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# Navigating value dynamics through daily work: Lithium-ion battery developers in the low-carbon energy transition

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ABSTRACT

Energy transition goes beyond technological substitution to involve changes in human values. To steer value shifts toward desired directions, it is important to understand what individual actor can do. While scholarship has explained general mechanisms of value change, far less is known about how individuals participate in micro value dynamics and shape these transformations. This study addresses this gap by examining how individual lithium battery researchers navigate value tensions in practice, centering on their value beliefs and value practices. Based on interviews with fifteen experienced researchers, the findings reveal that value dynamics in energy transition unfold through recursive dynamics between structured value landscapes and distributed navigation practices. Researchers inhabit possibility spaces shaped by material constraints, institutional requirements, and societal expectations, yet reshape these landscapes through translation, negotiation, positioning, and projection practices. The study argues that desired value change is not merely a shift toward isolated, fixed values but requires cultivating mutualistic relations between individual actors and evolving value landscapes. For the governance of the low-carbon energy transition, this perspective suggests effective interventions should focus more on enhancing the generative capacity of value landscapes, in addition to prescribing specific outcomes.

## 1. Introduction

The ongoing energy transition illustrates how technology development increasingly couples with human values. Popularized in the early 1980s, the term “energy transition” initially referred to a shift from fossil-based systems to renewable resources [1]; however, given the important roles of energy in modern society, this transition now encompasses broader social changes. In this transition, every decision in technological advances reflects values in a broad sense,[1] including economic, political, and moral considerations about what “a person or a group of people” believe is good and desirable [2–4]. While setting up a heat plan, designing an energy device, or even selecting a thermal functional material, engineers and designers balance values such as safety, sustainability, performance, justice, and cost. These decisions embedded in technology then further shape social interactions, which can influence both personal and shared understandings of value. The transition thus involves sociotechnical reconfigurations in which technologies, user practices, regulation, infrastructures, and cultural meanings develop together. Changes in energy systems both reflect prevailing social values and, in turn, contribute to ongoing value dynamics [5–7].

Such dynamics can be present at different levels. If values are seen as *evaluative devices* that help both individual and collective actors distinguish what matters [8], then value dynamics can operate at both personal and social levels. What individuals come to value is always influenced by shared norms and institutional expectations. Over the past decade, growing discussion on value dynamics has focused primarily on explaining the mechanisms of value change in technology development, but often through a simplified micro-macro connection. However, research on broader social transformation points to a far more complex picture, in which macro-level outcomes do not follow straightforwardly from the accumulation of individual change, but emerge through dynamic processes that make outcomes uncertain [9,10]. Steering value change requires focusing the inquiry: who is positioned at the contact

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[1] In this article, the concept of value is primarily grounded in discussions of technology and design. The study treated it as a working term rather than a fully specified philosophical definition.

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points where value dynamics emerge during the technological development? How do these actors encounter value dynamics in everyday work? What factors play a role in shaping actors' capacity to influence those dynamics? Under what conditions can they affect outcomes? Addressing these questions requires investigating the actors who directly shape technological trajectories.

This research therefore focuses on individual researchers, as their early design decisions constrain downstream possibilities, and their day-to-day practices fold particular values into technical work. Current models of value change recognize that values change at multiple levels and through a variety of mechanisms [11]. On the theoretical front, for example, Steinert [12] analyzes how sociologists argue that "changes in the value systems of individuals are linked to cultural, social, and economic changes". Empirically, Melnyk et al. [13] explore how values connect across agents, technologies, and institutions in community settings, yet they leave open how individual actors make sense of these dynamics and navigate them in everyday work.

The limitation signifies three gaps that drive this investigation. First, there is a theoretical gap in our understanding of how researchers make sense of value dynamics underlying value change in their specific work. Second, we lack empirical accounts of how values are implemented and modified through routine work in technology developments. Third, there is a need for a proper method to explore how the micro and macro levels are connected in value change, which focuses on individual perception without reducing the complexity of the context. Addressing these gaps requires both a theoretical framework connecting individual experiences to collective change and empirical investigation of contexts in which actors are experiencing value change within complex institutional settings.

To make these gaps empirically tractable, this exploratory study probes how researchers of lithium-ion batteries (LiB) engage in value dynamics through their technical practices. Spanning multiple application contexts and playing an important role in the energy transition, LiB technology offers an analytical window where multiple value systems intersect and evolve [14–16]. Through interviews with fifteen experienced battery experts, this study attempts to understand value dynamics from a bottom-up perspective. The study draws on existing theories about values and sociotechnical change to identify shared themes in how research make sense of value change and conflicts. Specifically, the study responds to how LiB researchers experience and navigate the value dynamics underlying value change in their technical practice, and what their experiences reveal about value dynamics in energy transition.

In the next section, the paper first introduces the theoretical assumptions that inform this exploratory approach, enabling the observation of individual engagement in macro-level change. Section 3 describes the methods of empirical data collection and analysis. Section 4 maps the complex landscape within which battery researchers operate, revealing how values emerge from and are shaped by multiple intersecting sources of expectations and constraints. Section 5 delineates specific patterns in how researchers engage with value change, illustrating how technical practice becomes a domain of value work. Section 6 combines these findings to give a new perspective on value dynamics as a property that comes from distributed practices, while Section 7 briefly discusses implications for current energy-transition debates.

## 2. Theoretical framework: a sociotechnical account of value dynamics in energy systems

Energy is increasingly understood as a sociotechnical problem, making value dynamics in energy technologies amenable to a sociotechnical lens. Such a lens provides a more systemic understanding of the co-evolution of technologies, human values, and individual practices. On the one hand, a sociotechnical perspective treats individuals as embedded actors navigating intersecting social power networks, revealing technology as a heterogeneous system and relationships between individuals and other system components. On the other hand, this perspective enables a contextual understanding of value concepts within specific situations, preventing conceptual drift amid the proliferation of value-related scholarship. This section synthesizes existing theories for conceptualizing value dynamics and rendering the investigation analytically tractable.

### 2.1. *Values in sociotechnical systems*

In fields like philosophy of technology and science and technology studies (STS), scholars generally acknowledge the co-shaping of values and technology. While some philosophers, such as Deborah G. Johnson [17], resist treating technology as a moral agent, most theories maintain that the design of technologies can still carry moral significance by enforcing or shaping norms. According to Latour [18], "the moral law is in our hearts, but it is also in our apparatuses (p.253)". In the narrative of co-shaping between values and technology, values can be traced in at least two ways: what people believe and how people practice. This study does not look into the complex definitional nuances of value; rather, it focuses on analyzing *value beliefs* and *value practices*. Value beliefs are justified beliefs or commitments about what counts as good or proper, and they can guide designers' situated value judgments [8]; whereas value practice refers to how such beliefs are routinely expressed through material arrangements and technical scripts that prescribe and constrain conduct [19,20]. Material arrangements and social norms solidify value beliefs into practices. These sociotechnical setups turn value beliefs into stable practices by making some steps default and others costly, which changes what people treat as proper or valuable [15,16].

In concrete design work, values shape actors' beliefs and judgments about what should be done and which trade-offs are acceptable. In LiB design, for example, researchers broadly recognized the move toward high-nickel, low-cobalt layered cathodes, largely because cobalt poses major supply and sustainability risks, even though cobalt helps layered oxides by suppressing Li/Ni cation mixing and supporting conductivity and rate capability [21,22]. Whilst a belief-based perspective highlights what actors consider important and why, a practice-based perspective shifts attention to how values are maintained and reproduced through organized routines. In this sense, values can also be understood through their enactment in practice [23]. Battery safety is a case in point: market expectations, industry standards, and government regulation set numerical thresholds and test protocols, thereby shaping material selection, abuse testing, and staged quality checks.

The two dimensions of values constitue a working definition. Values refers both to the reasons and obligations that actors can invoke, and to the organized repertoires of action through which actors ensure that the reasons and obligations are sustained or stabilized in practice. These repertoires respond to the social demands within specific domains and, over time, reshape those demands.

### 2.2. *Contextualizing value dynamics: an individual perspective through salient issues*

If we accept the co-shaping relationship between values and technology, values cannot be simply understood as fixed ends to be achieved by technical means. Because means change, these ends are reopened and subject to change [24]. From a broader view, pragmatist and sociological writings about value dynamics converge on a couple of points: values are continuously (re)created; they do not come out of nothing but are always constrained by existing value systems; and they are highly contextual [23–25]. Accordingly, the analysis of value dynamics focuses on how actors interpret and act in specific situations, taking up signals and translating them into beliefs and practices.

