV batteries. Whilst this would reduce their production and sale cost (cobalt is one of the most expensive materials in EV batteries), it also risks making recycling uneconomical since the other materials in EV batteries, in particular lithium, are currently cheaper to mine than to recycle (Castelvecchi, 2021).

The market for EV batteries and material demand is growing too quickly to be sustained only by recycled materials (Oeko-Institut et al., 2021). One report (Greenpeace East Asia, 2020) has estimated that **globally**, from 2021-2030 up to 10.35 million tonnes of lithium, cobalt, nickel and manganese will be mined for new batteries, using 30% of the world's known cobalt reserves. The same report estimates that from 2018-2030 lithium use for batteries will increase by almost 30 times. Another recent report stresses that without battery recycling, lithium demand will exceed currently-known reserves by 2050, but that universal battery recycling could lead to recycled lithium supply exceeding total annual demand by 2050 (BloombergNEF, 2021).

In the **EU**, demand for lithium for EV energy storage batteries is predicted to increase by 18 by 2030 (and 60 times by 2050), and demand for cobalt to increase by 5 times by 2030 (and 15 times by 2050) (European Commission, 2020c). Regarding cobalt, overall demand could increase by 3.7 times between 2017 and 2030, with the growing demand for EVs a significant driving factor (European Commission, 2019). It has also been estimated that 500 tonnes of cobalt could be recycled from end-of-life EV batteries in the EU by 2025, and up to 5,500 tonnes by 2030, providing for 10% of the EU's cobalt consumption in EVs in 2030 (European Commission, 2019). However, the quantities would be hampered if collection rates of waste batteries are not ensured, and/or if there are significant developments in potential for reuse. It has been estimated that recycling and material substitution could reduce the demand of cobalt for EV batteries by 29% between 2020 and 2030 (European Commission, 2019). Meanwhile, on a global level, the growth in the EV market and the trend towards LIBs with higher nickel content has led to an estimate that the demand for nickel from EV batteries may increase ten-fold between 2019 and 2030.

It is important that EV battery recycling is carried out to **high environmental standards**, since careless or improper recycling can have significant negative environmental impacts due to the hazardous materials contained in batteries. The emissions associated with the pyrometallurgical processes used to produce the energy required for recycling, together with emissions from smelting or hydrometallurgical processes, can contribute to climate change, environmental acidification and/or eutrophication (European Commission, 2019). In addition, specific transport, storage and treatment infrastructure is needed for waste batteries, particularly for LIBs, to reduce safety risks (Oeko-Institut et al., 2021). The technology needed for recycling EV batteries, and the environmental impact of recycling, depends on the chemistry of the battery types. The pyrometallurgical process and the refining of copper, cobalt and nickel used for LIBs produces significant GHG emissions, which can be reduced by the use of secondary recycled materials. Overall, around 0.7 tonnes of CO_2 equivalent can be saved per tonne of LIB recycled, in addition to the recovery of lithium (European Commission, 2019).

The economic basis for recycling is critical for policy frameworks to promote it. If there is money to be made by the recycling sector from managing waste EV batteries, this will be a key driver for the collection and management of those batteries. If the costs of recycling start to outweigh the value of the recovered materials, then policies will need to be put in place to support recycling activities (such as costs to be borne by vehicle and/or battery manufacturers through producer responsibility schemes, etc.). Of course the economic bottom line for the recycling sector may vary from country to country (depending on type and volume of batteries as well as other costs) and over time.

4. POLICIES FOR THE MANAGEMENT OF WASTE BATTERIES

This section summarises key points of the policy and legislation in place in the EU and ROK relevant to the management of waste batteries from EVs.

