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Using Second Life Electric Vehicle Batteries to Store Renewable Energy

Analysis of Regulatory Aspects in Israel and Germany

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About the program

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Against the backdrop of the Paris Agreement, the program invited policy professionals from Germany and Israel to explore issues relating to the transition to low-carbon economies with the aim of fostering increased cooperation and an exchange of ideas and knowledge between relevant stakeholders from academia, civil society and the government in both countries.

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Contents

1. Executive Summary

Climate change is among the most serious and urgent threats the world faces. Immediate action should be taken to address different sectors, and Energy and Transport in particular, since they contribute the most to greenhouse gas (GHG) emissions.

The energy sector is traditionally characterized by high-emitting centralized thermoelectric fossil fuels power plants. The share of Renewable Energy Sources (RES) should be increased, despite the challenge of their intermittent and non-dispatchable nature.

The transport sector is traditionally characterized by private Internal Combustion Engine Vehicles (ICEVs). The Electric Vehicle (EV) is the best substitute for the conventional car in the short term. However, the elevated price of the battery is a major obstacle to massive EV adoption.

Environmental issues regarding End-of-Life Vehicles (ELV) solutions must also be addressed. Battery recycling is an economic, logistic, and technical challenge.

The secondary utilization of EV batteries for storing electricity from RES may simultaneously help to address the main obstacles in the energy, transport and waste-management sectors. It could provide a range of benefits for customers, utilities, and independent and regional grid operators in the energy market, including:

- Energy Arbitrage;
- Spin Reserve;
- Frequency Regulation;
- Voltage Support;

- Black Start;
- Resource Adequacy;
- Distribution Deferral;
- Transmission Congestion Relief;
- Transmission Deferral;
- Time-of-Use Bill Management;
- Increase in PV Self-Consumption;
- Demand Charge Reduction;
- Backup Power.

At the European Union level, the main regulations concerning the secondary usage of batteries are Directive 2000/53/EC (ELV Directive) and Directive 2006/66/EC (Battery Directive). In Israel there is no specific regulation regarding the management of ELV waste and the "Environmental Treatment of Electrical and Electronic Equipment and Battery Law - 2012" regulates the treatment of used batteries. However, this legislation is outdated and does not address the need for decarbonization strategies in the 21st century.

This study analyzes the environmental, economic and regulatory aspects of using second life batteries, especially with regard to providing storage solutions for RES, with an emphasis on the Israeli and German cases.

A series of regulatory improvements are recommended in this paper, including:

- Standardization of battery chemistries;
- Standardization of battery design;
- Standardization of the State-of-Health of batteries;
- Labelling of batteries;
- Transferring producer responsibility from the EV manufacturer to the body in charge of battery repurposing;

- Extending the scope of the EU ELV Directive;
- Specifically addressing batteries from EVs;
- Prioritizing secondary usage over recycling;
- Supporting recycling of non-profitable chemistries;
- Improving battery recycling efficiency;
- Subsidizing remanufacturing and repurposing;
- Focusing on e-buses;
- Encouraging demonstration projects;
- Introducing ELV regulations in Israel.

2. Rationale for Action on the Problem

Climate change is one of the most serious and urgent threats the world faces. A recent report published by the International Panel on Climate Change (IPCC) states that "rapid, far-reaching and unprecedented changes" are required to limit global warming to 1.5°C and mitigate adverse consequences.[1] Several countries have been preparing national plans to drastically reduce GHG emissions by 2050. Germany, one of the pioneers of this movement, had its Climate Action Plan 2050 adopted by the government in 2016.[2] Israel has started its own process and intends to have it backed up by a national law. These plans should address different sectors, and Energy and Transport in particular, since they contribute the most to GHG emissions.

The energy sector has traditionally been based on high-emitting centralized thermoelectric fossil fuels power plants. In order to mitigate the effects of climate change, it is necessary to follow the principles of the Energiewende, increasing energy efficiency in general and generating a rising share of electricity with Renewable Energy Sources (RES). However, given the intermittent and non-dispatchable nature of RES (such as wind or PV), further adoption will depend on reliable and efficient grid management.

The transport sector has traditionally been based on the private usage of vehicles powered by fossil fuels (mainly diesel and gasoline). Those vehicles are responsible for elevated GHG emissions, as well as poor air quality in urban centers, a proven cause of severe adverse health effects.[3] The changes in the transport sector should focus, first, on reducing the usage of private vehicles and then on replacing Internal Combustion Engine Vehicles (ICEVs) with carbon-free technologies.

The Electric Vehicle (EV) is the most promising candidate to substitute the conventional ICEV in the short term. Nevertheless, the developing industry still has to overcome difficulties to establish itself as a viable alternative. The higher upfront cost of EVs is considered to be the main obstacle to massive market penetration, with batteries being the main reason for the price difference.[4]

Furthermore, as EVs reach the end of their useful lives, environmental issues regarding end-of-life solutions for used batteries must be addressed. In Europe, most used batteries are sent for recycling, but that brings its own economic, logistic, and technical challenges.

The secondary utilization of EV batteries for storing electricity from RES may simultaneously address the main obstacles in the energy, transport and waste-management sectors. It affords the necessary flexibility to the grid, while facilitating load leveling with regard to peak loads in energy demand.[5] Adequate business models for the penetration of EV batteries in "post-vehicle" markets can also generate revenues, helping to reduce the upfront cost of EVs and increasing their penetration rate. Moreover, postponing the recycling phase for used batteries saves resources and energy while reducing waste generation.

The secondary utilization of EV batteries for storing electricity from RES may simultaneously address the main obstacles in the energy, transport and waste-management sectors.

Yet, despite of the great potential, the integration of used EV batteries into the energy grid is still the exception to the rule. Major technical, logistical, regulatory and economic challenges still need to be addressed.

This policy brief aims at analyzing the environmental, economic and regulatory aspects of using second life batteries, especially with regard to providing storage solutions for RES, with an emphasis on the Israeli and the German cases.

3. Literature Review and Policy Options

3.1 Batteries from Electric Vehicles

Batteries have been used for centuries in a wide variety of applications. Different types of batteries have been developed over that time, with different chemistries, geometries and sizes. Lithium-ion batteries are becoming increasingly popular due to their relative benefits in terms of energy density, weight and lifetime. They are the standard choice for an EV battery.