While some studies map collective trends in value change using surveys and text mining, as noted earlier, this study focuses on the individual level. One way to observe value change at this level is to look at salient issues [26]. Salient issues,[2] such as bottlenecks, accidents, or conflicts, arise when a technology is failing or posing new dilemmas. In such moments, the limits of settled evaluations become visible, and people have to express, debate, and revise their commitments [23], thereby both testing existing value beliefs and activating practices based on these beliefs. In this sense, salient issues can be understood as situations in which change becomes visible. By concentrating the attention and effort of many individuals, these issues bring implicit value commitments into the open and generate responses that can be traced across multiple scales [27].

Inspired by "Coleman's macro-micro-model[3]", value change can be understood as a social phenomenon involving individual-level transformations [28,29]. Between system-level salient issues and collective-level value change, there is a necessary passage through the beliefs and actions of individual actors. On one hand, individuals interpret what salient issues mean for their work, form beliefs about what matters and why; on the other hand, individual actors respond through practices that, over time and in combination with the responses of others, contribute to patterns of change at larger scales. This assumption does not reduce value change to individual choice. It means that to understand how value dynamics work, we need to examine what happens at the individual level, even though the outcomes are collective.

Fig. 1 synthesizes a framework to provide a general sense of reference, showing value beliefs and practices across personal and social levels. Personal value beliefs reflect interpretations of and responses to external signals from multiple domains, often articulated as concerns about safety, performance, sustainability, or justice; while personal value practices contribute to system change across institutional and material arrangements. Salient issues thus inherently have a dual status. They rely on system understanding and elicit collective action. Identifying salience requires an understanding of system boundaries, structures, and trajectories, while it also signals the demand for urgent collective action. Consequently, belief and practice interweave at both personal and social levels: perceived problems orient interventions, whose feasibility, side effects, and outcomes then recalibrate what is valued, within individual trajectories and across collective fields of practice [30,31].

This paper focuses on the personal level of this framework and examines how individuals interpret and respond to the broader contexts (the shaded area and two highlighted arrows in Fig. 1). Regarding the value belief, derived from Kaiser's [32] perspectival account of value landscapes,[4] this study maps a situated *value landscape* as seen from the LiB researchers' vantage point. The analysis traces the value landscape as a structured justificatory terrain within which individual researchers form, defend, and revise their value beliefs through their own engagement with different components in sociotechnical systems. Subsequently, it examines *navigation practices*, which are value practices viewed from the angle of how individual actors engage with structured value landscapes that extend beyond their immediate situation. Researchers cope with tensions through these concrete navigation practices with shared routines and collective aspirations. Such a dual analytical lens allows the study to show two interrelated aspects of the same process (Table 1).

## 3. Methods

To observe how individuals experience and shape value dynamics, this section elaborates on how the framework outlined in Section 2 was operationalized in empirical investigation. The research design is qualitative and exploratory. The research deployed semi-structured interviews because semi-structured interviews are particularly well-suited for capturing personal experiences and situated interpretations, and the research examines how researchers engage in value dynamics by conceptualizing value commitments as beliefs and enacting them through everyday practices across different settings. Inspired by Reflexive Thematic Analysis (RTA) [33], the analyses adopted an iterative approach that allowed themes to emerge from the data while being informed by the research questions about how researchers navigate value tensions in their work.

### 3.1. Data collection: semi-structured interviews

Semi-structured interviews were conducted with fifteen researchers from different regions in China who have substantial experience in LiB technology. As the world's largest producer of lithium-ion batteries, China accounts for over 75% of global manufacturing capacity [34], positioning Chinese researchers strategically to illuminate value navigation in this critical low-carbon energy technology. Following the framework in Section 2, the study centered on two salient issues widely acknowledged as rising priorities: safety and recycling,[5] which have become increasingly critical amid higher performance demands and evolving regulatory expectations [35–39].

Participants were purposively sampled for their direct engagement with these values through their research on battery safety mechanisms or end-of-life management. All fifteen interviewees are researchers at academic institutions, specifically university laboratories or university-affiliated research institutes.[6] Their experience in the LiB field ranges from 5 to over 20 years, with an average of over 10 years. This selection reflects the study's focus on actors who directly shape technological trajectories through their research practices. While all participants are based in academic settings, roughly half maintain active industry collaborations, such as joint projects with battery manufacturers and consulting relationships. This variation allowed the study to capture differences in how researchers experience institutional pressures depending on their proximity to commercial applications. Moreover, participants were purposively sampled for their engagement with safety and recycling specifically, not as a representative cross-section of all LiB researchers. The study thus captures perspectives of researchers who are

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[2] Here, the idea of "salient issues" is inspired by Thomas Parke Hughes' discussion on reverse salient. Hughes defines reverse salient as a component of growing systems that "does not march along harmoniously with other components" [45] (p.70)." A reverse salient is one mechanism of systematic formation of salient issues, but other factors, such as the media, can also play a role.

[3] Coleman's macro–micro–macro model casts the micro level as the foundation of macro social change: (1) macro-level conditions shape individual situations, (2) individuals act based on their situations, and (3) these individual actions add up to create macro-level outcomes [29].

[4] While Kaiser uses "value landscape" to describe multi-dimensional configurations of interrelated values in a given context, this study adapts the term to foreground its justificatory function, i.e., how an existing value landscape, as a structured field of expectations and pressures, shapes the (re)formation of actors' value beliefs.

[5] Safety and recycling here serve as entry points to broader value dynamics. Given the relationality of values [13,71], researchers' engagement with safety and recycling can open onto a broader landscape of related values, including performance, cost, sustainability, and institutional expectations.

[6] This study received ethical approval from Technology University of Delft (Application No. 4162). Interview recordings and transcripts are stored in accordance with the organization's data management policy and are accessible only to the researcher(s) involved in the project.

The interviewees' names, affiliated institutions and other personal information are also not identified, in accordance with the informed consent form. These interviews were selected via snowball sampling from three geographic regions across China. However, because the paper does not focus on regional differences, this information is not listed in the table.

