INSIGHTS

POLICY FORUM

PHOTO: REUTERS/WOLFGANG RATTAY

RESOURCE POLICY

Global implications of the EU battery regulation

A much-needed law may have unintended global consequences

By **Hans Eric Melin[1], Mohammad Ali Rajaeifar[2,3], Anthony Y. Ku[4,5], Alissa Kendall[6], Gavin Harper[3,7], Oliver Heidrich[2,3,8]**

Transport electrification is a key element of decarbonization strategies; thus, the design, production, manufacture, use, and disposal of lithium-ion batteries (LIBs) are taking center stage. The environmental, economic, and social consequences of the battery life cycle are high on political agendas, owing to exponential growth in metals extraction; the climate impacts of battery production; and uncertainties in battery end-of-life (EOL) safety, recyclability, and environmental consequences (*1*) [see figs. S1 to S3 in the supplementary materials]. The European Union (EU) has proposed a new Battery Regulation (*2*) that intends to ensure sustainability for batteries placed on the EU market (see the figure), developing a robust European battery industry and value chain. The Regulation is very much needed, but, as discussed below, it will have global implications, with perhaps some unintended consequences. If left unaddressed, the Regulation, at worst, could hamper climate change mitigation targets and fall short of its intentions to promote a circular economy and establish a socially acceptable raw material supply chain.

The proposed Regulation will build upon and replace the 2006 EU Battery Directive (*3*) to address this era's challenges, stipulating labeling and information provisions, setting out supply chain due diligence requirements, and enforcing the use of recycled materials for batteries over 2 kilowatt-hours (kWh), most of which are used in electric vehicles (EVs). Historical data show an almost 10-fold increase of LIBs placed on global markets in the past 10 years (see figs. S4 and S5), and a similar growth rate is expected during this decade (see fig. S1). Therefore, it is imperative to address the global climate change challenge and battery issues in tandem (*4*–*6*).

Despite being the second-largest market for EVs in the world, Europe does not dominate LIB supply chains, instead relying on global markets for raw material extraction, refining, and battery manufacturing (*7*).

Voltage of a used lithium-ion car battery is checked by an employee of the German recycling firm Accurec in Krefeld, Germany, 16 November 2017.

From the moment the Regulation enters into force, potentially in 2023, producers and importers of batteries will need to comply with the Regulation to sell or use batteries on the European market. EVs not only help achieve global carbon reduction targets; they also serve as a driver of growth and job creation in Europe (*8*), the United States (*9*), China (*4*), and a few other markets such as South Korea and Japan. As such, the Regulation must balance concerns about environmental stewardship with regional interests in economic competitiveness. The Regulation thus comes with explicit aims to obtain a global competitive advantage, build barriers to entry, and provide incentives to invest in production capacity for sustainable batteries.

The new Regulation (*2*) brings European legislation up-to-date, anticipating near-term developments (in 2035) (see fig. S6). We distill the Regulation's 79 Articles into four key elements that are core to improving the sustainability of LIBs. First, the Regulation intends to increase transparency and traceability across the battery life cycle (e.g., Articles, 10, 47, and 65; see the figure), mandating third party due diligence of the supply and value chains for batteries >2 kWh (e.g., Articles 8, 39, and 72). Second, it addresses climate impact throughout the battery life cycle (e.g., Article 7) by mandating carbon footprint declaration and later establishing maximum thresholds. These first two elements seek to ensure the quality and availability of underlying data needed to guide environmental responsibility and track compliance by industrial players. Third, concrete actions to promote the circularity of critical materials are emphasized (e.g., Articles 47, 55, and 57), targeting increased collection and recycling efficiency; improving recovery rates for lithium, cobalt, and nickel; and mandating the use of recycled materials in new batteries (e.g., Articles 8, 55, and 59). Fourth, requirements for longevity and performance management are proposed, including access for waste processors to the battery management system (BMS), which verifies the state of health of the battery in real time and can determine the potential for the battery to be reused or repurposed before being recycled (e.g., Articles 51, 59, and 65; see the figure). These last two elements provide a foundation for EU efforts to establish circularity as an economic opportunity aligned with its long-term sustainability objectives.

