# D6.3

# Preliminary Social assessment

**version 1.0**

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## Abstract

This deliverable presents the mid-term results of the Social Life Cycle Assessment (S-LCA) activities within GRAPHERGIA, establishing a robust methodological framework aligned with UNEP/SETAC guidelines and integrated in the project's Life Cycle Sustainability Assessment (LCSA) approach. The work combines stakeholder-specific surveys (workers, researchers, value-chain actors, society) with secondary data from the Social Hotspot Database (SHDB), enabling both bottom-up insights and top-down risk screening. Preliminary findings highlight strengths such as contracts, social benefits, and safety training, but reveal critical areas for improvement: limited health surveillance, insufficient awareness of chemical-exposure protocols, and gaps in overtime compensation and contract stability. Research stakeholders emphasised healthcare applications, recyclability, and regulatory readiness as priorities for e-textiles and energy storage demonstrators. The deliverable outlines next steps including expanded survey participation, integration of SHDB with final Life Cycle Costing (LCC) datasets, and eco-design recommendations targeting fair work practices, Occupational Health and Safety (OHS) reinforcement, and design-for-circularity.

## Keywords

Social Life Cycle Assessment (S-LCA); Graphene-based technologies; Stakeholder engagement; Occupational Health and Safety (OHS); Circular economy & eco-design; Social Hotspot Database (SHDB)

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# Abbreviations

| | |
|---|---|
| **2D** | Two-dimensional |
| **DPP** | Digital Product Passport |
| **DRC** | Democratic Republic of the Congo |
| **EC** | European Commission |
| **E-LCA** | Environmental LCA |
| **EMAS** | Eco-Management and Audit Scheme |
| **EoL** | End-of-Life |
| **EU** | European Union |
| **EV** | electric vehicle |
| **GDPR** | General Data Protection Regulation |
| **GRI** | Global Reporting Initiative |
| **H&S** | Health and Safety |
| **ILO** | International Labour Organization |
| **ISO** | International Organization for Standardization |
| **LCA** | Life Cycle Assessment |
| **LCI** | Life Cycle Inventory |
| **LCC** | Life Cycle Costing |
| **LCSA** | Life Cycle Sustainability Assessment |
| **LCT** | Life Cycle Thinking |
| **LEED** | Leadership in Energy and Environmental Design |
| **LIBs** | Lithium-ion batteries |
| **LMO** | Lithium Manganese Oxide |
| **NGO** | Non-Governmental Organization |
| **NMC** | Nickel Manganese Cobalt Oxide |
| **NMC-G** | Nickel Manganese Cobalt Oxide - Graphite |
| **OHS** | Occupational Health and Safety |
| **PhD** | Doctor of Philosophy |
| **PPE** | Personal Protective Equipment |
| **PSILCA** | Product Social Impact Life Cycle Assessment database |
| **QA/QC** | Quality Assurance/Quality Control |
| **R&D** | Research and Development |
| **RRI** | Responsible Research and Innovation |



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| | |
|---|---|
| **SDGs** | Sustainable Development Goals |
| **SHDB** | Social Hotspots Database |
| **SETAC** | Society of Environmental Toxicology and Chemistry |
| **S-LCA** | Social Life Cycle Assessment |
| **SMEs** | Small and Medium-sized Enterprises |
| **STEM** | Science, Technology, Engineering, and Math |
| **TRL** | Technology Readiness Level |
| **UNDP** | United Nations Development Programme |
| **UNEP** | United Nations Environment Programme |
| **VRFB** | Vanadium Redox Flow Battery |
| **WP** | Work Package |



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# Executive summary

The GRAPHERGIA project, supported by the European Union and aligned with the Graphene Flagship initiative, focuses on developing and evaluating sustainable graphene-based technologies for applications in energy storage, smart textiles, and aerospace sensors. Its goal is to design innovative, circular, and socially responsible solutions from the earliest development stages, ensuring that advances in performance and functionality are matched by positive societal outcomes.

This deliverable presents a preliminary Social Life Cycle Assessment (S-LCA) of selected graphene-based demonstrators, aimed at supporting early-stage decision-making by identifying social risks and opportunities, evaluating stakeholder impacts, and guiding socially conscious design strategies throughout the development chain. The analysis follows the UNEP/SETAC S-LCA Guidelines and complements the environmental and economic assessments carried out in parallel.

The study focuses on three key demonstrators representative of distinct application domains:

- Self-charging textile systems for energy harvesting and storage in smart clothing and upholstery;
- Self-powered aerospace sensors, integrated into composite structures for wireless strain and temperature monitoring;
- Graphene-based lithium-ion battery modules tailored for space applications and tested on CubeSat platforms.