Not all lithium-ion batteries are the same, however; they may differ from each other in terms of size, shape and chemistry. Each chemistry has advantages and disadvantages, and the same holds true for designs. Thus, a variety of batteries can be found in the EV market.

Most of the raw materials for lithium-ion batteries are non-renewable minerals obtained through mining, predominantly lithium and cobalt. Most lithium mines are concentrated in South America, and lithium extraction is highly dependent on water, which may become contaminated during the process. More than half of the cobalt reserves in the world can be found in the Congo, and their exploration has been linked to environmental and human rights abuses.[6] In addition, the battery manufacturing process is highly energy consuming.

There are therefore environmental and social reasons to maximize the usage of existing batteries, in order to avoid the production of new ones.

3.2 Second Life of Batteries

A battery's performance decreases over time. Factors such as age, the number of charging cycles, charging and discharging patterns, and exposure to extreme temperatures may affect the depreciation rate of a battery's capacity. However, several studies suggest that EV batteries reach the end of useful life in a car after 8 to 10 years with still about 80% of their initial capacity. [7]

While batteries with reduced capacity will significantly limit the range of an EV and may not be suited to vehicle usage, they can still be used in other less demanding, stationary applications, such as the storage of RES energy.

Used batteries can be reused in various applications, depending on their State of Health (SoH).[8] Batteries with a high SoH could be reused in another EV. Batteries with lower SoH could be reused in a secondary application, such as storing energy from RES.

Several studies suggest that EV batteries reach the end of useful life in a car after 8 to 10 years with still about 80% of their initial capacity.

It should be noted, however, that used batteries can't just be taken out of a vehicle and used, as is, in other applications. For reuse in EVs, a remanufacturing process is required, in which damaged battery cells are replaced with new ones. For secondary applications, a repurposing process is required to develop a new control management system, reconfigure the cells, and, possibly, dismantle the batteries and reorganize the packs into the desired configuration. According to Reid & Julve, remanufacturing costs range between 25 and 50 €/kWh.[9]

While the battery is being used in a secondary application, its SoH will continuously decrease. The empirical data on the length of the second life is still limited, but a Bloomberg report suggests that those batteries can still be used for another 7 to 10 years.[10] A battery should only be recycled when it reaches a SoH that doesn't allow it to be used further.

3.3 Transport Sector

With an oil dependency of 96%,[11] the transport sector is one of the main sources of GHG emissions. EVs are expected to replace ICEVs in the medium term. Israel has set itself the ambitious goal of having 100% sales of EVs for private cars by 2030.

However, the change is still happening at a slow pace. EVs are still more expensive than ICEVs, and batteries represent the most costly element of EVs. Despite the notable advancements in battery technology and decreasing production costs in recent years (from around 1,000 US$ per kWh in 2008 to 350 US$ per kWh in 2016),[12] the widescale introduction of EVs is not expected to take place until the mid-2020s, when EVs and ICEVs are forecasted to achieve price parity. Indeed, about 2 million EVs were sold worldwide in 2018, and forecasted sales will reach 10 million in 2025 and more than 50 million by 2040.[13] Figure 1 presents the forecast for global vehicle sales by drivetrain, where ICE stands for Internal Combustion Engine, PHEV for Plug-in Hybrid Electric Vehicle and BEV for Battery Electric Vehicle.

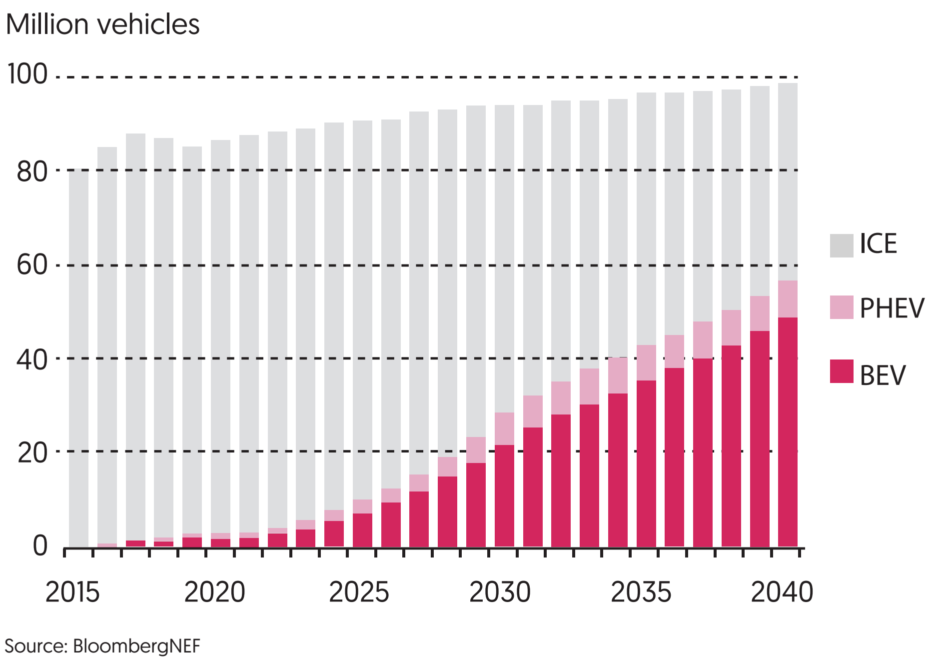

Figure 1. Forcast for global vehicle sales by drivetrain [14]

Additional efforts should be made to reduce the price of batteries. The creation of a secondary market for used batteries has the potential to add value to a component that would otherwise need to be recycled at a cost. Neubauer & Pesaran suggest that reuse pathways ensure a resale value for reused batteries, ultimately reducing the upfront costs of EVs.[15]

Additional efforts should be made to reduce the price of batteries. The creation of a secondary market for used batteries has the potential to add value to a component that would otherwise need to be recycled at a cost.