A GLOBAL SYSTEM

In addition to the proposed Regulation, the European Commission is supporting battery developments through a range of initiatives such as the creation of the European Battery Alliance and financial aid packages to support research and innovation along the entire battery value chain (*4*). Under the label "open strategic autonomy," the union seeks to combine free trade with an ability to manage its own destiny in key sectors. The LIB market is dominated by Chinese companies, which occupy more than two-thirds of the supply chain (*7*), including resources outside of China. The United States market has, through Tesla, been on the forefront of large-scale battery production but has, like Europe, failed to secure key elements of the supply and value chain such as refining, production, or recycling of battery materials (see fig. S7). The regulatory environment in each market will play a key role as electrification of the transportation sector intensifies.

In China, the LIB market has profited from rapid growth in the EV sector, fueled by strong government support in the form of both subsidies and investment stimulus. A whole-of-government approach has provided clear strategic guidance; and the Interim Measures for the Administration of the Recycling and Utilization of Power Batteries for New Energy Vehicles from 2018 reflect a number of the themes found in the EU Regulation (*10*). These included minimum standards for the reclassification of batteries for reuse applications, the recycling efficiency of plants treating batteries at the EOL, and requirements for product labeling to qualify for subsidies. In 2019, these regulations were tightened to levels stricter than those the EU Regulation plans to enforce a decade from now (*2*). In December 2020, China's State Council issued "Energy in China's New Era," a blueprint for energy sector development through 2030. It includes guidance on the development of battery supply chains, including recycling to support energy efficiency, and provisions for reducing the carbon intensity of electricity used to power EVs (*9*).

In the United States, electrification of transportation, and the supply of critical materials that enable it, has been declared a top priority of the Biden administration. This is reflected in an investment proposal of up to $174 billion in EV programs focused on reestablishing primary metals refining and manufacturing in the United States, and creating new recycling capabilities as part of materials criticality efforts. In the policy arena, however, the United States lags both the EU and China in mandating Extended Producers Responsibility or promoting circular economy principles other than basic legislation to keep batteries classified as hazardous waste out of landfills and incinerators.

CHALLENGES TO OVERCOME

Current battery legislation in all three major markets—China, the EU, and the United States—is geared toward the protection of local environment and human health. However, the scopes of China's and the EU's policies include measures that, directly or indirectly, give companies that manage to comply important competitive advantages both domestically and globally, the mandatory recovery rates for recyclers being a standout example (see table S1). An important distinction arises, however, in the manner by which Chinese and EU regulations affect the global value chain. Compared to the EU, China has more direct leverage owing to its dominance in materials refining, battery material and cell production, and a much more mature recycling infrastructure. Although tougher requirements for placing batteries on the European market force players around the world, including the EU, to comply, the domestic requirements imposed on the Chinese companies have already helped them do that.

This imbalance between new and mature markets is one of several factors that can lead to unintended consequences, such as described below, not just in Europe but globally, when a nascent market is shaped by regulation.