The S-LCA adopts a multi-method approach:

- Worker-level survey to collect bottom-up insights on employment conditions, rights, occupational safety, and well-being.
- Company-level questionnaire to assess organisational practices, social responsibility, and supply chain engagement.
- Product-level risk screening using the Social Hotspot Database (SHDB) implemented in SimaPro, enabling a comparative mapping of potential risks across global value chains for each demonstrator.

Preliminary findings highlight strong compliance with safety standards and the presence of skilled employment opportunities across the demonstrators but also point to improvement areas such as formalising gender equality policies and increasing transparency in sustainability reporting.



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SHDB analysis reveals that upstream stages involving critical raw materials for graphene synthesis are associated with higher social risk, particularly in relation to labour rights, governance quality, and community well-being.

While this is an initial assessment based on a mix of laboratory-scale and secondary data, it establishes a robust baseline for integrating social performance considerations into GRAPHERGIA's technology development. Future phases will expand the scope with improved datasets, broader stakeholder engagement, and inclusion of end-of-life stages to achieve a full life cycle perspective.

Ultimately, this S-LCA contributes to GRAPHERGIA's broader mission of enabling high-performance graphene-based solutions that are not only environmentally and economically viable but also socially equitable, aligned with European Green Deal objectives and the transition to a just, circular economy.



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# 1 Introduction

The social and socio-economic impacts of emerging technologies are increasingly recognized as critical factors in ensuring that innovation contributes to inclusive, fair, and sustainable development. As advanced materials such as graphene enter the market, assessing their potential effects on workers, communities, consumers, and value chain actors becomes essential to guiding responsible innovation and supporting societal well-being [1][2].

In this context, graphene and other 2D materials hold significant promise for sectors such as wearable electronics, aerospace, and next-generation energy storage systems. Their unique mechanical, electrical, and thermal properties enable technological breakthroughs, including self-powered textiles, integrated structural sensors, and graphene-based batteries, but also raise important questions about labour conditions, supply chain transparency, and equitable access to benefits [3][4].

Turning promise into practice requires early and systematic attention to social performance across the entire life cycle—from raw material sourcing and synthesis to product use and end-of-life. Upstream, the provenance of carbon precursors and the energy intensity of certain production routes interact with local employment prospects, health and safety practices, and regional development strategies. Midstream, scale-up often occurs in start-ups and SMEs operating under tight timelines and financial pressure; without careful planning, this can translate into precarious contracts, overtime peaks, and gaps in training for safe handling of nanomaterials. Downstream, the integration of graphene into electronics, vehicles, and textiles creates new maintenance and repair routines for users and service workers, who must be equipped with guidance and protective measures tailored to the specific form and matrix of the material [4][5][6].

A responsible approach integrates Social Life Cycle Assessment with human-rights due diligence and safety-by-design. Concretely, this means mapping supply networks, identifying social hotspots, and co-developing mitigation measures with suppliers, workers, and communities. Practical actions include engineering controls and closed systems to minimize emissions and dust, transparent disclosure of process chemicals, living-wage and fair-working-hours policies, and grievance mechanisms that elevate worker voice. Third-party audits should be complemented by participatory monitoring and continuous improvement plans that are publicly reported, not merely filed away for compliance [7][8][9].

Community impacts extend beyond the factory gate. The siting of pilot lines and gigafactories can reshape local economies, transport flows, and land use, with implications for housing affordability, air quality, and emergency preparedness. Early and ongoing engagement with municipalities, unions, and civil society helps align project design with local priorities, while community-benefit agreements, local procurement targets, and investment in workforce development ensure that value creation is anchored where production actually happens. Environmental monitoring and transparent incident reporting further reinforce trust and accountability [10][11][12].

On the demand side, consumer trust depends on safety, performance, and usability, but also on durability, reparability, and responsible end-of-life. Graphene-enabled devices and textiles should be designed to minimize particle shedding, facilitate disassembly, and interface with collection and recycling systems that already struggle with complex electronics and multi-material garments. Clear labeling and traceability tools—such as Digital Product Passports (DPPs)—can make claims verifiable, inform circular business models, and help avoid greenwashing. Extended producer responsibility and accessible repair services can align incentives throughout the chain [13][14][15].