The expected lifespan of an EV is not yet determined. There are still not enough EVs on the market, and most of them are still in their first service life. Oguchi & Fuse observed a wide variation in the lifespans of ICEVs even within Europe, ranging from 13 years in Ireland to 22 years in Finland. The average lifespan of a vehicle in Germany was found by the same study to be 13.7 years.[16]

The warranty granted by EV manufacturers can serve as an indicator. Tesla, the leading EV seller in Europe, has a warranty of 8 years or 192,000 kilometers for the Tesla 3 model. A major car importer in Israel gives a battery warranty of 8 years or 160,000 kilometers. Canals & Casals suggest that most car manufacturers grant battery warranties of 8 to 10 years or 100,000 to 150,000 kilometers.[17]

Virtually all major car manufacturers are increasing their portfolio of EV models. As power density increases and battery prices continue to fall, the next generation of EVs is expected to have a higher battery capacity.

3.4 Potential Storage Capacity of Second Life Batteries for EVs

The above developments raise the question of how much storage capacity second life EV batteries will be able to provide. While it seems undisputable that EVs will become the dominant type of road vehicles in the coming years, predicting the storage capacity available from second life batteries is a difficult task, since it is highly dependent on uncertain factors. A simulation for the case of Israel was made in this study based on the following assumptions:

1. **EV introduction rate**: Starting at 1% at 2020 and achieving 100% by 2030 (according to the Ministry of Energy's plans).
2. **EV battery capacity**: 40 kWh.
3. **Service life:** 10 years.
4. **Fleet size**: 3 million private vehicles.
5. **State of health of the batteries**: 80% of initial capacity.

Figure 2 presents the forecasted accumulative EV sales and the accumulative potential storage capacity provided by those vehicles' second life batteries in Israel. The potential for storage grows at a fast pace, reaching 5.3 GWh in 2035. Five years later, in 2040, capacity has increased seven-fold to 35.8 GWh – enough to power the whole country for 2.5 hours.

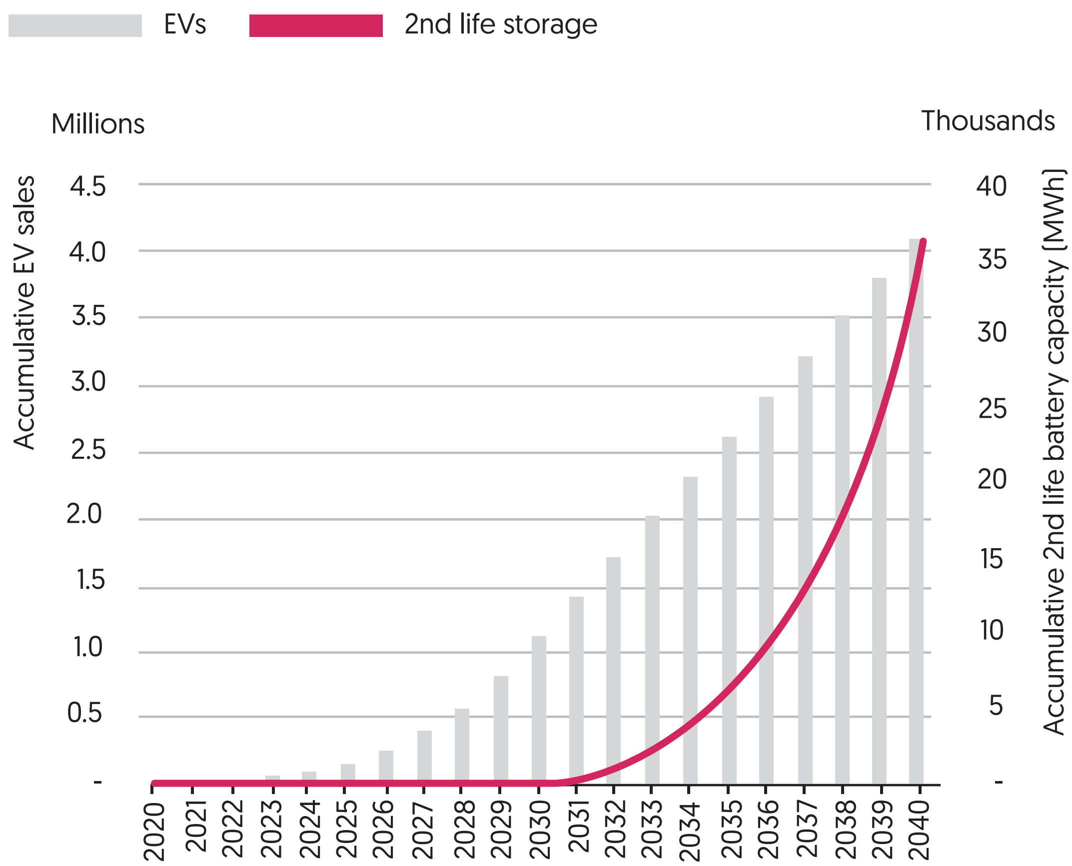

Figure 2. Forecast for EV sales and capacity of 2nd life batteries in Israel

Second life batteries from electric buses have certain advantages over their equivalents in private cars. First, the electrification of urban buses will happen sooner. Second, the segment of urban buses in public transportation is more regulated and closely controlled by public authorities. Third, each bus battery is significantly larger than a battery from a private car. Fourth, all urban buses are operated by only a few operators, making battery collection easier. Fifth, since the whole population of urban buses comprises only a few models, standardization of batteries is more likely.

Figure 3 presents the forecasted accumulative sales for e-buses in Israel and the accumulative potential storage in Israel. The following assumptions were made:

1. **E-bus introduction rate**: starting at 20% at 2020 and achieving 100% by 2025.
2. **E-bus battery capacity**: 300 kWh.
3. **Service life:** 10 years.
4. **Fleet size**: 6,000 urban buses.
5. **State of Health of the batteries**: 80% of initial capacity.