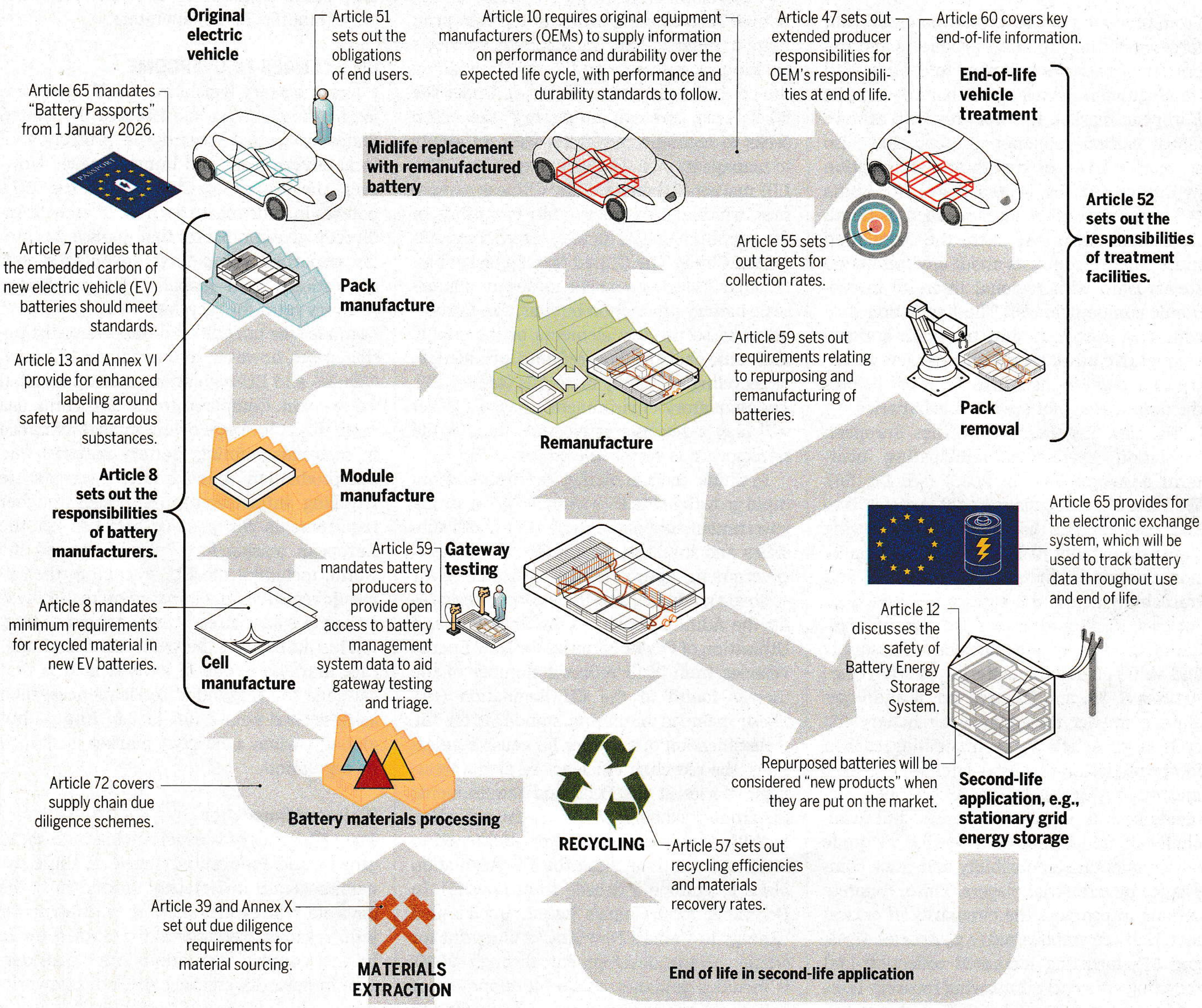
Distorted innovation

The LIB industry is experiencing both rapid growth and innovation. Together, these dynamics create uncertainty around how the markets will evolve, making it difficult for industry to properly invest for future growth. In this context, regulations offer considerable impetus by creating stable frameworks under which market players operate. Overly stringent regulations on batteries risk imposing compliance costs that hinder competitiveness, leading to reduced innovation and lower EV adoption rates. Few, if any, other technological products appear to be presently regulated in quite the same way—with manufacturers needing to provide details on product life cycle, material sourcing, third-party audit, and recycled content. This means that batteries, the product at the core of transport decarbonization, may in some respects face tougher requirements than the incumbent industry serving the internal combustion engine vehicle market. Even if

[1]Circular Energy Storage Research and Consulting, London, UK. [2]School of Engineering, Newcastle University, Newcastle upon Tyne, UK. [3]Faraday Institution (ReLiB project), Quad One, Harwell Science and Innovation Campus, Didcot, UK. [4]National Institute of Clean and Low Carbon Energy (NICE) America Research, Mountain View, CA, USA. [5]NICE, Future Science City, Changping District, Beijing, China. [6]Department of Civil and Environmental Engineering, University of California, Davis, CA, USA. [7]Birmingham Centre for Strategic Elements and Critical Materials, University of Birmingham, Edgbaston, UK. [8]Tyndall Centre for Climate Change Research, Newcastle University, Newcastle upon Tyne, UK. Email: oliver.heidrich@ncl.ac.uk; hanseric@circularenergystorage.com

A circular economy for electric vehicle batteries: Key articles from the proposed EU Battery Regulation

The proposed Regulation addresses the battery life cycle, from initial extraction of raw materials (bottom left) through end of life and recycling.