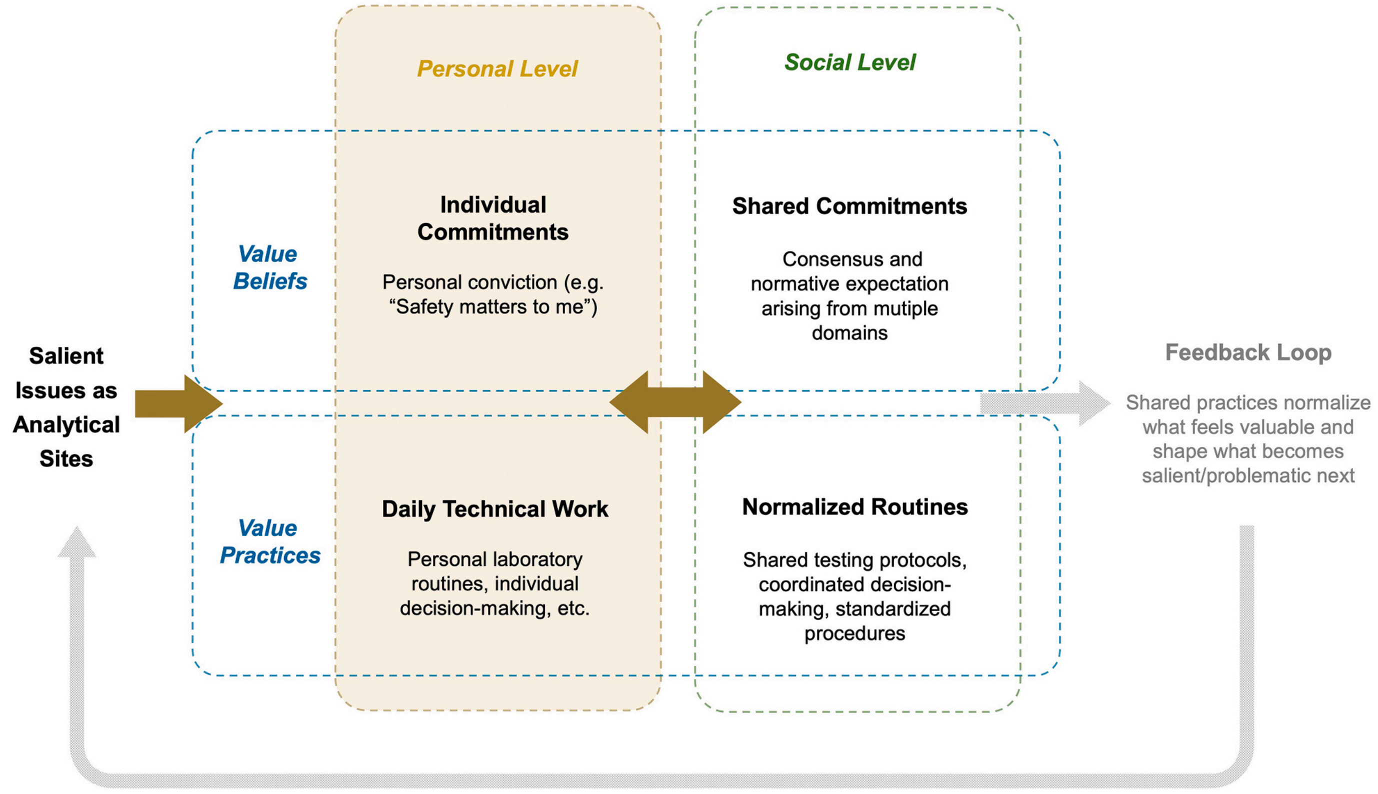

**Fig. 1.** A general framework for studying value dynamics across levels.

**Table 1**
Core concepts of the analytical framework.

| Framework concept | Definitions | Analytical concept and its relationship with framework concepts |
|---|---|---|
| Value belief | Justified evaluative beliefs about what counts as good or proper, and they guide designers' situated value judgments. | Value landscape as the structured field of justification sources shaping value beliefs across different domains from the actor's perspective. |
| Value practices | Routinized enactment of commitments through material arrangements and technical scripts. | Navigation practices as value practices viewed from the angle of how individual actors engage with a broader macro context. |

positioned at the intersection of technical development and evolving normative expectations around these two salient issues.

Interviews were conducted between May and September 2024.[7] Each interview lasted between 45 and 70 min. Depending on participants' availability and location, 4 out of 15 interviews were conducted online. All interviews were audio-recorded with participants' consent and transcribed verbatim.[8] The interview protocol was designed to primarily focus how these researchers perceive and practice two key values and its related salient issues: safety (often in tension with energy density and the demands of material design) and sustainability (with a particular emphasis on recycling). Participants were asked to reflect on (1) their work content and how it has evolved over time; (2) their understanding of salient issues and values at the field level (how they perceive salient issues, how the related values manifest, whether they have changed, and how they relate to the participant's own work); and (3) their visions for the future of LiB battery technology.

A summary of participant characteristics is provided below (Table 2).

### 3.2. *Data analysis: emergent coding of beliefs and practices*

This study employed an RTA-inspired [33], iterative analysis that is mainly deductive but also combined with inductive elements. Whilst the principal coding themes are grounded in existing theory, the specific details derive from the data. The belief-practice framework (Section 2) provided the overarching analytical orientation, which treats value beliefs and value practices as different but related dimensions of the data.

The belief dimension was operationalized by coding what participants said mattered and why, including the audience and context they referenced. The analysis approaches value beliefs as "justified normative beliefs" that actors invoke when explaining their decisions and responses. Both explicit value statements and implicit value commitments that can be identified in the described practices were coded.

Regarding the sources of justification for value beliefs, the analysis has employed common categories from STS studies. Drawing on common sociotechnical systems components—artifacts, actors, and institutions, the study first distinguished beliefs shaped by material constraints, institutional structures, and actor-based factors, especially those arising through public interactions [40,41]. Material sources captured limits, failure modes, and test behaviors. Institutional sources captured established rules, standards, funding, review processes, and laboratory protocols. Drawing on "triple helix" frames [42], institutional sources were further differentiated in terms of academia, industry, and government. Beliefs originating from actors' interactions with other roles were treated as arising from perceptions embedded in public discourses, capturing social salience, media narratives, and informal attitudes. Within these theoretically informed categories, the specific beliefs, tensions, and justificatory patterns were identified through close

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[7] In each of the two main categories, interviewees are listed in the order of the date of the interviews.

[8] All interviews were conducted in Mandarin, and the quotes were translated into English by the author with the help of DeepL.

**Table 2**
Expert interviewees by research specialization and experience in the LiB field.

| Interviewee no. | Main interview focus | Current research focus | Collaborating with other domains? (especially the industry) | Years of experience in the LiB field | Interviewee ID |
|---|---|---|---|---|---|
| 1 | Safety | Battery Material Design | √ | 20 | R1 |
| 2 | | | √ | 12 | R2 |
| 3 | | | | 14 | R3 |
| 4 | | | √ | 9 | R4 |
| 5 | | | | 8 | R5 |
| 6 | | | | 7 | R6 |
| 7 | | | | 7 | R7 |
| 8 | | | | 12 | R8 |
| 9 | Sustainability | Recycling | | 5 | R9 |
| 10 | | | | 12 | R10 |
| 11 | | | √ | >20 | R11 |
| 12 | | | | 5 | R12 |
| 13 | | | √ | 12 | R13 |
| 14 | | | √ | 10 | R14 |
| 15 | | | | 11 | R15 |

engagement with the interview data.

For the practice dimension, the analysis adopted a theoretically informed approach to identifying how researchers navigate value tensions. Following the macro-micro-macro structure of Coleman's (1990) model, the analysis priorly distinguishes two orientations of navigation practice – *situational work* by which researchers deal with macro-level conditions that already bear on their work and *transformational work* by which researchers actively contribute to broader value transformations beyond their immediate work. As the interviews and analysis proceeded, the complexity of the situation became apparent. Situational work does not always involve directly operating on values; more often, it requires dealing with tensions between values. Transformational work, likewise, does not always involve reshaping existing values and evaluative systems according to the researcher's own ideas and visions. In order to actively shape the future by their own visions, researchers often need to understand their own position within the broader context and weave themselves into commonly acknowledged visions, so that their work can achieve greater significance within existing value systems. The analysis therefore decided to further distinguish different types of situational work and transformational work.

As Table 3 shows, situational work is divided into translation and negotiation, while transformational work is divided into positioning and projection. These further distinctions are grounded in the empirical data, while also drawing conceptual inspiration from several sources. Translation rooted in Actor-Network Theory's concept of how actors operate meanings across contexts[9] [43]. Negotiation can be seen as an inquiry under tensions, which reasonates with the pragmatist idea of deliberation as "weighing various alternative desires (and hence end-values)" [23] (p.25). Positioning and projection, in turn, draw on discussions of visions and sociotechnical imaginaries. The former is akin to embedding oneself within already existing imaginaries, while the latter involves putting forward one's own vanguard visions [44]. These theoretical resonances emerged alongside the research, rather than fully preceding the initial analysis and coding.

**Table 3**
Orientations and definitions of navigation practices.

| Navigation practice | Practice orientation and related process in Coleman's model | Definition |
|---|---|---|
| Translation | Situational Work (Macro - > Micro) | Operationalizing broad values into specific technical goals |
| Negotiation | | Managing competing value-based demands |
| Positioning | Transformational Work (Micro- > Macro) | Anchoring personal work with broader value-laden narratives to build access to collective venues |
| Projection | | Advancing desirable futures to reshape collective understandings of values |

## 4. Mapping the value landscape

This section illustrates how researchers interpret and justify value beliefs in response to demands from their material, institutional, and societal contexts. It maps the structured value landscape in which LiB researchers operate by showing how their technical decisions and normative reasoning are shaped by entangled pressures from three interrelated domains:

- *material constraints* (the physical properties, limitations, and possibilities inherent to battery technology),
- *institutional structures* (academic, industry, and government requirements),[10] and
- *public concerns* (public discourses, media narratives, and informal social attitudes toward battery technologies).[11]

These domains overlap and generate tension, particularly around salient issues like safety and recycling. Technical "reverse salients", represented by bottlenecks and failures encountered in the material world, often catalyze the surfacing of latent value tensions and trigger both institutional and societal responses [45]. While these reverse salients appear rooted in material constraints, their recognition and framing are always shaped by social and institutional interpretation. As such all three areas become certain sources of expectations that respondents draw on when articulating their beliefs and practices in their inquiries.