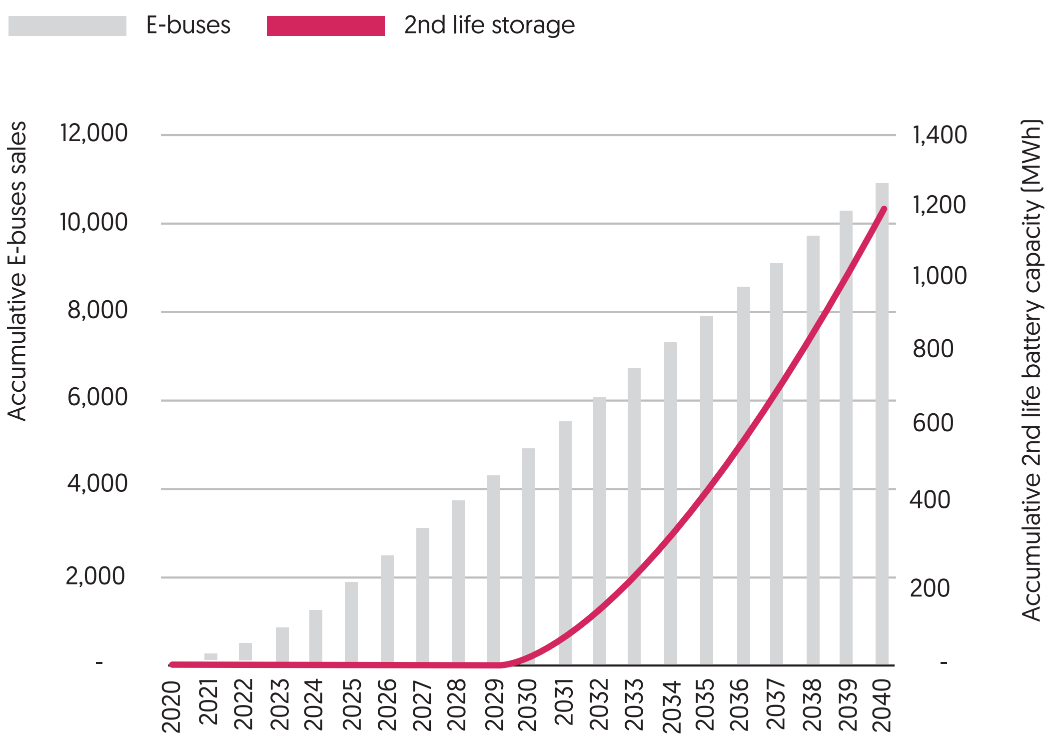

Figure 3. Forecast for e-bus sales and capacity of 2nd life batteries in Israel

The accumulative storage capacity in 2035 is 461 MWh, and 1,181 GWh in 2040. Just 6,000 buses can provide 8% of the total storage capacity provided by 3 million private vehicles by 2035.

3.5 Energy Sector

Electricity systems have traditionally relied on centralized power plants powered by coal or natural gas, which are generally located far from end users, and have adverse environmental impacts on a local, regional or global level. This is also the case for both Germany and Israel. Total CO_2 equivalent emissions from Germany were 902 Mt in 2014, with 40% due to electricity generation.[18] In Israel, recent annual total CO_2 emissions are 77 Mt, and the electricity sector accounts for 60%.[19]

Proper functioning of the electricity grid requires that, at any given moment, the electricity supply must meet electricity consumption. While a constant load profile – or one with known and smooth variations – would be ideal, this is far from the reality. In fact, energy generation has to follow a highly fluctuating profile characterized by fast ramping up or down, which can sometimes be unpredictable.

Without the advent of storage solutions, various techniques have been used to deal with this challenge. On the supply side, they include turning power stations on or off, increasing or decreasing generation loads, or importing and exporting energy when possible. On the demand side, techniques to encourage a shift in consumption from peak hours to hours of lower demand (nighttime or weekends) are used, such as differential tariffs for electricity.

Israel's total electricity consumption in 2017 was about 67 TWh. By dividing this value by the number of hours in a year, it becomes evident that average hourly consumption was about 7,650 MW, about 40% lower than peak consumption. Installed capacity provides for more than twice the average consumption.

In Germany, renewable energy accounted for 31.6% of the electricity consumed in 2016,[20] while in Israel, this figure was only about 7%. The targets the two countries have set for 2030 are, respectively, 50% and 17%.

Most of the electricity from RES used today is provided by wind power (in Germany) or solar PV (in Israel). Those two sources are non-dispatchable, characterized by an intermittent and unpredictable generation profile. That means that increasing the share of RES in the electricity system calls for greater overall flexibility. Castelnuovo & Vazquez indicate that different mechanisms can provide that flexibility: improved demand-side management, smart grids, flexible thermoelectric generation, but energy storage is regarded as a "game changer" for future electricity systems.[21]

Energy storage is regarded as a key element for the efficient management of modern grids. It is the only option that provides the required flexibility when dealing with an elevated share of intermittent renewable energy.

In fact, energy storage is regarded as a key element for the efficient management of modern grids. It is the only option that provides the required flexibility when dealing with an elevated share of intermittent renewable energy. Different storage technologies are already available today. According to Castelnuovo & Vazquez, examples include thermal, mechanical (pumped hydro-power, compressed air or flywheel), chemical (hydrogen and power-to-gas), electrical (double-layer capacitors and superconducting magnetic energy storages), or electrochemical (batteries).[22]

Today, stored hydropower is the most widespread energy storage system in the world.[23] Batteries, however, can offer advantages over the other technologies. For example, they can quickly respond upon request; they can be used as an advance control mechanism due to their ability to charge or discharge; they occupy little space; and they offer the possibility of decarbonizing the transport system simultaneously. They can also serve as a catalyst for decentralizing grids.

Decentralized systems reduce the costs of building and maintaining transmission (and potentially also distribution) infrastructure. They also reduce losses in transmission (usually estimated at about 5–15%). Moreover, they allow for coupling of the power and heat sectors (since heat can't be transported over long distances), increasing the overall efficiency of the process.

3.6 Services Provided by Storage

Energy storage can provide a variety of services to the electricity system. Moreover, stakeholders at all phases (generation, transmission, distribution and retailing) can benefit from it. Figure 4 presents a classification of the services provided by energy storage by the European Association for Storage of Energy (EASE).