GRAPHIC: ADAPTED BY N. CARY/SCIENCE

stricter emission standards are underway, there are no proposals to provide the same value chain transparency.

The new regulation also means that European EV manufacturers will be more constrained in their options to source batteries than manufacturers in the less regulated United States but also in a strongly regulated China as their share of the LIB market is simply so much bigger and their players much more mature. The fact that smaller producers are not exempted from the many potentially burdensome requirements presents a considerable risk that innovation in alternative transportation areas and technological niches may be disadvantaged.

A second mechanism for distorted innovation involves situations where regulatory guidance lags the technical realities in the market. In an extreme case, specific regulatory targets might become obsolete even before they enter into force, owing to the introduction of new chemistries or battery designs. A second case concerns unexpected "work-arounds." Rather than direct compliance on specific materials, producers might opt for raw material substitutions; such decisions upstream in the value chain could unintentionally weaken future markets for recyclers expecting different levels of material availability. In addition, manufacturers might simply incorporate the threshold of 2 kWh as a design parameter to avoid the heavy burden of supply chain due diligence and the use of recycled content, which could make the Regulation less effective. A third case of distorted innovation is that the requirements for recycled content could hamper the pace of the roll-out of new technologies as well as higher ambitions for the overall growth of the LIB market. This could be particularly relevant for individual manufacturers, as the availability of recyclable materials effectively establishes a limit on the amount of certain materials that can be used in the batteries (*11*). All three cases reinforce the importance of continual monitoring and adjustment of regulations to ensure that outcomes remain aligned with both their environmental stewardship and economic goals. This importance has been addressed in work preceding the

Regulation that motivated the use of "secondary legislation" for specific measures, including recycled content, which will be adaptable over time. However, there is a trade-off between adaptability and stability, which is one of the intentions of the regulation.

Material leakage, investment slowdown

One objective of the Regulation is to responsibly secure material supply chains for Europe's EV industry. Recycling is here a core activity, with recycled content and recovery targets as main measures. However, the Regulation neither requires recycled material to be sourced in Europe nor restricts the source of recyclables to EOL batteries. With considerable experience in battery material production, including the use of recycled materials from both EOL batteries and production scrap, several companies in markets like China and South Korea are as well, and likely better, positioned to meet EU requirements for recycling than European companies. With China's and South Korea's dominance in battery production, these companies also have better access to feedstock of recyclables, which already has provided many of the companies with economies of scale and thus a competitive advantage in sourcing recyclables from both Asia and Europe. This extends to both Asian battery material producers, which are the users of the recycled materials, and battery manufacturers with close access to these materials. The net effect of this dynamic could be a higher barrier to entry for European material producers, and ultimately battery manufacturers, in their own market. This issue has been raised by battery manufacturers in consultations both before and after the adoption of the Regulation.

This potential outflow of recyclable materials comes on top of the fact that battery-containing products, as well as the batteries themselves, usually cascade through multiple owners and are traded on international markets (*11*). EOL batteries still have value and are often exported for reuse and refurbishment, or recycling (*12*). This outflow makes it more difficult for recyclers in Europe to reach the necessary economies of scale, making them less competitive and less attractive to invest in.

The Regulation's clarification of producer responsibility for repurposed batteries, as well as its waste status, and the mandated access to BMS data might help keep batteries in the EU, facilitating the manufacturing of new battery products, which ultimately can reach end of life in Europe. However, it also provides a route for traders to declare the used battery "a resource or product," which facilitates its export, adding to the leakage of recyclable materials. Access to EOL batteries and recyclable materials is primarily a concern for the companies involved in the end-of-life value chain. However, with requirements for recycled content in the batteries, this dependency extends to the entire industry, including the manufacturing of electric vehicles.