Transparency is also a precondition for fair competition and policy alignment. Companies and research consortia can publish social key performance indicators alongside technical metrics: exposure measurements and occupational safety incident rates; hours of training per worker; supplier audit coverage and follow-up closure rates; share of local procurement; and gender and diversity indicators in STEM roles. Open, machine-readable data standards allow these metrics to travel with materials and components across complex chains, enabling regulators, investors, and civil society to compare progress. Verification by independent laboratories and public dashboards reduces the risk of selective disclosure [16][17].

Equity considerations arise at multiple scales. Within firms, the transition to advanced materials demands new skills; inclusive hiring, paid apprenticeships, mentorship, and reskilling programs reduce the risk of widening wage gaps. Across regions, public funding and strategic procurement can prioritize projects that deliver affordable, reliable benefits—safer batteries for grid storage, sensors that extend the life of public infrastructure, and wearables that improve occupational safety—to communities that would otherwise be last in line. Licensing models, technology transfer, and open standards can support local manufacturing capacity and prevent excessive concentration of value in a few hubs [18][19].

Responsible innovation is iterative. It requires anticipatory scenario analysis for rebound effects and unintended consequences—for example, wearable sensors that collect more personal data than users expect, or supply bottlenecks that concentrate market power and weaken labour rights. Crucially, workers and end-users should be treated as co-designers whose experiential knowledge informs requirements, testing protocols, and acceptance criteria [20].



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Ultimately, delivering on the promise of graphene depends as much on governance as on physics. By pairing scientific excellence with social intelligence—embedding safety, participation, and fairness from lab to market—innovation is more likely to enhance resilience and public value, supporting societal well-being [1]. In parallel, credible traceability, worker protections, and open access to knowledge can help ensure that breakthroughs do not amplify inequalities but instead expand opportunity, strengthen supply chain transparency, and improve equitable access to benefits [3].

The GRAPHERGIA project addresses these dimensions through a dedicated Social Life Cycle Assessment (S-LCA), complementing environmental and economic analyses. The S-LCA evaluates the potential social risks and opportunities associated with GRAPHERGIA technologies, using a methodology aligned with the UNEP/SETAC guidelines and tailored to the project's value chains. It covers five stakeholder groups: workers, consumers, local communities, society, and value chain actors.

Primary data are collected through customized surveys targeting individuals and organizations directly involved in GRAPHERGIA-related processes, while secondary data from recognized social assessment databases provide a global and comparative perspective. This integrated approach allows for the identification of:

- Potential positive contributions, such as job creation, skills development, and enhanced safety standards.
- Possible risks, including labour rights issues, unequal distribution of benefits, or negative community impacts.

By embedding social considerations from the earliest development stages, GRAPHERGIA ensures that technological advances are not only high-performing and cost-efficient, but also socially responsible and widely accepted. The outcomes of this S-LCA contribute to the European Green Deal objectives and support the transition toward a circular, climate-neutral, and socially inclusive economy.

## 1.1 Description of the document

This deliverable presents the methodological framework, implementation process, and main findings of the sustainability assessments conducted within the GRAPHERGIA project, with a specific focus on the S-LCA carried out under Task 6.3. The S-LCA complements the environmental and economic evaluations performed for selected graphene-based technologies in key application areas, including electronic textiles, energy harvesting, and advanced materials.

The overall goal is to provide an integrated evaluation of environmental, economic, and social performance, supporting the GRAPHERGIA vision of developing high-performance, sustainable solutions. The environmental component is addressed through a comprehensive Life Cycle Assessment (LCA) of selected graphene-enabled products and components, covering multiple impact categories across their full life cycle. The economic dimension is analysed via Life Cycle Costing (LCC) and cost-feasibility assessments to evaluate viability and scalability.

The social dimension, developed through S-LCA, focuses on identifying social and socio-economic benefits and potential risks linked to GRAPHERGIA processes and products.

The methodology follows four main steps:

- Goal and scope definition aligned with project objectives.
- Inventory analysis, mapping drivers of social impacts for five key stakeholder groups: workers, consumers, local communities, society, and value chain actors.
- Impact assessment using selected social indicators.
- Interpretation to identify opportunities for improvement.

The S-LCA methodology combines field-based primary data collection via customised surveys with secondary data from recognised social assessment databases. The results are expected to provide actionable insights for promoting stakeholder and consumer acceptance, stimulating demand for sustainable materials, and contributing to strategies for job creation and local development.

The outcomes of this deliverable will offer decision-support for research, industrial innovation, and European policymaking in the field of advanced and sustainable materials. By integrating environmental, economic, and social indicators, this assessment fosters responsible innovation and supports the transition toward more inclusive and sustainable production systems.