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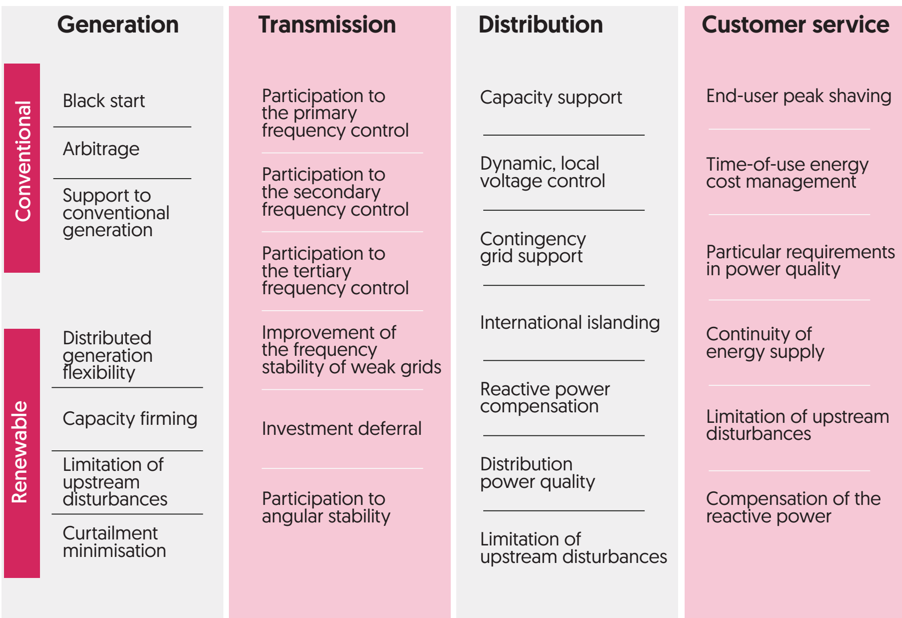

Figure 4. Services provided by energy storage (European Association for Storage of Energy)

Castelnuovo & Vazquez studied the policies and regulations pertaining to energy storage systems and suggest that electricity storage services can be classified into two major "arenas": [24]

- Time arena: relates to buying and selling energy in different periods (including ancillary services).
- Location arena: relates to avoiding the need to transport energy from one point to another (including reducing the usage of transmission and distribution networks).

Researchers from the Rocky Mountain Institute have analyzed the economic aspects of battery storage. They found that three stakeholder groups – customers, utilities, and Independent System Operators (ISO) and Regional Transmission Operators (RTO) – may benefit from up to thirteen services provided by batteries: [25]

1. **Energy Arbitrage**: purchasing energy when prices are low, and storing, selling or using it when prices are high;
2. **Spin Reserve**: the capacity to quickly meet demand in case of unexpected grid situations;
3. **Frequency Regulation**: immediate response in order to guarantee the required standards of frequency. Batteries are especially suited for this task due to their ability to quickly ramp up or down;
4. **Voltage Support**: immediate response in order to guarantee the required standards of voltage;
5. **Black Start**: restoring operations at large power stations in case of a general outage;
6. **Resource Adequacy**: decreasing the need to invest in power plants to meet generation requirements during peak consumption;
7. **Distribution Deferral**: decreasing the need for utility investment in distribution systems;

8. **Transmission Congestion Relief**: relieving congested transmission lines at certain times;
9. **Transmission Deferral**: decreasing the need for utility investment in transmission systems;
10. **Time-of-Use Bill Management**: reducing the electricity bill by shifting consumption to times when the price of electricity is low;
11. **Increase PV Self-Consumption**: minimizing consumption of grid electricity by storing energy during hours of solar incidence and consuming at nighttime.
12. **Demand Charge Reduction**: in some places, demand charges are set based on the highest demand of a certain period. Using batteries to reduce peak demand can lead to drastically reduce electricity costs;
13. **Backup power**: In the event of grid failure, batteries can provide backup power in multiple scales for industrial facilities, hospitals and residential areas.

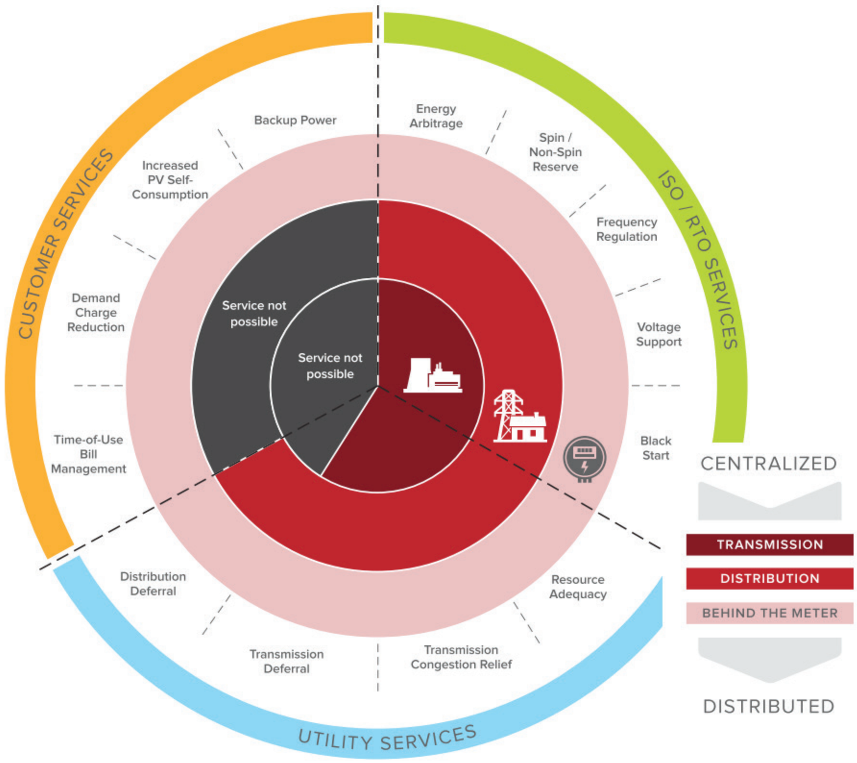

Figure 5. Services provided by energy storage and benefited stakeholders[26]

3.7 Regulation of Vehicular Waste Management

In the European Union there are two major regulations governing the management of waste from vehicles that reach the end of service life and their batteries:

- Directive 2000/53/EC - the End of Life Vehicles (ELV) Directive
- Directive 2006/66/EC - the Battery Directive

The ELV Directive (Directive 2000/53/EC) regulates the management of the waste generated by End of Life Vehicles in the EU. It was established in September 2000 and its objectives are:

"*as a first priority, at the prevention of waste from vehicles and, in addition, at the reuse, recycling and other forms of recovery of end-of life vehicles and their components so as to reduce the disposal of waste, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles and especially the operators directly involved in the treatment of end-of life vehicles.*" [27]

The Directive is based on the concept of Extended Producer Responsibility (EPR), i.e. the costs of managing the waste are covered by the agent that put the vehicle on the market (manufacturer or importer). Member states are required to introduce national legislation on recycling and to ensure that the Directive is being implemented on their territories.