4.1 Policies in the EU

The existing EU **Batteries Directive** (Directive 2006/66/EC), dating from 2006 and last revised in 2013, requires the separate collection and regulated storage or treatment of EV batteries. EU Member States must maximise the separate collection of waste batteries and meet targets for the collection of waste batteries (45% of the amount placed on the market by 2016) and for recycling efficiencies for lead-acid (65%), nickel-cadmium (75%) and all other 'general' batteries (50%). In addition, the Directive required the development of extended producer responsibility (EPR), whereby battery producers are made responsible for the collection and recycling of batteries when they become waste, and the associated costs. Finally, the Directive prohibits the disposal of automotive batteries in landfills or by incineration (although residues of treated and recycled batteries may be disposed of in these ways).

The Directive has been successful in creating EPR for batteries, and increasing the collection rate for waste batteries, although it should be noted that by 2019 only 14 of the then-28 EU countries had met the 2016 collection target (European Commission, 2019). Most countries had also met the required recycling efficiencies by 2016. The Directive has also been criticised for not setting specific targets for the collection of waste industrial or automotive batteries. In its current form, LIBs are only included in the recycling efficiency target of 50% for 'other' batteries; there is no specific target for LIBs, nor specific provisions for their treatment or recycling. This means that at present there is not a sufficient incentive to make significant efforts to recover LIBs (European Commission, 2019). The Directive also does not contain a reporting obligation on the collection of vehicle batteries. Although it is assumed that the high economic value of EV batteries ensures a high collection rate, there is no specific data to support this. However, based on information from EV and battery producers and manufacturers, it has been estimated that around 2-4% of waste automotive batteries in the EU are lost each year, for example through exports or illegal scrapping of used vehicles (European Commission, 2019).

In 2020, however, the EU proposed a **new Batteries Regulation** (European Commission, 2020a) to replace the existing Batteries Directive. If adopted and enacted, it would require large batteries, including EV batteries, to be collected and recycled in full. It sets a **recycling target for LIBs** of 65% by average weight by 1 January 2025, and 70% by 1 January 2030 (European Commission, 2020d). It sets the following **targets for recovery of materials**: 90% for cobalt, copper, lead and nickel by 1 January 2026 (95% by 1 January 2030), and 35% for lithium by 1 January 2026 (70% by 1 January 2030). From 1 January 2027, EV batteries would have to declare their recycled cobalt, lead, lithium and nickel content, and from 1 January 2030, and **recycled content** would have to reach 12% for cobalt, 85% for lead, 4% for lithium and 4% for nickel (increasing to 20% for cobalt, 10% for lithium and 12% for nickel from 1 January 2035) (European Commission, 2020b). In addition, the Regulation would aim to facilitate the **repurposing** of EV batteries for a second life, such as for stationary energy storage or integration into electricity grids, and require each EV battery to have a **'battery passport'** (see section 5 for more information on this).

EV batteries (and other automotive batteries) are also subject to the requirements of the EU **End-of-life Vehicles (ELV) Directive** (Directive 2000/53/EC), including those on recycling and use of substances. The Directive's vehicle reuse and recovery rate of 95% is consistently met by EU countries. However, with recent technical developments and the growth of EVs, it may become harder to correctly categorise new types of batteries, such as those in hybrid cars which can act as both ignition and electromobility batteries. In addition, it can cause confusion that the vehicle batteries retired from ELVs count towards the ELV Directive's targets, but when they are recycled they count towards the Batteries Directive's targets (European Commission, 2019).

It is worth noting that these pieces of EU legislation apply to all batteries (or vehicles, where appropriate) placed on the market in the EU, and therefore Korean manufacturers must also abide by their provisions in order to export their EVs or EV batteries to the EU, with the accompanying implications for trade.