### *4.1. Material constraints*

Material constraints constitute the physical foundation of battery

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[9] Translation here focuses on the interpretation and operationalization of value and related salient issues, and its scope is more limited than that of Actor-Network Theory and the sociology of translation.

[10] Here "institutions" refer to the rule environments that define what is considered legitimate or acceptable.

[11] The domain of public concerns represents researchers' interpretations of societal attitudes toward battery technologies, including media coverage of accidents, consumer talk, and informal expectations that circulate outside formal institutional channels. Unlike formal institutions with specific rules, this domain is narrative-based, diffuse and implicit.

research, defining what is technically achievable and establishing fundamental trade-offs between competing performance criteria. These constraints are not merely technical limits but carry normative weight. They shape what researchers see as possible, desirable, and worth pursuing. In addition to safety and sustainability, energy density[12] also emerges as central values because material properties make certain combinations difficult or impossible, turning technical challenges into value tensions.

### *4.1.1. From physical properties to values*

Material properties shape both the feasible and the salient in technology development, making certain values especially relevant when material constraints conflict with basic needs. Across all interviews, experts consistently identified that central material features in battery research—especially energy density and safety—are fundamental drivers of materials development, while sustainability is also receiving increasing attention. Expectations are rising not only for better technical performance but also for compliance with stricter regulations. Interviewees widely agreed that safety and environmental criteria will become more stringent in the future. They linked this to both the demands and limits of battery materials and to the overall visioned trajectory of the field.

Energy density emerged first as a basic technical property and increasingly functioned as a value in battery research. It was justified not only by technical ambition but also by broader social aims, such as enabling lighter batteries or reducing costs: “graphite can store 372 mAh per gram of lithium, but silicon is over 3,000, so to store the same amount of electricity, you need much less silicon, which is also an abundant and low-cost material (R3).” [4] Interviewees also stressed that energy density has increased significantly over the last decade but is now approaching its theoretical limit, despite demand for further gains persisting.

Safety is consistently framed as a critical value due to complicated risks associated with LiB technologies. LiB may undergo thermal runaway under abuse conditions or internal failure, which can lead to fire or explosion and raise significant safety concerns, These concerns must be addressed through material design, cell design and thermal management. In existing literature and interviews, researchers broadly acknowledge that absolute safety remains unattainable, especially as new systems introduce new challenges. Although their confidence varied, some experts believed that continued innovation could improve safety over time, even as expectations grow.

Sustainability has become increasingly important because of regulatory pressures. In addition to encouraging recycling practices, this growing emphasis shapes material choices, including replacing formaldehyde-based wood adhesives with soy-based formulations and utilizing soy-derived binders or separators in batteries. Economic aspects also matter, since soy protein has been described as a cheaper bio-based alternative to PVDF (polyvinylidene difluoride) binders, as PVDF binders are relatively costly and rely on the toxic solvent NMP (*N*-methyl-2-pyrrolidone). Yet, experts noted that environmental performance can only be evaluated reliably at an industrial scale; therefore, early-stage impacts are usually estimated using life-cycle assessment and related modeling tools.

In summary, some values are not simply responses to social expectations but are fundamentally understood as intrinsic material properties. Other aspects, such as cyclability and fast-charging capability, are regarded as device-level or production-level qualities whose relationship to the underlying material remains more complex and is mediated by additional engineering and system considerations.

### *4.1.2. The normative significance of material constraints and tensions*

While Section 4.1.1 showed how material properties shape individual values, these discrete values do not exist in isolation. Material conditions create inherent tensions and connections among values, transforming technical trade-offs into normative dilemmas.

On the one hand, most performance metrics are subject to theoretical and physical limits. These constraints are not merely limitations on performance. They also serve as a key motivation for ongoing research and innovation. The pursuit of new materials and battery architectures responds to the limits of energy density: “now that researchers are approaching the theoretical limits of current systems, people are exploring all kinds of new battery chemistries; the demand for higher energy density is ongoing, but the approaches keep evolving (R3).” The material constraints themselves thus become an enduring source of technical challenge and creative drive.

On the other hand, material conditions can also generate tensions among values. Specifically, the tension between energy density and safety is universally recognized as being dictated by the fundamental properties of battery materials and the laws of physics, creating not just a simple trade-off but an ongoing constraint and source of complexity in the field. “Whenever there's a reaction in the cell, there will be heat; and as long as there is heat, there is a safety problem... thermal runaway and explosions happen when heat cannot be dissipated (R5).” Pushing for higher energy density almost inevitably increases safety risks due to material and structural limitations.

The conflict between safety and energy density exists not only in the physical properties of the materials themselves, but also in the characteristics of devices and application technologies. For example, questions regarding driving safety can arise about constantly pursuing higher energy density: “Once you reach 400 Wh/kg, I don't think it makes much sense to go further… an electric car cannot simply be made lighter and lighter, because [driving] safety still has to be ensured. If the weight is reduced too far, safey becomes a problem as well (R11).” This reflection suggests that cutting-edge work also extends beyond the narrow pursuit of particular performance metrics towards more responsible and well-balanced ways of thinking in real-world contexts.

Although this tension between safety and energy density has, to some extent, driven the current surge of interest in solid-state lithium batteries, experts hold different views on their safety performance. Some argue that solid-state structures can improve stability, while others question whether solid-state batteries are actually safer than liquid-based ones. “Even solid-state batteries are not truly safe; they still develop dendrites… and there are various factors that require careful control (R4).” This also aligns with the uncertainty noted in parts of the literature [46,47], such as the possibility that the temperature of a fire in a solid-state battery may be higher than that of conventional LiBs. Moreover, because solid-state batteries have not yet achieved large-scale commercialization, their safety performance is difficult to assess using a uniform standard.

With the development of solid-state lithium batteries, a tension has also emerged between energy density and sustainability. Experts have different opinions on the sustainability of solid-state lithium batteries, which can also be supported by existing literature. Some all-solid-state battery designs may be easier or safer to recycle because they avoid flammable liquid electrolytes and may reduce the number of separable components [48]. However, the materials and structures of solid-state batteries can be more complex. These batteries introduce different solid electrolytes such as oxides, sulfides, and polymers, making existing liquid lithium battery recycling routes hard to apply. Some design features such as stronger bonding, different binders, and fiber additives will all alter the dismantling and separation processes [49]. In addition to affecting recyclability, some systems may provide additional safety concerns and environmental hazards. Sulfide solid electrolytes, for instance, can produce hydrogen sulfide when improperly handled or

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[12] Energy density is a material property, but in the context studied here it also functions as a value in the pragmatist sense. Researchers and decision-makers treat higher energy density not merely as a technical fact but also as an end worth pursuing, which is justified by broader aims such as enabling lighter batteries, extending vehicle range, and reducing costs.

when failure occurs and therefore would need stricter controls in terms of manufacturing and recycling.

In navigating these constraints, researchers articulate a certain normative hierarchy, but these priorities often vary from person to person. Although safety is almost always treated as a non-negotiable foundation, particularly in high-risk applications, and increasing energy density and other performance metrics remain a major direction for development, some still regard energy density as the core value driving battery research. While some experts consider sustainability important but not something that requires excessive concern, others argue that sustainability is still insufficiently considered at the material design stage.

Despite these differing views, experts generally agree that battery research is always a process of negotiating and reassessing what is actually possible and worthwhile. “Improving a single metric isn't always good in real battery tests. We have to keep everything in balance (R6).”

### *4.2. Institutional structures*

Institutional structures shape the organizational and normative environments within which battery research unfolds. With distinct requirements and expectations, academia, indusrty and government each create different rules that researchers must navigate. These domains often respond to similar issues, but prioritize and interprete values differently. Academia rewards novelty and publication output, industry prioritizes manufacturability and cost reduction, and government emphasizes regulatory compliance and strategic resource security. The analysis of each institutional domain first examines the demands and pressures from that domain, and then explores how researchers personally understand these related values.

### *4.2.1. Academia*

The academic domain is the primary institutional setting for most of the interviewees, shaping their everyday work and sense of professional identity. As academic researchers, they must meet requirements for funding, publication, and collaboration while navigating less visible unwritten rules, such as following supervisors' directions and working within laboratory constraints. These overlapping expectations define legitimate research and shape academic career paths.