CONCLUSIONS

The EU Battery Regulation has admirable intentions—from spurring the growth of domestic industries, to environmental protection at local and global scales, to achieving a truly circular economy. All these goals are intertwined, and one could reasonably argue that they need a unified policy. However, development of largely uncoordinated regional and domestic policies across globally important consumption and production regions makes the consequences of the proposed EU Regulation hard to predict. Although unintended consequences might first affect the EU, they will also be felt by manufacturers, recyclers, and other actors across the world. Ultimately, disruptions in the European battery value chain might limit automotive makers' ability to produce EVs at the scale that is required by 2030, when several countries have placed a ban on the sale of new internal combustion engine vehicles.

Efforts to disentangle the goals of different measures and instruments, and better understand the effects on global supply and value chains, may be made more predictable and powerful if addressed by the global community in coordinated fashion. For example, shifting to open BMS architectures (namely, battery passports, a digital representation of battery environmental, social, governance, and life cycle–specific information in Article 65) represents a major departure from existing business models in which manufacturers maintain tight control over the data generated. It is unknown whether and how locally acquired battery data will be shared across global value chains. What is likely is that in a unified global market, the dominant market's standard will drive compliance.

Having clear and stringent global standards in areas where regulations are limited in scope such as recycling, circularity, and cascaded use for batteries could provide EU firms with a first-mover advantage in achieving product differentiation in battery markets. Perhaps this can form a non-tariff barrier to cheaper imported products, affording some protection to European battery makers. Over the longer term, a more robust global supply chain with many players is good for the environment overall—and will benefit innovative players regardless of their origin.

Because standards on battery supply and value chains are uneven around the world, establishing global standards that all countries adhere to could help ensure a level (and sustainable) playing field and facilitate coordination on these global challenges and solutions. The EU Regulation is among the most advanced environmental standards influencing environmental stewardship and sustainability. Though embedded resistance from market players alongside the challenges inherent in international negotiations presents formidable hurdles to the establishment of global standards, the EU's share of the EV market provides it with considerable leverage to set standards that might be accepted on a de facto basis. In similar fashion, there should be an ambition to align other product areas with the same standards, ensuring that the battery industry is not disadvantaged in relation to other energy storage and power technologies.

The EU Regulation places the EU on the forefront of regulating battery markets, providing much-needed policies and legislation that address environmental and social issues. However, these policies need to contemplate the unintended consequences, both in the near and distant future. ■

REFERENCES AND NOTES

1. T. L. Curtis, L. Smith, H. Buchanan, G. Heath, "A Circular Economy for Lithium-Ion Batteries Used in Mobile and Stationary Energy Storage: Drivers, Barriers, Enablers, and U.S. Policy Considerations" [National Renewable Energy Laboratory (NREL), 2021].
2. European Union, "Proposal for a regulation of the European parliament and of the council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020" (European Commission, Brussels, 2020).
3. European Union, in *OJ L266/1* (Official Journal of the European Union, Brussels, 2006).
4. "State aid: Commission approves €2.9 billion public support by twelve Member States for a second pan-European research and innovation project along the entire battery value chain" (2021); https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226.
5. G. Crabtree, *Science* **366**, 422 (2019).
6. B. K. Sovacool *et al.*, *Science* **367**, 30 (2020).
7. J. Baars, T. Domenech, R. Bleischwitz, H. E. Melin, O. Heidrich, *Nat. Sustain.* **4**, 71 (2021).
8. "FACT SHEET: The American Jobs Plan" (2021); www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/.
9. "Energy in China's New Era" (2020); www.xinhuanet.com/english/2020-12/21/c_139607131.htm.
10. State Council, Ministry of Industry and Information Technology (Ministry of Industry and Information Technology, Bejing, China, 2018).
11. R. Sommerville *et al.*, *Resour. Conserv. Recycling* **165**, 105219 (2021).
12. UNEP, "Used Vehicles and the Environment" [United Nations Environment Programme (UNEP), Nairobi, Kenya, 2020].

ACKNOWLEDGMENTS

This research was supported by the UK's Engineering and Physical Sciences Research Council (EPSRC), the Faraday Institution (EP/S003053/1), and its Recycling of Li-Ion Batteries (ReLIB) project (FIRG005). None of the funders had input or a role in the conceptualization, design, data collection, analysis, decision to publish, or preparation of the study or this manuscript. We thank reviewers for comments.

SUPPLEMENTARY MATERIALS

science.sciencemag.org/content/373/6553/384/suppl/DC1

10.1126/science.abh1416