4.2 Policies in Korea

The ROK adopted a policy for **EPR** for battery recycling in 2003 (Kim et al, 2018) as mandated by the 2002 Act on the Promotion of Saving and Recycling of Resources. EPR applies to a range of batteries including primary lithium batteries (Heo & Jung, 2014), with the producer responsibility organisation the Korea Battery Recycling Association (KBRA) founded in 2004 and funded by battery manufacturers and importers to manage battery recycling on their behalf (Kim et al, 2018). End-of-life batteries are typically placed in collection boxes installed by local governments or KBRA, then collected by local governments and sent either to KBRA or directly to battery recycling facilities (Kim et al, 2018). In 2015, the collection target for recycling of primary lithium batteries was 329 tonnes, but only 173 tonnes were actually collected, and the collection rate was just over 34% (with 506 tonnes placed on the market) (Kim et al, 2018).

As mentioned in section 3.2.1, there are subsidies available for the purchase of EVs in ROK. Since December 2018, drivers of these subsidised EVs who scrap their cars must **return the spent batteries** to the municipality that provided them with the subsidy (Korea Herald, 2020). The Korea Automotive Recyclers Association (KARA) then collects and stores the batteries, but there is apparently no government supervision over how this is done, meaning that there are no data on collection and storage (Korea Herald, 2020). In addition, the rule only applies when subsidised EVs are scrapped, which means that there is a gap in regulation if only the battery is being discarded, as well as for unsubsidised EVs (Korea Herald, 2020).

Up to 2020 there was no regulation in the ROK relating specifically to the **recycling** of end-of-life EV batteries (Choi & Rhee, 2020). However, in July 2021, the Ministry of Environment (MOE) amended the Enforcement Decree on the Act on Resource Circulation of Electrical and Electronic Equipment and Vehicles (Presidential Decree No. 31874). The amendment delegates to the Korea Environment Corporation (KECO) the operation of four **EV battery collection centres** across the country (in Gyeonggi Province, South Chungcheong Province, Jeollabuk Province, and Daegu Metropolitan City), expected to start full-scale operation during 2022. The centres will collect, store and facilitate the recycling of used EV batteries, assessing the residual value (remaining capacity and residual life) of returned EV batteries and selling them to private companies (Enviliance Asia, 2021). In November 2020, the MOE revised the Enforcement Rules of the Wastes Control Act, adding used EV batteries to the waste type list and setting **standards** that must be met by facilities to obtain a recycling license (Enviliance Asia, 2021). The MOE was also reported to be developing **recycling centres** for spent batteries, with one already completed on Jeju Island during 2020 and two others under construction in Pohang, North Gyeongsang Province (due for completion in August 2021) and Naju, South Jeolla Province (Korea Herald, 2020).

5. CONCLUSIONS AND FUTURE POLICY OPTIONS

This final chapter discusses some of the key aspects to be addressed to improve the management of EV batteries in both the EU and the ROK throughout their life-cycle. Aspects are discussed relating to: policy, legislation and targets; battery design and information; economic and financial considerations; and international considerations.

5.1 Policy and legislative considerations

It is crucial to ensure that there are **policy and legislative frameworks** in place that put a value on the sustainability of EV batteries throughout their lifecycle (IEA, 2021a). Such frameworks have multiple purposes and impacts, including the setting of targets (for collection, reuse, recycling and so on), providing support for the development of recycled materials from EV batteries, and incentivising stakeholders throughout the battery value chain, from manufacture right through to end-of-life, to pursue the most sustainable solutions possible. Legislation also has an important role in clarifying the **priority for the management of waste EV batteries**, namely reuse, then repurposing, then recycling. Legislation should also ban the landfill or incineration of EV batteries, as is the case in the **EU**'s Batteries Directive.

It is also important to **engage stakeholders in policy-making**, to ensure that their expertise and knowledge is used in the design of policy and legislation, and also that policies have broad support. One example of this is the Global Battery Alliance (GBA), which in 2020 agreed a set of guiding principles to create a sustainable battery value chain by 2030 that have been supported by 42 organisations from the automotive, mining, chemicals and energy sectors (IEA, 2021b). They include aspects such as: maximising a battery's first life; enabling a second life use; ensuring the circular recovery of battery materials; reducing GHG emissions; prioritising energy efficiency and renewables; protecting public health, workers' rights and the environment; and supporting responsible trade.