*4.2.1.1. Productivity pressures and hierarchical norms.* One of the most significant tensions in academia is the pressure to pursue productivity and novelty. Interviewees, especially early-career researchers, describe strong anxiety about publishing and project applications. They feel compelled to search for new materials, or keep trying to gain advantages in a crowded research space. The drive to get measurable results can overshadow more meaningful or long-term inquiry and sometimes lead to competitive exhaustion.

Hierarchical norms[13] further limit researcher independence. Supervisor preferences often determine research directions. One interviewee recalled, “[choosing this research direction] was more about the professor's arrangement, as my own ideas were still not mature (R6).” Newcomers and junior scholars often feel obliged to follow established lines of work or to prioritize group goals, especially when they have not formed their own ideas. Due to path dependence, these initial directions can also shape the trajectories they pursue later on.

*4.2.1.2. Material standards and laboratory conditions.* Academic research is expected to adhere to specific standards and technical benchmarks to maintain credibility. These standards for battery safety testing or environmental impact evaluation are widely recognized as essential for field development. In practice, however, applying these standards is not always straightforward. Even basic performance tests can depend on available resources and personal judgment, which brings a level of uncertainty. This is partly due to limitations in access to equipment and laboratory space. Researchers often have to adjust or improvise depending on what equipment and materials are available in their own labs. On the other hand, there are also shortcomings in the standardization of tests [50], and testing conditions may themselves vary across different R&D settings.

*4.2.1.3. Making sense of academic responsibility.* Interviewees generally recognized a tension between scholarly contribution and relevance to real-world problems. In some LiB research directions, industry has already surpassed academia [51], highlighting the limitations of academic research in this area. Scholars are not unaware of industry's complaints, but showing different attitudes. While some prioritized academic novelty and intellectual interest, many believe research should not just be about academic curiosity but should aim to solve actual problems and respond to practical needs. This often pushes researchers to seek connections with industry or to present their work in terms of broader social benefits, which should “be grounded and solve actual problems, starting from practical needs (R4).” At the same time, there is a “self-amusement (R4)” in academic research, leading to a decoupling (R8) between academia and industry [52].

As a developing industry, lithium battery development is no longer driven solely by academic research institutions, and industry is increasingly pushing academia forward. Academia's role as the main provider of scientific knowledge is being challenged, with its role shifting, to some extent, toward being a source of battery talent [53].

### *4.2.2. Market and industry*

In the domain of industry and market, scientific research is tested under real-world conditions. Industrial success means turning new ideas into reliable, scalable products. Researchers working with industry must balance innovation with quality standards, profit goals, and the need to adapt quickly to shifting markets, competition, and regulations. This environment requires practical solutions and constant adjustments to meet the expectations of the market and society.

*4.2.2.1. Economic filtering and risk management.* For practitioners and researchers alike, this domain is primarily governed by the logics of profitability, risk management, and rapid adaptation. While social values, such as sustainability, safety, and environmental responsibility, may influence industrial decision-making, they are consistently filtered through an economic lens. “Ultimately, all problems boil down to money (R3).” Companies may choose to assume responsibilities or adopt recycling practices if those choices align with regulatory mandates or bring economic benefits. For instance, “Companies recycle valuable elements like lithium and nickel, but not manganese (R11).” The logic of market survival means that even risk management, such as ensuring safety or minimizing reputational damage, operates not as a social mission but as a business strategy. For example, firms comply with strict wastewater and emission regulations because “wastewater must be evaporated, emissions treated—these are strict compliance requirements (R13).” Safety incidents are seen primarily in terms of market impact, as accidents clearly affect market sentiment.

*4.2.2.2. Scaling, segmentation, and standardization.* Industry has an influence on the agendas and direction of policies in other domains via its technological standards and scaling demands. “Mass production is very different from making something in the lab (R2).” Success in industry is

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[13] These hierarchical relationships are not merely informal customs but are formalized in university policies. For example, Chinese institutional documents explicitly designate graduate supervisors as “first responsible persons” for student research [72], and often require student projects to be consistent with their supervisors' research direction. This institutional regulation intensifies supervisory authority beyond informal mentorship.

based not just on being innovative in selective aspect(s), but also on being able to manufacture new materials or designs in a reliable manner and meeting the requirements of various application environments. The product's applications require a sophisticated “balancing” of multiple performance dimensions. Innovation has no value if it cannot be manufactured at scale with consistent quality, thus transferability becomes a key criteria for evaluating the relevance of research.

Scaling requires more holistic perspectives, but the market always follows a logic of division, making everything more challenging. Companies rarely pursue universal solutions; instead, they develop targeted products for specific sectors: “No one tries to cover the entire industry; companies supply for specific sectors (R3).” This logic of division and market segmentation not only affects how company operate, but also encourages professionals to specialize in particular technical domains, such as electrolytes, electrodes, recycling processes, or application contexts such as safety tests for electric vehicle batteries, and they would not normally aspire to become experts across the full spectrum of battery technology.

Furthermore, the industry actively participates in setting technical standards, often in partnership with academic experts: “Standards, jointly set by companies and experts, are crucial for the healthy development of the industry (R3).” Dominated by the interest of industry, this collaborative approach to standardization shapes the metrics and priorities by which innovation is assessed in both academia and government, further solidifying industry's position as an important gatekeeper of practical value.

*4.2.2.3. Justifying economic logic.* Economic logic is well embedded in industry participants' thinking and justification, though to varying degrees. Profit and market demand are widely accepted as not only the foundation for business actions but also as the legitimate driver for innovation and progress: “people work on batteries because there is profit; only profit motivates industry to keep advancing (R11).” This profit-centered view is often further rationalized. Commercial standards themselves are seen as legitimate, because being able to make money is taken to mean that a product has passed the test of the market and has demonstrated reliability, scalability, and the ability to meet public demand. In addition, the difficulty of commercialization leads people to view commercial products as advanced in their own right.

Trust in commercial standards becomes particularly evident when industry participants address safety incidents. When asked about reported traffic accidents involving battery fires, some argue that most incidents originate from low-level manufacturers with inadequate quality control rather than leading companies. Furthermore, they contend that while media reports of accidents persist, the actual accident rate has been declining as user bases expand, with products from major producers “generally very safe and going through strict standards and testing (R1).” This perspective highlights not merely approval but even a pride for the industry's discipline, reliability, and rigorous standards, frequently contrasted with perceived academic laxity: “Industry is ahead of academia, especially in quality control (R4).”

While researchers affirm the industry's high standards, some interviewees are more critical than others. They flip the coin and highlight the pathologies of capitalization, especially overinvestment cycles in which market-driven expansion exceeds demands, sustains zombie capacity, and produces uneven development across sectors [54]. In China, regulators curb “low-end, redundant expansion” by tightening industry rules [55]. Strategy analyses warn that capacity could exceed demand by as much as twofold in the next few years, forcing consolidation and squeezing margins [56]. This overshoots demand, channels firms into volume-chasing and thinner margins, creating governance gaps that standards cannot swiftly fix. Profit-driven imperatives can also shape corporate behavior, further exacerbating existing problems in standardization and even encouraging overhyped promotion, thereby affecting the credibility of the field as a whole.

### 4.2.3. Government and administrative authorities

Administrative bodies define the rules, priorities, and long-term direction for the battery field. Governments wield authority to create binding standards, control market access, and steer the overall trajectory of research and industrial practice. For researchers, policy decisions and regulatory frameworks are an unavoidable part of daily work, shaping what is institutionally permitted and often determining which projects or products will succeed.

*4.2.3.1. Rule-setting and regulation.* Governments establish national standards and ensure their implementation across the battery industry. Environmental and safety regulations have become increasingly stringent over time, making compliance a non-negotiable aspect of daily operations: “now basically not a drop of water can be discharged – requirements are much higher (R13).” Strict enforcement also applies to safety. If there is a major accident, such as a large fire or explosion, factories can be forced to shut down for a long period and “very hard to reopen in a short time (R13).” People working in the sector see the government's job as extending beyond standard-setting to enforcement, inspection, and rapid response to violations. This broad role is seen as necessary to protect the natural environment, ensure workplace safety, and keep the industry fair and stable.