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# 2 Methodology

## 2.1 Social Life Cycle Assessment: A Framework for Assessing Social Sustainability in Industrial Systems

In the past decade, the social dimension of sustainability has gained prominence alongside environmental and economic considerations. Whereas traditional assessments primarily addressed ecological impacts and financial performance, there is now increasing recognition of the need to account for factors such as labour conditions, human rights, and community well-being. In this context, S-LCA has emerged as a structured methodology for identifying and analysing the potential social and socio-economic impacts of products and services throughout their life cycle, from raw material extraction and processing to manufacturing, use, and end-of-life management.

Within European research and innovation initiatives, particularly those aligned with the objectives of the European Green Deal, the Just Transition Mechanism, and the United Nations Sustainable Development Goals (SDGs), S-LCA plays a key role in assessing how technological innovation and value chain transformations affect diverse stakeholder groups, including workers, local communities, consumers, and society at large. The insights derived from S-LCA help ensure that innovation pathways avoid reinforcing social inequalities or breaching ethical principles.

S-LCA is one of the three pillars of Life Cycle Sustainability Assessment (LCSA), complementing Environmental LCA (E-LCA), which quantifies environmental burdens, and LCC, which evaluates economic performance. Unlike these two approaches, S-LCA adopts a human-centred perspective, emphasising aspects such as well-being, equity, labour rights, occupational health and safety, and social inclusion along the value chain. This integrated approach is especially relevant in emerging bio-based and circular systems, where social impacts may vary considerably depending on geographic context, supply chain structures, and institutional frameworks.

By embedding the social perspective into Life Cycle Thinking (LCT), S-LCA supports evidence-based and ethically sound decision-making for the development of sustainable production and consumption systems [1][21][22][23].

## 2.2 Methodological Foundations and Stakeholder Perspectives

S-LCA builds upon the well-established principles of LCT, as codified in the ISO 14040 and ISO 14044 standards. These standards provide the general structure for conducting Life Cycle



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Assessment (LCA), including goal and scope definition, inventory compilation, impact assessment, and interpretation. However, S-LCA extends these principles by incorporating methodological elements tailored to evaluating social and socio-economic impacts. The main reference framework is the UNEP Guidelines for Social Life Cycle Assessment of Products and Organizations [22], which offer a systematic approach for integrating social considerations into life cycle-based studies.

Unlike Environmental LCA, which relies predominantly on quantitative, physical, and emissions-related data, S-LCA frequently requires the integration of qualitative and semi-quantitative data, derived from stakeholder engagement, expert judgement, and proxy indicators. This methodological flexibility enables the assessment of complex and context-dependent issues such as labour practices, equity in resource distribution, and community well-being dimensions not easily captured by environmental or economic metrics alone.

The stakeholder-oriented nature of S-LCA is a defining feature. Stakeholder groups considered may include:

- Workers (covering aspects such as wages, occupational safety, freedom of association)
- Local communities (including access to infrastructure, social cohesion, and cultural heritage)
- Value chain actors (e.g., suppliers, distributors, service providers)
- Consumers (e.g., product safety, access, and affordability)
- Society at large (broader public health and governance impacts)

The selection of relevant indicators depends on the potential risks and benefits faced by these groups and requires contextualisation within the geographical, cultural, and industrial setting of the study [24][23][25][22][26]. This participatory and context-sensitive approach enhances transparency and ensures that social impacts are meaningfully interpreted rather than treated as generic metrics.

### 2.2.1 Data Collection Challenges and Impact Assessment

A significant challenge in implementing S-LCA lies in obtaining reliable, site-specific social data, especially within complex, multi-tiered global supply chains. Environmental LCAs can often rely on harmonised and quantitatively robust datasets (e.g., Ecoinvent, GaBi), whereas social data tends to be more fragmented, qualitative, and sensitive to local socio-economic contexts. Data sources may include government statistics, sectoral reports, industry audits, and structured interviews, each with varying levels of transparency and reliability.



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The qualitative nature of many social indicators inevitably introduces a degree of uncertainty and subjectivity into the assessment. To manage this, best practices include triangulation of multiple data sources, explicit documentation of assumptions, and the use of proxy measures when direct data are unavailable. Participatory approaches, such as focus groups, stakeholder workshops, and ethnographic observation, can enhance both the credibility and legitimacy of the findings [27][28].