In the **EU**, **setting (legislative) targets for recycling of lithium** from (EV) batteries (as per the proposed new Battery Regulation) will provide a major incentive for collection and recycling, supporting the development of the recycling market. Although LIBs contained in EVs should be relatively easy to track, collect and manage since vehicles are typically well-regulated throughout their life cycle, setting such recycling targets would incentivise more **efficient and effective collection**. The need for more effective and diverse collection pathways has also been identified as an issue to be addressed in the **ROK** (Kim et al, 2018). Improved collection would help to tackle the shortage of waste batteries (one of the major current barriers to recycling). This would in turn allow greater cost-effectiveness and efficiency of recycling, as well as increasing the share of secondary lithium and cobalt available for the manufacture of EV batteries (in the EU) (European Commission, 2019). It would also create a greater incentive to scale up existing recycling infrastructure in preparation for future years, when many more EV batteries will become waste. It is worth noting that some commentators suggest recycling infrastructure will develop precisely in response to the future increase in waste EV batteries, which will create economies of scale that make recycling more economically attractive. Indeed lead-acid batteries (which are used in petrol cars) are economical to recycle because of the volumes available, leading to a recycling rate of over 98% even though they are less valuable than LIBs (Castelvecchi, 2021).

It is important to have a **coherent, regularly reviewed and updated body of legislation** related to EV batteries and their management when they become waste. For example in the **EU**, there are indications that there can be confusion about how EV batteries count towards the targets of the ELV Directive and the targets of the Batteries Directive. There is also confusion over when a battery becomes categorised as waste, which has impacts for how the battery must be dealt with. Issues such as this should be addressed to ensure that targets in different pieces of legislation are complementary without overlapping, and also to ensure that waste management of batteries can be accurately monitored and reported. **It is important that legislation in the EU and the ROK is clear and unambiguous so that it can be readily and accurately interpreted by the private actors and public authorities whose responsibility it is to implement that legislation**.

With regards to **reuse and repurposing**, rules and/or guidance on secondary applications for EV batteries after they reach the end of their initial life in vehicles would help to ensure that they can be reused for those purposes. Clear and comprehensive **definitions** for EV battery components and appropriate second-life uses, together with minimum **quality standards** for used batteries would help to enable reuse and repurposing (Hill et al, 2019). Mandatory (legislative) or voluntary (business-led) **reuse and/or repurposing targets** could also be considered (Hill et al, 2019). As of 2017, there were no standards or regulations in place worldwide related to battery reuse (Tytgat & Tomboy, 2017). In the **EU**, the provisions of the current Batteries Directive have been identified as a barrier to reuse of EV batteries in other applications. However, the proposed new EU Battery Regulation will require EV batteries to have a battery management system that stores, and allows easy access to, the data needed to determine the health and anticipated lifetime of batteries.

Regarding **extended producer responsibility (EPR)**, the fees paid by producers via EPR schemes for batteries in the EU and ROK can be used to provide financial support for recycling infrastructure, helping to make recycling (more) financially viable. In the **EU**, there has been some uncertainty around EPR obligations when repurposing EV batteries, and the suggestion that greater clarity is needed on who becomes responsible for recycling when a battery is repurposed (Andersen et al, 2021). In the **ROK**, it has been proposed that the existing EPR system for batteries should be extended to all portable battery types (and specifically to LIBs), similar to the batteries EPR in the EU (Kim et al, 2018). Exchange of information between producers, consumers and governments should also be improved (Kim et al, 2018).

Options regarding policy and legislation in the EU and the ROK

Ensure policy and legislative frameworks related to EV batteries are coherent, regularly reviewed and up-to-date, place a value on the sustainability of EV batteries throughout their lifecycle, and clarify that waste EV batteries should first be reused, then repurposed, then recycled.

Ensure that legislation is clear and unambiguous with regard to its obligations and to whom they apply.