*4.2.3.2. Policy direction and strategic resource allocation.* Government policy signals, such as those related to carbon neutrality, new energy priorities, or resource security, shape the direction of research, funding, and business strategy across the sector. Researchers shift projects and investments to align with policies. For example, researchers have responded to local demands for carbon neutrality by shifting their focus to battery recycling and carbon reduction. Additionally, governments are making efforts to ensure resource security and supply chain stability, especially as global competition or policy changes threaten access to key materials: “If foreign policies tighten, prices can rise sharply, so the biggest significance is having reserves. China has a lot of sodium, so resource security and supply chain stability are crucial (R7).”

*4.2.3.3. Calling for systematic governance.* Stakeholders in the battery sector clearly expect more systematic governance as the industry matures. From their perspective, the industry should move from fragmented efforts to more coordinated actions, such as promoting international standards, standardizing battery codes for full lifecycle tracking, or building infrastructure for intelligent and automated recycling. Furthermore, respondents believe that managerial intervention is as important as technology, and sometimes even more difficult to implement. However, conflicts remain widespread over when and how intervention should take place. While government support is widely seen as necessary for battery recycling, the design of intervention remains contested, since single policy instruments may undermine firms' motivation, reduce firm profitability, and create enterprise dependency. Additionally, one-size-fits-all regulation may produce unintended consequences by prematurely directing retired batteries into recycling even though many still retain substantial residual capacity and may be suitable for second-life use.

To a certain extent, the expectations for more systematic governance in the LiB industry reflect a desire for government and authorities to act as systemic intermediaries and coordinators. Through standard-setting, access management, infrastructure development, and long-term policy coordination, they are expected to bridge the gaps between academia, industry, and other sectors of the industrial chain [57].

## 4.3. Public perceptions

Public perceptions of battery technology shape an informal normative environment distinct from institutional explicit rules and accountability structures. Such a discursive domain operates through diffuse public attitudes, anxieties, and lived values, which are largely shaped by concerns about safety and risk. Researchers report acute public anxiety about accidents and skepticism toward new technologies; however, in this China-based study, they seldom face direct public pressure on environmental sustainability.[14] Accordingly, environmental concerns figure only marginally in public expectations. Analytically, society appears in interviews primarily as audience groups, such as consumers, invoked when researchers justify their decisions rather than as an organized domain.

### 4.3.1. Perceived safety anxieties and risk concerns

Interviewees perceive public attitudes toward LiBs, particularly those used in electric vehicles, as a mix of skepticism, optimism, and lingering anxiety. Many interviewees described public concerns about safety as a natural reaction to the uncertainties posed by new technology: “the public's belief that electric vehicles are unsafe is a natural reaction; when something new appears, people are afraid of the unknown (R3).” This sentiment was also reflected in the history: “When Tesla was first made in 2012-2013, there was a lot of doubt in both academia and industry; people thought it was unreliable (R2).”

Interviewees believe that these fears are perpetuated by “high-profile” incidents, such as battery fires in electric vehicles, which often dominate public discussion and become symbolic markers of technological risk. “Electric vehicles, being a relatively new technology, attract much more public attention than gasoline cars… once there's a technical problem, it triggers negative emotions (R11).” The endless news coverage of battery accidents creates an atmosphere of heightened vigilance, and makes the public more concerned about the safety of electric cars despite technical evidence already suggesting improvements. Underlying these concerns, both the public and the government firmly believe that “people's lives and property come first (R5)” and “safety is the most important thing (R8).”

### 4.3.2. Researcher responses to public concerns

Researchers acknowledge current risks but emphasize the need for objective and balanced perspectives. While public anxiety is understandable, they point out that not all battery applications carry the same level of danger, and some uses, such as in consumer electronics, are already highly safe in practice. For example, “with mobile phone batteries, there may be only one safety issue out of hundreds of millions or even a billion batteries, so basically there are no major problems (R11).” Similarly, “batteries for electric vehicles are basically produced by leading manufacturers, are generally very safe, and only enter the market after passing strict standards and testing (R1).” Alongside ongoing efforts to further reduce risks and address hidden dangers, researchers call for a more nuanced public understanding that avoids overgeneralization.

Meanwhile, researchers internalize, reflect on, and sometimes challenge societal views. As one interviewee stressed, “safety is a veto point. Once something goes wrong, you can [immediately] find reports of explosion or fire incidents online, and it feels terrifying. Companies worry about these risks all the time, and you must strictly follow standards, but there will always be hidden risks because of the materials involved (R13).” Researchers also perceive themselves as agents who can shape future attitudes and practices: “As a teacher, researcher, or engineer, you bring this perspective into your future work, spreading the idea that safety matters above all. It's never a joke (R11).”

Despite these tensions, many are optimistic that reliability and social acceptance will improve with trust and experience: “In another ten or twenty years, battery safety will be many times better. In fifty or a hundred years, this industry will be extremely safe (R11). ” Researchers noted that expectations for progress are strong: “Solid-state battery development has made things possible that once seemed impossible. Progress is visible every year (R2).” Most interviewees believe that public attitudes can gradually shift as familiarity and technological maturity increase. Yet risk understanding and anxiety remain highly individual and context-dependent. “Consumers' attitudes toward safety come from their own considerations; everyone has their own understanding, which is normal (R5).” Meanwhile, broader social structures, including policy, logistics, and everyday practices, shape both the perception and handling of batteries: “It's not just a technical issue—it also involves policy, the market, logistics, and the whole system, like how batteries are tested and handled (R4).”

## 5. Navigation practices: shaping value dynamics

Building on the landscape described above, this section examined four concrete navigation practices outlined in Section 3.2. Situational work is about working within a value landscape, translating ideals into technical goals and negotiating their tensions. Transformational work concerns how they reshape that landscape, positioning one's research within larger narratives and projecting futures that redefine what matters. This analysis shows that researchers in the LiB field are shaped by existing normative frameworks, while also actively responding to, adjusting, and sometimes challenging those frameworks [23,30,43].

### 5.1. Translation practices

In translation practices, researchers turn broad social values, like safety and sustainability, into specific technical goals and laboratory routines [58]. Instead of treating values as abstract principles, researchers work to make them concrete and testable in a laboratory. This process is fundamental to bridging the macro-level expectations of society, industry, and policy with the micro-level realities of laboratory experimentation and product development.

There are different approaches to increase the safety performance of the design. Researchers pick additives that lower the risk in high temperatures, short circuits, or overcharging, and design materials and battery parts to fix common problems, such as silicon swelling or gas build-up. As one interviewee explained, “At that time, I was working on these safety additives... the main purpose was to see, under conditions like high temperature, short circuit, or overcharging, how to reduce the reaction inside the battery and thus improve safety (R1).” Researchers also test materials to see how much heat is produced and at what temperature reactions start, making safety a concrete, testable metric.

Sustainability follows similar translation processes. Researchers select cheaper or less polluting materials, and some use soy-based binders to reduce both pollution and costs. In battery recycling, they focus on recovering valuable metals and reducing secondary pollution from wastewater and harmful gases [59]: “We pay close attention to environmental protection during the recycling process, especially secondary pollution issues, such as fluoride in electrolytes and wastewater... hoping that recycling processes achieve clean handling and don't cause secondary pollution (R13).” In practice, this means tracking gas, water, and waste produced, measuring energy use, and minimizing emissions and pollution.

These translations are neither one-to-one nor neutral. A given value can be translated into different technical targets and laboratory routines, and a particular technical translation may also respond to multiple expectations at macro level. For example, raising the onset temperature of thermal instability may simultaneously serve academic contribution, regulatory requirements, and industrial expectations. At the same time, these translations are highly path-dependent, because these evaluations operate through the standards and logics they have already established. Translation therefore does not simply make values concrete and actionable. It also narrows them by privileging indicators and specifications through which a value is defined and pursued in research and development.

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[14] This is also consistent with the comparative volume of media coverage on safety and sustainability issues.

### 5.2. Negotiation practices

While translation establishes specific metrics, it can also foreground tensions when different values or translations clash. A tension enters negotiation when researchers come to see that, under current technical conditions, it cannot be removed through further optimization of an existing design. The issue then becomes how to decide among different options. However, when the same tension is still seen as technically open, especially in early-stage research, it can also become a point of excitement and a target for a breakthrough. This helps explain part of the enthusiasm around solid-state lithium batteries, as some researchers believe the present tension between safety and energy density may be eased in the future.