In the impact assessment phase, S-LCA practitioners often apply structured frameworks such as reference scales, risk matrices, or scoring systems that translate qualitative inputs into semi-quantitative categories. This enables systematic comparison across life cycle stages. Databases and tools like the Social Hotspot Database (SHDB), Product Social Impact Life Cycle Assessment (PSILCA), and the Fair Wage Network provide pre-calculated country- and sector-specific risk profiles, including indicators on wages, corruption levels, child labour prevalence, and gender equity. While these resources are valuable for screening and benchmarking, results must be carefully contextualised to reflect site-specific realities [29][30].

### 2.2.2 Application of S-LCA in European Technology and Innovation Projects

In European research and innovation projects, particularly those funded under Horizon Europe, Horizon 2020, and other strategic EU programmes, S-LCA provides a systematic means to evaluate the societal implications of emerging technologies. These projects often emphasise not only environmental and cost efficiency but also inclusiveness, equity, and ethical responsibility in line with Responsible Research and Innovation (RRI) principles.

In sectors such as advanced materials, electronics, and energy systems, S-LCA can highlight potential risks and opportunities related to employment quality, occupational safety, technology accessibility, and local community impacts. For example, innovations in graphene-based components for energy storage or aerospace may create high-skilled employment in manufacturing hubs but could also rely on critical raw materials sourced from regions with elevated social risks.

By identifying these upstream and downstream effects early in the innovation process, S-LCA enables the anticipation of unintended consequences and supports the design of socially responsible supply chain strategies. This is particularly relevant for projects like GRAPHERGIA, where technology deployment may involve globalised material sourcing and high-value niche applications. Insights from S-LCA can inform targeted mitigation measures, strengthen supply chain governance, and enhance stakeholder acceptance, ultimately contributing to a more just and equitable innovation pathway [29][31][32][33][34].



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### 2.2.3 Future Outlook and Development Pathways

As the European Union advances toward climate neutrality and a just transition, through policy frameworks such as the European Green Deal and the Fit for 55 package [35][36], the integration of social sustainability metrics into LCT will become increasingly indispensable. While environmental and cost assessments remain essential, they provide only part of the picture; the social dimension is critical to ensuring that technological change benefits all segments of society.

S-LCA's stakeholder-centred and context-driven methodology makes it uniquely suited for uncovering systemic inequalities, identifying social risks, and co-creating mitigation strategies. In the case of cutting-edge industrial systems such as those developed in GRAPHERGIA, this approach helps align technological feasibility with societal desirability, ensuring that advanced material applications also meet ethical and inclusivity standards.

Looking ahead, the development of harmonised social indicators, open-access datasets, and dynamic modelling tools will be key to mainstreaming S-LCA in both research and industrial practice. Greater integration of participatory methods, scenario analysis, and digital monitoring platforms will further enhance its relevance for policy and strategic decision-making [37][38][39][40][41].

Incorporating S-LCA into the GRAPHERGIA sustainability framework demonstrates a clear commitment to proactive social responsibility, ensuring that innovations are not only technically and economically viable but also socially just and inclusive across their life cycles. This aligns with the broader shift from compliance-driven sustainability to strategic and anticipatory governance, which is essential for fostering trust, legitimacy, and resilience in future industrial systems.

### 2.2.4 Deliverable & Work Package Context

This report forms part of GRAPHERGIA's integrated sustainability assessment activities, as outlined in Work Package 6: Life cycle assessment, sustainability and ecodesign approach. Within this WP, the objective is to apply a LCSA approach, combining Environmental LCA, LCC, and Social LCA (S-LCA), to ensure that the innovations developed in the project align with the European Green Deal objectives, the Just Transition Mechanism, and the United Nations Sustainable Development Goals (SDGs).

The present deliverable focuses on the Social Life Cycle Assessment component, providing a framework for identifying, characterising, and evaluating potential social impacts of GRAPHERGIA's technological developments along their entire life cycle.

Particular emphasis is placed on:



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- The upstream supply chain, including the sourcing of graphene-related raw materials and other critical inputs.
- The manufacturing and processing stages, with attention to working conditions, occupational health and safety, and skills development.
- The use phase, considering end-user accessibility, societal benefits, and potential inequities in technology deployment.
- The end-of-life stage, focusing on waste management practices, material recovery, and local community impacts.

By systematically applying S-LCA within the GRAPHERGIA framework, this deliverable supports evidence-based decision-making to maximise societal co-benefits, reduce risks of negative social outcomes, and strengthen overall project sustainability performance. The methodology and findings outlined here will also feed into cross-WP activities, including risk management, stakeholder engagement, and exploitation planning. In line with the RRI approach, this work integrates early-stage social considerations into the innovation process, thereby enabling proactive mitigation of potential social risks and enhancing societal acceptance of GRAPHERGIA technologies. This proactive approach ensures that the project not only advances technical and economic objectives, but also contributes meaningfully to social equity, inclusion, and well-being in the European and global contexts where its technologies will be deployed.