Set (legislative) targets for the recycling of lithium from EV batteries, to incentivise collection and recycling and support the development of the recycling market.

Provide guidance on secondary applications for EV batteries to facilitate their reuse and repurposing, including clear definitions and minimum quality standards.

Ensure EPR is applied to LIBs from EVs, and also that it is clear regarding who is responsible for EV batteries when they are reused or repurposed.

Consider setting targets (mandatory/legislative or voluntary/business-led) for reuse and repurposing of EV batteries.

Ensure stakeholders throughout the batteries value chain are engaged in policy-making.

5.2 Battery design and information considerations

The **design of batteries** can pose a challenge to their reuse, repurposing or recycling. If batteries are not designed for recycling, disassembly and sorting can be difficult, time-consuming, costly and even potentially dangerous. It has been estimated that current battery design means around 50-60% of materials can be recovered, but that improved design could result in rates of up to 80-90% recoverability (Oeko-Institut et al., 2021). For example, many current batteries include components that are welded together and can be difficult to break apart (The Guardian, 2021b). This can be addressed by alternative design such as fasteners that compress metal components together and can be decompressed at the end-of-life stage of the components in question (The Guardian, 2021b). The **variety of battery types** also poses a challenge, since it has an impact on exactly how the battery can be recycled. In addition, EV batteries have a lower embedded value per kWh than consumer electronics batteries, which means recyclers will need to extract more and purer material for recycling processes to be economically viable (IDTechEx, n.d. d). Nevertheless, recyclers have stated that all metals recovered from LIBs through recycling processes can be used to manufacture new LIBs, provided they are adequately purified (Oeko-Institut et al., 2021).

To facilitate reuse, repurposing or recycling, consideration could therefore be given to regulating the integration of environmental aspects into battery design, for example through **eco-design requirements** relating to battery composition and disassembly (Hill et al, 2019).

Adequate and accurate information about/labelling of batteries and their chemistry/content, modular design, and greater harmonisation of battery chemistry and design (Oeko-Institut et al., 2021), would facilitate their reuse or recycling. This would enable recycling technologies to be developed, infrastructure to be increased, and safety (both human and environmental) to be maximised, including during the transportation and storage of EV batteries at the end of their life. One approach that has been proposed would be to increase consumer awareness about batteries' recyclability by implementing a label comparable to those already in use for the energy efficiency of domestic appliances (e.g. A+, A, B, C, etc.) (Oeko-Institut et al., 2021). However, some researchers have noted that many producing companies in Japan, the ROK, China and the US are reluctant to share information, which hampers greater harmonisation of battery design and the processes and infrastructure to deal with them during their end-of-life phase (Oeko-Institut et al., 2021).

Nevertheless, significant progress is being made towards the introduction of **product passports** for batteries. This would offer a more reliable and accessible source of information relevant to reuse and recycling, to support the batteries value chain. The **EU**'s proposed new Battery Regulation would require manufacturers to provide a 'battery passport' for each EV battery placed on the market from 2026. This will be a unique electronic record linked to information about the basic characteristics of the type and model of battery which will be stored in an electronic system common across the EU (Oeko-Institut et al., 2021). This obligation would apply to any batteries or EVs imported from the **ROK** into the EU and, therefore, could have knock-on consequences for the domestic EV market in the ROK. The Global Battery Alliance (GBA) is currently working on a digital passport (possibly a QR code or RFID tag) with information on the materials (and possibly recycled content), health and remaining capacity of a battery, thereby allowing vehicle manufacturers to assess its suitability for reuse or recycling (The Guardian, 2021b). The GBA's battery passport would effectively be a 'digital twin' of its physical battery (in line with the EU's proposed requirement), and the GBA aims to develop it to be fully functional during 2022 (IEA, 2021b).

Options regarding battery design and information in the EU and the ROK

Ensure EV batteries are designed with the end of their first life in mind, to enable their reuse, repurposing, disassembly, sorting and recycling.