A basic strategy of resolving tensions is to negotiate through pre-existing evaluation systems. Existing guidelines, testing procedures, and regulatory requirements all help to define acceptable levels of safety, sufficient performance, and meaningful changes. While tensions can arise between values, they can also be aligned in specific institutional settings. In academic research, novelty is often identified by significant advancements in a single performance characteristic. Therefore, academic value is often associated with advancements in a single dimension. While this focus on singular parameter advancements can encourage exploratory research during the initial phases of research development, it is also often criticized for isolating one dimension from the wider evaluative framework that limits eventual uptake and use.

As research moves closer to product application and market entry, balancing becomes more pressing. Researchers also focus on balancing and optimizing multiple factors, such as performance, cost, and safety. As one interviewee put it, "in product applications, you cannot compromise existing performance, and there must be clear improvements in some areas. Only then can the technology be used in practice (R1)." At this stage, progress is assessed across several dimensions at once, and gains in one area have to be weighed against losses or risks in another. The result is rarely a solution that is the "best" in every respect.

Another common way to resolve tension is to assign different priorities and even what is considered desirable in different application contexts. For example, researchers continue to develop alternative battery technologies, such as zinc-ion and sodium-ion batteries, and select zinc-ion batteries for large-scale grid-based power storage because "they are safer and cheaper than lithium-iron-phosphate and therefore better suited for large-scale power storage, although their energy densities are lower (R2)," while electric vehicles require greater energy density and more stringent safety protocols. Therefore, the relative importance assigned to energy density can vary depending upon the application scenario, since some application scenarios do not require the maximum possible energy density, and further increases in energy density may also experience diminishing returns.

### 5.3. Positioning practices

Positioning practices establish researchers' relational location within institutional and industrial landscapes, building connections that define "where I am" in the field [60]. In positioning practices, researchers frame their work as contributing to established broader societal, technological, or industrial goals. Researchers present research objectives in terms of supporting national competitiveness, solving practical problems, or deepening theoretical understanding. They often describe their work as fitting within these broader agendas, for example, by supporting material testing or improving recycling capacity. This positioning is reinforced through their participation in collaborations with companies, government departments, and multi-institutional platforms.

Positioning is based upon personal decisions regarding a researcher's area of study and are influenced by both the mentorship and macro-level needs. Some interviewees pursued a specific line of research for many years, and even longer than two decades, becoming closely identified with that direction and its perceived social value. For example, after early shift, one interviewee has "basically only worked on lithium batteries (R11)," and believed that "lithium batteries are not a short-term technical enterprise (R11)." Others explained that they had begun working in solid-state batteries very early in their careers and were proud of being able to "develop methods before most researchers in China (R2)" and that their group's work had "pushed the industry and research field forward (R1)."

Positioning also takes shape through close collaboration with industry and government. Researchers described established partnerships aimed at moving technical expertise into products. Some researchers work through industry alliances where universities and companies solve practical problems together, or participate in government-supported projects focused on closed-loop recycling or developing key new materials. These collaborative efforts offer researchers the potential to support national strategic objectives, industrial modernization, and public welfare. Through such collaborations, researchers establish their daily work within the context of previously established agendas and development pathways.

### 5.4. Projection practices

Unlike positioning's descriptive stance, projection practices articulate normative visions of desirable futures for policy, infrastructure, and system-level change [61]. In projection practices, researchers not only envision these futures but also strive to actively shape the future of the battery industry at both the project and policy levels. This forward-looking mindset extends beyond individual research topics to address large-scale industry transformation.

Researchers in projection mode take more active roles than positioning alone. Some researchers lead or participate in major national projects designed to drive technological innovation and shape future industry standards. For example, some researchers take responsibility for national-level projects to advance large-scale energy storage solutions; some collaborate closely with government agencies, collecting and analyzing regional data to optimize the management. Through these collective efforts, researchers are not just responding to external needs but proactively working toward more coordinated and systematic industry development.

Researchers also express hopes for more systematic, industry-wide improvements that cannot be achieved by individuals or single teams alone. While calling for better macro-level management, especially for recycling and closed-loop systems, some researchers already contribute through activities such as refining industry standards and helping companies diagnose material performance issues. However, more complex directions of collaboration, such as "more intelligent and precise recycling, using robots for disassembly rather than people" (R14), and "cleaner, greener production, using low-toxicity reagents and technologies that cut waste and emissions" (R13), require cross-disciplinary collaboration.

The projected future states are beyond the ability of individual researchers or small groups of researchers to realize alone. Thus, projection practices express not only what desirable outcomes could occur, but also a vision for system-wide directions that will require coordinated effort from multiple parties in academia, industry and government to realize. In addition, many of the value-based hopes of researchers, such as the development of closed-loop recycling systems and improvements in the safety of battery management systems for electric vehicles, are far beyond the capabilities of individual actors and require collaboration. However, securing such collaboration in reality has proven to be a challenge due to the existence of disparate responsibilities, information flows and regulatory frameworks along the battery supply chain.

## 6. Discussion: possibility space, processes, and tensions in transition

The findings suggest that the low-carbon energy transition can be better understood as an ongoing process of exploration in which ends and means co-evolve, not as linear progress toward predefined and fixed goals [23,62]. In LiB research and development, both the meanings attached to values and the tensions among them change continually. Material trade-offs become intertwined with changing standards of acceptable performance. Thus, technical practice became a site where competing visions of the energy transition are enacted and contested.

In response to the question of how technology developers engage in value dynamics, the empirical analysis shows that value dynamics emerge through a recursive process at two levels. First, researchers operate within a pre-existing structured value landscape where material constraints, institutional rules, and public perception generate different priorities, which creates a complex terrain of intersecting expectations and pressures. Second, researchers actively reshape this landscape through navigation practices, so that responding to value tensions simultaneously reconstitutes what values mean and how they are prioritized.

Building on this, Section 6.1 interprets the value landscape mapped in Section 4 and describes it as a possibility space that both limits and enables researcher action. Section 6.2 examines the navigation practices identified in Section 5 and analyzes how individual practices propagate and stabilize into field-wide transformations. Section 6.3 further discusses what LiB researchers' experiences reveal about value dynamics in energy transition.

### *6.1. The value landscape as possibility space for the low-carbon energy transition*

Section 4 revealed that researchers' value beliefs are shaped by three domains: material constraints, institutional structures, and public perceptions. While researchers have general agreement about what is valued, such as safety, energy density and sustainability, they diverge in how they rank these values, justify their priorities, and interpret the values in practice. This divergence is shaped by researchers' personal value systems and their positions within the landscape. This section interprets these findings by characterizing the value landscape as a “possibility space” that both limits and enables researcher action.

The ongoing energy transition is developing a bounded space of possibilities. The material domain defines the basic boundaries of what is technically achievable by imposing physical constraints. The institutional domain establishes standards and rules for legitimate practices. Public perceptions create normative pressures around safety mainly through concerns about safety and environmental issues, although its constraining force remains relatively weak. Crucially, values within these areas remain unrealized until actors implement them through practice. The values of the material domain are successfully embedded through the design and use of artifacts; values in the institutional domain are activated through the actual compliance with institutional codes or hidden norms.

Individual researchers play important roles in this value realization process. The analysis shows the researchers are actively reflecting upon the normative terrain. Researchers bring their own values and understanding to this landscape, functioning like magnetic elements within a larger field. Their personal convictions about safety, sustainability, and technical innovation interact with collective expectations, creating localized variations in how values are understood and pursued. For more experienced researchers, there is often broad consensus, to some extent, on what is important or valued. What tends to shape their concrete actions is the priorities of those values and the justifications behind them. Because individuals differ in how they understand scientific innovation and economic value, they may make different choices when faced with weariness toward publication-driven academic incentives.

This possibility space for the low-carbon energy transition is neither uniform nor static. Tensions between domains can create productive friction. On the one hand, different domains operate according to distinct core logics and requirements, such as academic demands for novelty versus industry requirements for reliability, or material constraints versus societal safety expectations. On the other hand, different domains may interpret the same value differently. The trade-off between energy density and safety was interpreted quite differently depending on the institutional setting. In industrial collaboration, researchers have tended to define safety as a non-negotiable threshold established by regulatory authority, whereas in fundamental academic research, safety can be viewed as an open-ended problem whose boundaries could be pushed through the development of new materials.