The ELV Directive also sets targets for recycling ELV. It urged member states to reach recovery rates of at least 85% and recycling rates of 80% by 2006, rising to 95% and 85%, respectively, by 2015.

Despite the wide variety of vehicle categories, the ELV Directive applies only to M1 (vehicles for transporting passengers with up to 9 seats), N1 (vehicles for transporting goods weighing up to 3.5 tons), and three-wheel motor vehicles. This means that vehicles used for transporting more than 9 passengers (minibuses, buses) or goods weighing in excess of 3.5 tons (medium and heavy trucks) as well as other categories are not covered by the ELV Directive.

The Battery Directive (Directive 2006/66/EC) covers various types of batteries, including those removed from ELV and handed over to recyclers for further treatment.

The purpose of the Battery Directive is to establish rules regarding the placing of batteries and accumulators on the market and the collection, treatment, recycling and disposal of these devices. To that end, the Battery Directive defines limits for the usage of hazardous materials in batteries, stipulates how batteries should be labelled, and sets targets for the collection, treatment and recycling of waste batteries.

The Battery Directive differentiates between different types of batteries, including:

- Automotive battery or accumulator: "any battery or accumulator used for automotive starter, lighting or ignition power".
- Industrial battery or accumulator: "any battery or accumulator designed for exclusively industrial or professional uses or used in any type of electric vehicle".

This means that all the batteries classified as "automotive" are the lead-acid batteries present in ICEV. The batteries used in electric vehicles fall under the category of "industrial batteries".

Like the ELV Directive, the Battery Directive is based on the concept of EPR. While this measure makes sense when it comes to guaranteeing that used batteries are recycled, it can serve as a barrier to a second life for these batteries, since manufacturers are discouraged from selling or reusing ELV batteries, and instead consider them waste.

The labelling system stipulated by the Battery Directive does not capture the different chemistries used in EVs, where dedicated recycling techniques may be necessary. More comprehensive labelling with reference to the li-ion electrochemical systems (like LTO, NMC, NCA, LMO or LFP) could facilitate the process of disassembling and dealing with used batteries.

It should be noted that there is no official definition of "second use," and it is not explicitly mentioned in the Batteries Directive.

In Israel there is no regulation specific to the management of ELV waste. A related regulation addresses vehicle dismantling facilities, and requires them to have an appropriate business license for dealing with hazardous materials. Vehicles that reach the end of useful lives must first be deregistered with the Ministry of Transportation. Then, they are taken to a dismantling facility, where they are dismantled and the different parts sold separately.

Where used batteries are concerned, the relevant regulation is the "Environmental Treatment of Electrical and Electronic Equipment and Battery Law - 2012" (Israel's Battery Law). It is based on the principle of EPR and the main goals are to encourage reuse of electric and electronic equipment, to reduce the amount of waste generated, to increase the share of recycling, and to establish treatment conditions for generated waste.

Since batteries are considered hazardous waste, both regulations pertaining to the management of hazardous waste apply to them: Regulation for Business Licensing (1990) and the Regulation for Hazardous Materials (1994). There is no recycling facility for lithium-ion batteries in Israel, so the used batteries are collected and sent to recycling facilities in Europe, with the expenses covered by the importer.

The current market for lithium-ion batteries is still not well developed. Only a few companies in Europe commercially recycle lithium-ion batteries. In addition, the recycling efficiency of lithium-ion batteries ranges from 50% to 80%, considerably lower than that of lead-acid batteries (which reaches about 97%). Stricter requirements in the Battery Directive could increase recycling efficiencies.

Furthermore, the recycling of specific chemistries is more profitable than others. For example, there is a relatively profitable secondary market for cobalt. But the recycling of non-cobalt chemistries can be unprofitable, and the incentive to recycle is therefore low. Efforts should be made to promote the concept of recycling and the circular economy.

3.8 Circular Economy

According to the European Parliament, Circular Economy is "an economic model based inter alia on sharing, leasing, reuse, repair, refurbishment and recycling, in an (almost) closed loop, which aims to retain the highest utility and value of products, components and materials at all times". In practice, the goal is to reduce waste to a minimum, keeping used materials in the economy wherever possible, and creating further value. Figure 6 illustrates a "waste hierarchy" pyramid. In this logic, reusing is ranked higher than recycling.

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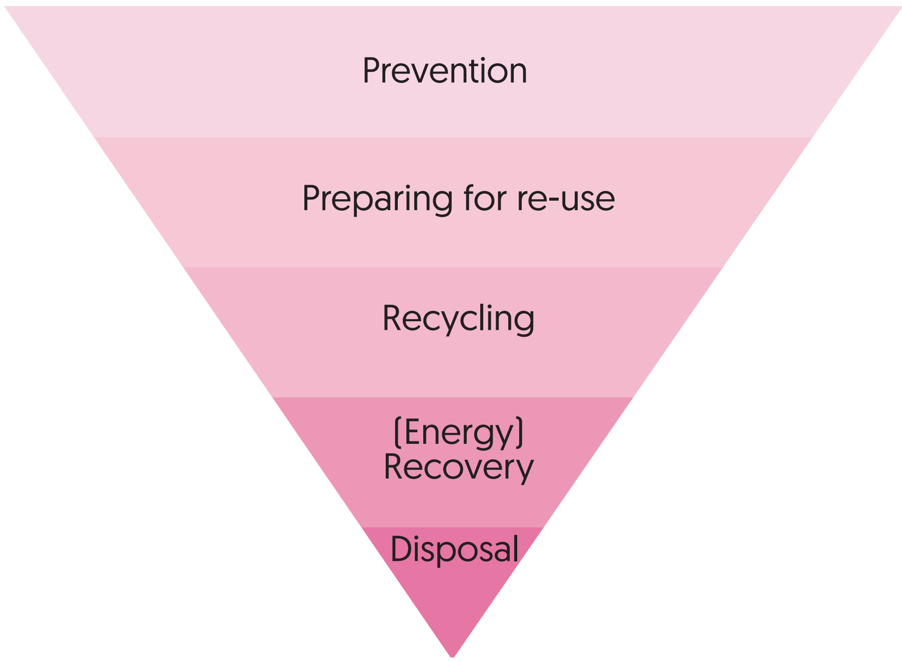