## 2.3 Benchmarking Definition and Reference Systems for S-LCA

Benchmarking in the S-LCA is defined as the comparison of the social risk profile of GRAPHERGIA demonstrators with the sectoral and regional reference values provided by the SHDB. Unlike environmental and economic assessments, S-LCA benchmarking does not involve direct product-to-product comparison but rather evaluates how the supply chains of GRAPHERGIA technologies perform relative to global or sectoral averages for key social indicators (**Table 1**). This approach enables the identification of potential social hotspots and improvement opportunities along the value chain, ensuring methodological consistency with UNEP/SETAC guidelines.

| Assessment level | Benchmark source/reference system | Functional basis | Benchmarking rationale |
|---|---|---|---|
| **Upstream supply chain** | SHDB – sectoral and country-level data for "Manufacture of electronic components", | 1 unit process within each | Comparison of social risks (e.g., labour rights, health & safety, fair salary) against global and regional |

| | | | |
|---|---|---|---|
| **(materials and components)** | "Textile manufacturing", and "Battery production" | supply chain segment | sectoral averages to identify high-risk regions or activities. |
| **Graphene and advanced materials processing** | SHDB – subsector: "Chemical and material manufacturing" (NACE C20–C21) | 1 kg of processed material | Assessment of social performance of graphene-related processes compared to chemical industry averages, focusing on occupational health and governance indicators. |
| **Assembly and device manufacturing (Demonstrators 1–3)** | SHDB – sector: "Electronics manufacturing" and "Apparel manufacturing" | 1 functional product unit (sensor, textile, battery module) | Evaluation of manufacturing-related social risks in relation to industry baselines; supports early identification of hotspots for SSbD improvements. |
| **Global supply chain (aggregated level)** | SHDB – weighted aggregation by country and process contribution | System-level inventory (cradle-to-gate) | Provides overall social risk index (SRI) benchmarked against the global average of the corresponding industrial sector, allowing comparative interpretation of social hotspots. |

**Table 1.** Benchmarking framework and reference systems for the S-LCA of GRAPHERGIA technologies



The benchmarking exercise will therefore rely on SHDB-derived reference values, complemented by qualitative information from partner questionnaires for validation purposes. This ensures that results are contextualised, reproducible, and compatible with the SSbD framework applied across WP6.

### 2.3.1 Benchmarking Approach for GRAPHERGIA Demonstrators

The application of the benchmarking framework to the three GRAPHERGIA demonstrators follows a sectoral approach based on SHDB reference data. Each demonstrator is assessed in relation to the corresponding industrial sectors and geographical supply chains identified through the project's inventory data. The comparison is therefore relative, focusing on deviations from the SHDB average risk levels to highlight potential social hotspots and improvement opportunities (**Table 2**).

| Demonstrator | Main SHDB sectors involved | Main countries of reference (estimated supply chain) | Key social impact categories | Benchmarking approach |
|---|---|---|---|---|
| **#1 - Self charging textile for energy harvesting and storage** | Textile manufacturing; Electronics components manufacturing | EU (Italy, Spain); Asia (China, India) | Fair salary, health & safety, workers' rights | The S-LCA of the GRAPHERGIA textile demonstrator will be compared to SHDB sectoral averages for textile and electronics industries, identifying potential hotspots related to fibre production and electronic integration. |
| **#2 – Self powered wireless sensor embedded in aerospace composite structures** | Electronics manufacturing; Electrical equipment production | EU (France, Germany); Asia (China) | Occupational health, working hours, social security | The SHDB benchmark for "Electronics manufacturing" will be used to compare the GRAPHERGIA sensor supply chain against sectoral averages, identifying high-risk stages in component production and assembly. |
| **#3 – Graphene based LIBs battery module for space applications** | Battery manufacturing; Chemical and materials production | EU (Germany, Italy); Asia (China, South Korea) | Child labour, workers' rights, health & safety | SHDB data for "Battery production" and "Chemical manufacturing" will serve as benchmarks to evaluate social risks in the LIB module supply chain relative to global industry averages. |

**Table 2.** Application of the S-LCA benchmarking framework to the three GRAPHERGIA demonstrators

This process establishes a consistent benchmarking framework for the S-LCA of GRAPHERGIA technologies. By comparing demonstrator-specific supply chains to SHDB sectoral reference data, the project will generate a relative assessment of social performance, supporting the identification of key hotspots and guiding future SSbD improvements.