The ways individual researchers interpret these values also evolve continuously. When researchers react to salient issues like battery fires or recycling challenges, these issues draw attention across the entire sociotechnical system, triggering regulatory reviews, industry responses, media coverage, and public debate. Consequently, researchers encounter evolving expectations and understandings across these domains. Their perceptions of values are influenced more directly by the increasingly strict test metrics and the increasing number of regulatory requirements. While researchers may perceive that public discourse makes their work more relevant, they view it as less influential than other sources because i can be mediated by problematic media coverage. The degree to which researchers experience these influences depends on their individual experiences and interactions with individuals in their environment.

### *6.2. How individual practices relate to macro transformation*

Building on Section 5, this section examines how individual navigation practices relate to collective transformation. Positioning and projection bear more direct relation to emerging macro transformation, as they link local research to broader agendas, collective expectations, and future-oriented commitments that can organize attention and access beyond the immediate research setting [63]. Translation and negotiation, by contrast, reflect macro changes that are already taking place, which can shape further scaling. Through the creation of parameters, tests, and standards that are transferable across contexts [64], and through the aggregation of these into templates for prioritizing based upon specific contextual circumstances, translation and negotiation create signals that shape other actors' perceptions of what the field is heading toward and what will be considered relevant, credible, and worthy of pursuit. As such, the existing outcomes of translation and negotiation play an important role in personal understandings of macro-level trends, even before they are taken up through more influential coordination.

These practices are loosely coordinated by two forces. First, institutional frameworks specify accountabilities and pathways for uptake that channel individual practices toward collective recognition; second, researchers reflect on the material constraints and social expectations in the milieu of their daily work and determine how to best adapt to them. Researchers' translation of abstract values can specify detailed technical objectives and bring hidden value tensions to light, necessitating negotiation to resolve them. Negotiation is based on existing translations but also depends on the context of positioning. Projection likewise depends on an understanding of the current position and, if successfully taken up, will further influence subsequent navigation practices.

However, these practices do not always contribute to the intended changes in the landscape. Successful scaling requires institutional leverage and temporal opportunity. Leading scientists who are important members of organizations or projects can convert positioning and projection into field-level levers more easily, while laboratory researchers typically perform translations as adaptations rather than as drivers of change. Having access to the institutionalized venues where coding and diffusion can occur, such as committees, shared testbeds, and data formats, accelerates codification and diffusion [65]. The representation of relevant issues such as accidents, can open temporal windows for introducing new tests or templates, and the political organizational opportunity structure determines when and how the individual practices can contribute to collective transformation [66].

### 6.3. *Asymmetric recursion and distributed transition*

So far, this section has pictured a bidirectional process where researcher practices and value landscapes continuously reshape each other. However, the conditions identified in Section 6.2 reveal that this reshaping encounters significant constraints and operates unevenly across the field. The process is asymmetric; even highly authoritative actors encounter structural limits. The landscape evolves through the cumulative effects of multiple navigation choices, rather than through centralized decision-making.

The asymmetry can appear in three ways. (1) Temporal Asymmetry: individual researchers can be affected by the current landscape of values as soon as they enter the field, whereas the effects of their actions can be time delayed depending upon whether others adopt, codify, scale up these actions; (2) Scalar Asymmetry: landscapes can exist at a macro level due to dominant narrative structures, while practices can occur at a micro level as part of an individual's decision making process, in the context of local negotiation(s), and/or in relation to specific project(s); and (3) Mechanistic Asymmetry: landscapes condition or selectively constrain what is possible, while practices influence landscapes through constitutive and interpretive mechanisms [30] that define what is meaningful and/or acceptable.

The capacity to shape energy transition is neither equally distributed nor completely localized in any particular actor or site. Agency is distributed across the entire sociotechnical system, where artifacts possess “delegated agency” [19]. Moreover, sociotechnical momentum generates uneven traction, and the agency to alter trajectories is correspondingly uneven. To steer sustainable transition, effective interventions begin by mapping the carriers of momentum, including artifacts and installed bases, routines and skills, institutions and finance, standards and quality control, and field narratives and expectations.

This asymmetric and distributed structure can create tensions. At the individual level, researchers can experience constraint and marginalization. Sociotechnical momentum produces weak participation where engagement becomes perpetual adaptation rather than genuine shaping of transition processes. When individual values fail integration, industrial priorities can drift from ground-level needs. For instance, the relentless chase for higher energy density yields diminishing user returns once typical daily driving is already covered by current ranges. In such cases, lower-cost, safer batterie, such as lithium iron phosphate (LFP) batteries, often become more attractive in applications like stationary storage, where cost, cycle life and safety matter more [67].

Yet the landscape's distributed character also constitutes its generative capacity, as power and possibility circulate through multiple sites rather than concentrating in a single locus, thereby enabling polycentric, modular interventions to redirect momentum through coordinated local adjustments rather than wholesale reconfiguration [68]. To further progress the desired energy transition, the problem is not whether to embrace or resist this distributed structure, but how to make the structure more generative, which requires reducing coordination friction. Examples of such include testing infrastructures that facilitate the translation process, boundary-spanning consortia that facilitate negotiation processes across domain boundaries, and experimentation spaces that keep alive options that would be foreclosed by the pressures of markets.

## 7. Conclusions and implications: toward a more generative energy transition

This study zooms into the micro-level dynamics underlying value change in energy transition through interviews with LiB researchers. By conceptualizing values as justified beliefs, the study maps the value landscape around the salient issues of safety and recycling across material, institutional, and public domains. The analysis further showed that energy transition occurs in an ongoing interplay between structured value landscapes and distributed navigation practices. The findings suggest that low-carbon transition is not a simple linear move toward sustainability; changes toward sustainability also reshape the wider value landscapes, because values are interconnected, differently prioritized, and interpreted through researchers' personal commitments. Accordingly, the outcomes of transition are generated from the continuous restructuring of value landscapes while actors navigate tensions, which limits the possibility of steering them toward a single predefined end-state. Governance should therefore focus more on shaping conditions under which practices responsive to shifting value tensions can emerge, circulate, and stabilize.

Encouraging these practices is not simply a matter of promoting technological innovation and its diffusion, but of better reconciling actors to the value landscapes they navigate, recognizing that they are neither fully empowered nor merely constrained. As particular values and their translations become entrenched in standards, metrics, and common routines, they will establish some stability for certain practices, yet they will also confine researchers to path-dependent ways of defining what counts as progress, relevance, and worth optimizing. On this basis, a governance approach that fosters mutually beneficial co-evolution is preferable to one that imposes conformity or leaves actors to navigate value tensions in isolation. This means creating conditions for ongoing calibration between individual values and systemic needs. Such governance may include legitimizing multiple value translations, supporting experimentation without immediate scaling pressure, building circulation infrastructures such as shared testbeds and cross-sector forums, and establishing reflexive feedback loops for course correction [69,70].

The scope of this analysis is limited by several factors. The focus on LiB researchers in specific institutions limits the generalizability of the value interpretations and specific value practices described in this study to other technologies or other institutional settings. Primarily based on researcher perspectives, the research represents only one perspective on the interactions among the various stakeholders involved in the process of developing LiB technology. Moreover, interviews allow access to first-person descriptions of experiences but do not permit precise assessment of the degree to which individual actions contribute to macro-level transformations. However, at the same time, the basic structure of the value landscape and the broader pattern of navigation practices may be relevant beyond LiB research. Other energy technologies are also shaped by competing technical, economic, and societal demands, even if specific translation, negotiation, positioning, and projection practices can take different forms. The study offers an analytical approach for examining how those micro-level dynamics link to larger-scale sociotechnical transitions.

Future research can build upon this study in several ways. For example, to better explore micro-level dynamics, studies could examine action-formation processes more closely through fieldwork around critical events. Studies that consider additional actors such as policymakers, industry managers, and users could provide a more comprehensive view of the distributed transition. To better understand the micro-macro linkage in energy transition, research can integrate methods from other social science disciplines. Policy analysis, for instance, could trace how navigation practices crystallize into formal institutions. Comparative work across technologies and across national contexts could clarify which dynamics are technology-specific and which reflect broader patterns of sociotechnical change. Finally, experimental policy studies that design and evaluate governance interventions could provide evidence for the practical applications of hypothetical ideas and help to refine our understanding of how to cultivate more generative energy transition landscapes.

## CRediT authorship contribution statement

**Yunxuan Miao:** Writing – review & editing, Writing – original draft,

Project administration, Methodology, Investigation, Data curation, Conceptualization.

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The author declares no known competing financial interests or personal relationships that could be perceived to influence the work reported in this paper.

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## Data availability

The data that has been used is confidential.

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