Figure 6. Waste hierarchy [28]

End-of-life batteries from EVs can be reused in other secondary applications. The main factor that determines the destination of these batteries is the current SoH after the first use. Batteries with an elevated SoH after the first life could potentially be reused in EV applications. Batteries with a lower SoH could be used in another less demanding applications, such as stationary storage of RES. Batteries with very low SoH may not be found suitable for reuse, and should be directly recycled.

One of the more comprehensive studies conducted on the subject proposes a pathway that prioritizes the following: first, closed-loop direct reuse in EV applications; second, open-loop cascaded use in stationary applications; third, recycling of the batteries; and fourth, landfill of the materials not reused or not recycled. [29]

Figure 7 presents a proposed waste management hierarchy for used EV batteries, which was developed for the current study. Materials obtained from mining are used to manufacture batteries, which are used in first life EV applications. After the first life, the SoH is used to determine the destination of used batteries. Batteries with high SoH are remanufactured and used again in EV applications. Those with medium SoH are repurposed and used in second life stationary applications. Batteries that reach low SoH are taken to recycling. Extracted materials are used for manufacturing new batteries, and non-recyclable materials are sent to landfills.

Batteries with high SoH are remanufactured and used again in EV applications. Those with medium SoH are repurposed and used in second-life stationary applications. Batteries that reach low SoH are taken to recycling.

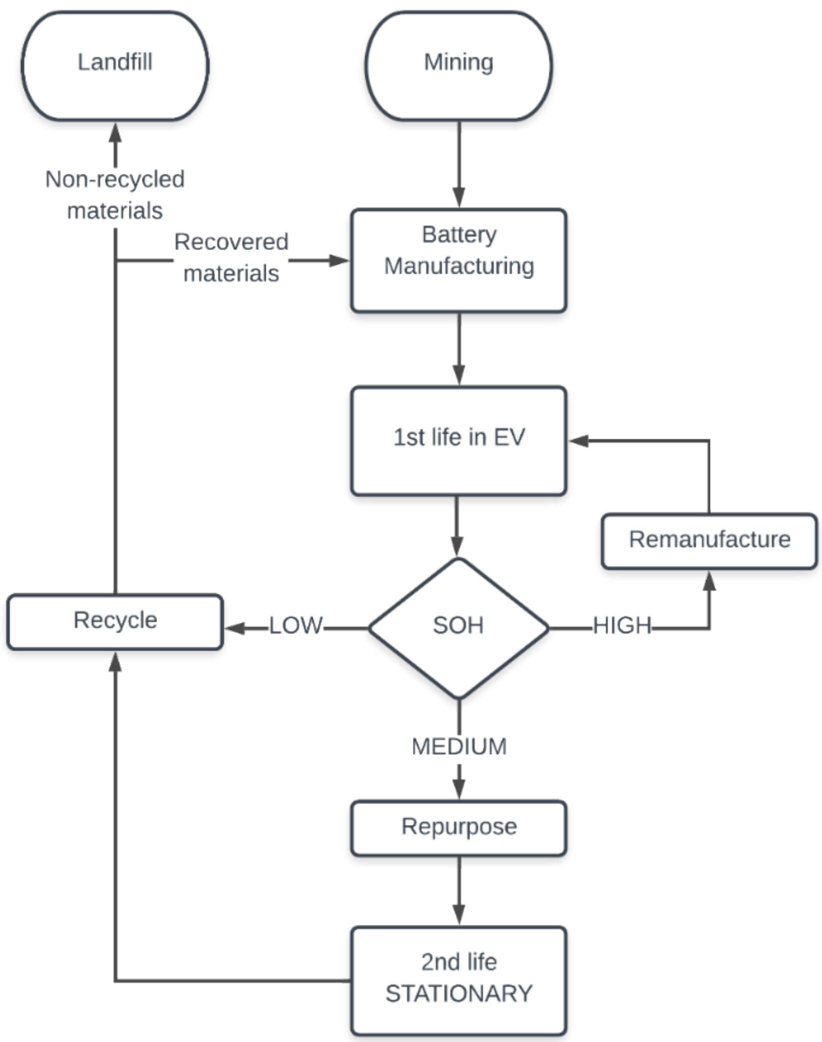

Figure 7. Proposed waste management hierarchy for used EV batteries

While being used in a secondary application, the SoH of a battery will continue to decrease to the point where the battery is no longer suitable for usage. The length of the second life is still not well established. It depends on many different factors throughout its lifespan, including the first life and the quality of the repurposing/remanufacturing process. Moreover, since relatively few batteries have been used in real secondary applications, not enough empirical data are available at present.

While secondary applications can optimize the usage of a battery, eventually, the second life batteries will reach the end of their useful life. Thus, in the end, all batteries should be recycled.

The secondary usage of EV batteries is associated with a series of environmental and economic benefits over the entire lifecycle of a battery. It reduces the need to purchase new batteries, either for EV applications (in the case of direct reuse) or for stationary applications (in the case of a cascaded usage). This measure alone reduces the environmental damage (saving energy, resources and water) and the social damage associated with the production process. Also, it lengthens the useful life of a battery, postponing the need for recycling. In this way, it buys more time for the recycling infrastructure to improve.

4. Policy Recommendations

As presented throughout this policy brief, the usage of second life batteries from EVs has the potential to provide environmental and economic benefits to the Transport, Energy, and Waste Management sectors. The current regulation on lithium-ion batteries from EVs and their potential for secondary application is not appropriate for future needs. Well-defined regulations to deal with the large amount of lithium-ion batteries from EVs need to be established.