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# 3 Materials and methods

## 3.1 Survey Investigations

Within GRAPHERGIA, Work Package 6 (WP6) applies a life-cycle sustainability lens—environmental (LCA), economic (LCC), and social (S-LCA)—to laser-assisted synthesis, processing, and integration of graphene materials into energy harvesting and storage devices. The three surveys operationalize the S-LCA component by eliciting perceptions, experiences, and organizational practices across key stakeholder groups relevant to smart textiles and battery production. Together they establish a coherent evidence base that complements environmental and cost assessments and informs eco-design choices across the value chain.

### 3.1.1 Workers' Survey — Objectives, Scope, and Content

**Objectives**

The workers' questionnaire captures first-hand evidence on social performance at the workplace. Its primary objectives are to: (i) document conditions related to wages, working time, and contractual stability; (ii) assess the prevalence and quality of Health and Safety (H&S) measures, including training, Personal Protective Equipment (PPE), and medical surveillance; (iii) gauge access to social protection and benefits; and (iv) evaluate the practical realization of freedom of association/collective bargaining and non-discrimination. By prioritizing workers' lived experience, the instrument supports hotspot detection in S-LCA worker sub-categories and triangulates firm-level claims with individual-level data.

**Scope and target population**

The survey is addressed to employees engaged in sectors connected to GRAPHERGIA's demonstrators—e.g., textiles, energy-related manufacturing, logistics, distribution, raw-material supply, and waste treatment—while remaining open to "other" sectors to capture adjacent roles in the value chain. Basic demographics and industry affiliation are collected to enable stratified analysis and contextualization of results.

**Structure and key constructs**

After general information, the questionnaire proceeds through clearly delineated modules aligned to common S-LCA stakeholder themes. The Wages module records gross monthly wage bands, perceived sufficiency to meet basic needs, and overtime/bonus practices. Working hours captures typical weekly hours and overtime compensation linkages. H&S documents training exposure (with follow-up on annual training hours), PPE provision, periodic medical checks (with frequency), awareness of accident/chemical-exposure protocols, and occurrence of workplace accidents. Social benefits inventories access to insurance, pensions, childcare, canteens, transport, scholarships, etc. Working conditions examines access to parental/special leave, employer influence on take-up, flexible hours, contract documentation, permanency status, holidays, and commuting time. Freedom of association/collective bargaining assesses awareness of rights and access to information on labour organizations. Non-discrimination probes both perceived fairness independent of union membership and awareness of complaint mechanisms. Skip-logic is used in several places (e.g., additional questions triggered by "Yes" answers on training or health checks) to collect detail while minimizing respondent burden.

**Measurement approach and rationale**

The instrument relies on categorical bands (e.g., wage brackets, training hours ranges) and dichotomous items (Yes/No), complemented by occasional open responses. This balances comparability across contexts with sufficient granularity for risk screening. The constructs map onto recognized S-LCA worker-related sub-categories (e.g., health and safety, fair salary, working hours, social security, freedom of association, discrimination), enabling later aggregation into performance profiles and cross-tabulation by sector, country, or role.

**Intended use and integration**

Results will (i) identify priority improvement areas at facility/process level, (ii) triangulate company-provided information, and (iii) feed into eco-design recommendations that reduce social risk alongside environmental load. Worker insights provide the "ground truth" needed to interpret organizational policies and to assess whether benefits from innovative graphene-enabled products diffuse equitably to the workforce.

### 3.1.2 Company Survey — Objectives, Scope, and Content

**Objectives**

The company questionnaire characterizes organizational practices and performance across the enterprise and its local interface. It aims to: (i) describe the production context and markets for e-textiles, energy-storage components, sensors, or related 2-D materials; (ii) document H&S systems, wages and overtime policies, benefits, working conditions, training, and labour rights; (iii) assess non-discrimination and gender equality; (iv) evaluate interactions with the local community (accidents, infrastructure, education/health initiatives, local employment); (v) capture sustainability governance, transparency, and certifications; and (vi) probe membership in socially responsible initiatives and relationships with value-chain actors. This provides organization-level evidence to align with S-LCA stakeholder categories: workers, local community, and value-chain actors.