Consider setting eco-design requirements for EV batteries, for example relating to composition and disassembly.

Ensure that adequate and accurate information about batteries, for example through labelling.

Consider the introduction of product passports for EV batteries, e.g. as mandated in the EU's proposed new Battery Regulation, and seek harmonisation of such passports globally to ensure ease of trade.

5.3 Economic and financial considerations

Whilst reuse and repurposing activities are increasing, many are still not fully operational, or remain at the scale of smaller trials. In addition, the cost of recycling of EV batteries remains high. Further, businesses require a reasonable level of predictability before making investments. As mentioned above, keeping legislation up to date is important as it helps to provide greater certainty to businesses throughout the battery value chain. This can help to encourage businesses to develop appropriate business models to facilitate the reuse, repurposing and recycling of batteries, as well as enabling the development of appropriate collection and waste management infrastructures.

Funding for research and development (R&D) would also help to facilitate developments of this type (Oeko-Institut et al., 2021). Other **financial incentives** can also help to attract investors, such as tax credits or subsidies for certain investments, or reduced tax rates for reuse, repair or repurposing.

Options regarding economic and financial considerations in the EU and the ROK

Provide funding for R&D for the development of circular business models and recycling technologies for EV batteries.

Consider the use of financial incentives such as tax credits, subsidies or reduced tax rates to encourage investment in EV battery circularity.

5.4 International considerations

Until the costs of recycling and disposal of LIBs in the **EU** become lower, there is the risk that they (and/or the EVs that contain them) may be exported to non-OECD countries just prior to their end of life for reuse (Oeko-Institut et al., 2021). This is a plausible scenario in particular if demand for renewable energy technologies and EVs in these countries increases in the coming years. If those countries do not have stringent environmental regulations or appropriate infrastructure for the waste management of batteries and vehicles, this could have **severe environmental impacts on the importing countries**. To tackle this, it would be important to **place additional requirements/controls on the export** of used LIBs in EVs, such as quality standards requiring batteries to be "at least as good as new" in terms of their capacity or lifetime, safety measures for shipments and appropriate labelling of hazardous substances (Oeko-Institut et al., 2021).

Exports of waste EV batteries also lead to the **loss of valuable critical raw materials** from the exporting country. Although it may be economically advantageous and efficient to concentrate recycling in a small number of countries or markets, the risks, costs and environmental impacts of the transportation of waste or near-end of life EVs and/or EV batteries also need to be considered.

As noted earlier in the report, **international cooperation**, in particular between trading partners such as the **EU** and the **ROK**, would help to ensure safe and environmentally sound trade in EV batteries. Trading partners must of course be aware of the **policy and regulatory landscape** relating to EVs and EV batteries in the markets to which they export products, to ensure that any exported products meet the necessary requirements and standards. For example, the EU legislation outlined in this report applies to all batteries (or vehicles, where appropriate) placed on the market in the EU, and as such Korean manufacturers must also abide by their provisions to export their EVs or EV batteries to the EU. Deeper cooperation could also be considered. A more formal **alignment of legislation and standards** may be appropriate, and would also have the benefit of facilitating trade. **Certification schemes** that require international standards to be applied to manufacturing would enable traceability across borders (Hill et al, 2019). Other less formal types of cooperation between businesses could also be considered, for example creating **platforms to share best practices** and lessons learned from national or local initiatives (Hill et al, 2019) throughout the battery value chain.

Options regarding international considerations for the EU and the ROK

Ensure there are appropriate requirements, controls and quality standards placed on the export of used EV batteries, to reduce environmental and safety impacts on importing countries.

Ensure compliance with EV battery-related policy and regulatory frameworks in export markets.

Consider alignment of legislation and standards between trading partners (such as the EU and the ROK).

Consider the introduction of certification schemes for EV batteries based on international standards, to facilitate trade.

Create platforms to share best practices and lessons learned from national or local initiatives.

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