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In this section, the main existing barriers are identified, and policy recommendations are made, categorized by the scope of the target policymaker groups: European Union or national government levels (Germany or Israel).

4.1 Scope of the European Union

1. Standardization of battery chemistries

Different battery chemistries are currently in use. This situation presents technical and logistical challenges for the remanufacturing, repurposing and eventual recycling of batteries.

Standardization of battery chemistry and shape could help solve these problems. Ideally, it should be synchronized with North American regulation.

2. Standardization of battery design

Currently, batteries come in various shapes and sizes, which presents technical challenges for the removal, disassembling, repairing, repurposing and eventual recycling of used batteries.

Thus, it is proposed that standardization norms regarding the size and shape of batteries are established.

3. Standardization of the State of Health of batteries

The SoH of a battery is the most important factor that determines its destination for secondary application, but there is no consensus or regulation regarding the methods used to assess it.

The methods used to assess the SoH should be standardized, as well as boundary values for specific applications and safety concerns.

4. Labelling of batteries

The EU Battery Directive requires labelling in a way that is not appropriate for EV batteries.

The Directive should stipulate labelling that includes specific chemistries used in lithium-ion batteries from EVs (such as LTO, NMC, NCA, LMO or LFP). This could help to identify, separate and deal appropriately with different batteries.

5. Transferring producer responsibility

Both the EU Battery Directive and Israel's Battery Law are based on the concept of EPR. While this aims to increase the collection and recycling rate of batteries, it fails to provide incentives for secondary usage.

It is thus proposed to establish a mechanism to transfer the responsibility from the EV manufacturer/importer to the body responsible for the secondary usage when the battery undergoes repurposing.

6. Extending the scope of the ELV Directive

The EU ELV Directive applies only to light vehicles and three-wheel motor vehicles.

The ELV Directive should be updated at the European level to include all vehicle categories, including medium and heavy trucks, minibuses and buses, as well as Non-Road Mobile Machinery (NRMM).

7. Specifically addressing batteries from EVs

Both the EU Battery Directive and Israel's Battery Law don't directly identify and address batteries from electric vehicles. Instead, they are classified as "industrial batteries".

Specific regulation on batteries from EVs should exist. The European Union could create such regulation by 1) updating the Battery Directive; 2) updating the ELV Directive; or 3) creating a new directive. Israel should use the same approach as the European Union, since the majority of vehicles in Israel comply with the European type approval regulation.

8. Prioritizing secondary usage over recycling

The EU Battery Directive and Israel's Battery Law set goals for placing on the market, collection, treatment, recycling, and disposal of batteries and accumulators. Neither regulation mentions secondary usage of batteries.

The EU Battery Directive and the Israel's Battery Law should be updated to define the term "secondary usage" and establish ambitious targets for secondary usage. Economic incentives might be given in the beginning.

9. Supporting recycling of non-profitable chemistries

Lithium-ion batteries can be made of various materials, some of which are more lucrative to recycle than others.

Economic incentives for recycling lithium-ion batteries should be created to provide price parity for raw materials from non-profitable chemistries.

10. Improving battery recycling efficiency

The EU Battery Directive sets targets for recycling efficiencies of 50% for EV lithium-ion batteries (included in the "other waste batteries").

Lithium-ion batteries should be specifically addressed, and increasingly high recycling efficiencies should be required. R&D programs for improving the efficiency and reducing the costs of recycling could be encouraged.

11. Subsidizing remanufacturing and repurposing

The process of remanufacturing or repurposing a battery can include dismantling, redesigning and reconditioning it to the new application. The current costs of these processes can be relatively high.

Economic incentives should be created for battery remanufacturing and repurposing.

4.2 Scope of National Government (Germany and Israel)

12. Focusing on e-buses first

Second life batteries from e-buses have five advantages over those from e-cars: 1) faster electrification process; 2) more regulated and controlled; 3) larger batteries per vehicle; 4) few operators owning thousands of e-buses; 5) few e-bus models.

Specific policy focusing on e-buses batteries should be developed, setting targets for the collection and reuse of the batteries.

13. Encouraging demonstration projects

The number of projects and companies dealing with the secondary usage of batteries from EVs is still very limited.

Specific programs to encourage demonstration projects should be created. These programs should focus on both academic institutions performing basic and applied research, as well as on small and medium companies performing pilot projects and trying to scale up.

4.3 Scope of the Government of Israel

14. Creating ELV regulation in Israel

There is currently no specific regulation governing the management of ELV waste in Israel.

Israel should create a specific regulation to deal with waste from ELV. It could be based on the EU ELV Directive, but should be more ambitious. All the related recommendations for improving the European ELV Directive cited in this paper should be adopted.

5. Conclusion

In order to limit global warming and avoid catastrophic consequences, drastic action is required very soon. This action should be primarily directed at the sectors responsible for most GHG emissions, namely Energy and Transport.

Second life batteries from electric vehicles can still be used for various applications, such as storing energy from RES. They are therefore a means to simultaneously reduce the carbon footprint of both the transport and energy sectors. The creation of a secondary market will reduce the upfront cost of EVs, accelerating their massive adoption. Storage solutions provide up to 13 different services in the electricity system, including the flexibility to integrate large shares of renewable energy. Moreover, they exemplify the circular economy, reducing the need to manufacture unnecessary batteries and the pressure on the recycling industry.

The current regulations regarding the usage of secondary batteries in Germany and in Israel are outdated and that do not address the need for decarbonization strategies in the 21st century. A series of regulatory improvements are recommended, including: standardization of battery chemistries; standardization of battery design; standardization of the SoH of batteries; better labelling of batteries; transferring producer responsibility; extending the scope of the ELV Directive; specifically addressing batteries from EVs; focusing on e-buses, prioritizing secondary usage over recycling;

supporting recycling of non-profitable chemistries; improving battery recycling efficiency; subsidizing remanufacturing and repurposing; and encouraging demonstration projects.

In a fast-changing world, regulators should adopt be proactive and prepare the regulatory framework to deal with the foreseen changes as early as possible. Because there is just no time to waste.

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