**Scope and production context**

The opening section gathers location (including multi-site footprints), sector affiliation, end-product focus (with an e-textile sub-tree allowing sports/fitness, healthcare, wellness, military, fashion, automotive, or other), a brief process description limited to product-relevant steps, and indicative selling-price bands. These items situate social performance within business models and cost structures that can influence labour conditions and community impacts.

**Structure and key constructs**

- **Workers as stakeholders/H&S.** Items cover PPE availability, regulatory compliance, contingency planning, presence of an H&S committee, accidents related to harmful substances (with frequency bands), periodic health checks, and annual training hours. These enable assessment of preventive capacity and monitoring systems.
- **Wages and overtime**. The survey requests bands for average and lowest gross monthly salaries, typical overtime volume, and whether overtime is compensated—critical indicators of fair remuneration and decent work.
- **Social benefits**. A checklist covers health insurance, pension funds, childcare, dormitories, canteens, transport, scholarships, and "other," providing a snapshot of social protection at enterprise level.
- **Working conditions**. Items track weekly hours, flexible working prevalence, documentation of contracts, permanency rates, holidays, and shift patterns (rotating/night). This enables comparability with international decent-work benchmarks.
- **Non-discrimination and gender equality**. Questions test equal-opportunity hiring regardless of religion, nationality, or sexual orientation, the share of female employees, annual discrimination complaints, and the existence of a gender-equality plan. These indicators speak to diversity, equity, and grievance management maturity.
- **Training**. Coverage and participation rates in training are recorded to approximate capability development and career pathways.
- **Freedom of association/collective bargaining**. The instrument documents formal rights to associate, presence and representativeness of worker committees, negotiation experience, participation in decision-making, and rights to bargain/strike. These provide a governance view on industrial relations.



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- **Local community as stakeholders**. The survey asks about environmental accidents, contributions to local infrastructure, education/knowledge initiatives, and community health/safety programs—key for assessing place-based impacts.
- **Local employment and spillovers**. It records new jobs created, indirect opportunities in other sectors (e.g., waste management), and preference policies for local hiring/suppliers, linking enterprise activity to regional socio-economic outcomes.
- **Sustainability governance and transparency**. Items evaluate measurement/reporting practices, public disclosure, and adherence to external standards/certifications (e.g., ISO 14001/50001, EU Ecolabel, LEED, Carbon Trust Standard, SA8000, EMAS, GRI), offering anchors for verification and comparability across firms.
- **Value-chain responsibility**. Membership in social-responsibility initiatives is queried to reveal collective action and due-diligence alignment.

**Measurement approach and intended use**

Predominantly closed questions with banded responses facilitate benchmarking, outlier detection, and aggregation for S-LCA stakeholder performance mapping. When triangulated with the Workers' Survey, company data helps distinguish policy intent from actual outcomes and supports targeted eco-design and supplier-engagement strategies within GRAPHERGIA demonstrators.

### 3.1.3 University/Research-Institute Survey — Objectives, Scope, and Content

**Objectives**

This survey elicits expert perspectives on the applicability, social value, and adoption barriers of GRAPHERGIA-relevant technologies—namely e-textiles for wearable power and self-powered sensors, and next-generation lithium-ion battery electrodes. It seeks to (i) map perceived social benefits and risks, (ii) identify design features and research needs that influence usability and acceptance, (iii) evaluate sustainability contributions to EU transition goals, and (iv) pinpoint levers for technology transfer and market uptake. As such, it complements the worker- and company-level lenses with a forward-looking, system-innovation viewpoint.

**Scope and respondent profile**

The instrument addresses staff across public/private research centres and universities (researchers, professors, PhD students, project managers, etc.), with fields spanning advanced materials, energy, electronics, environmental sciences, and related domains. Basic institutional/location metadata and role classification support segmentation of opinions across disciplinary and regional contexts.



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**Structure and key constructs**

- **Applicability and social impact of e-textiles**. Items probe familiarity with e-textiles for wearable power/self-powered sensing; perceived high-impact domains (healthcare, sports, defense, industry); the expected contribution of self-powered sensors to safety monitoring; main social benefits (e.g., quality of life, workplace safety, accessibility); and principal adoption challenges (e.g., cost, user acceptance, regulation, durability). Respondents may suggest desired product features (e.g., washable electronics, flexible displays) and weigh the importance of aesthetics, concluding with anticipated impacts on the traditional textile sector.
- **Applicability and social impact of Li-ion electrodes**. Questions assess awareness of next-generation electrodes, perceived limitations of current batteries (cost, lifetime, environmental impact), potential improvements in efficiency/sustainability, priority application areas (e-mobility, consumer electronics, renewable storage), and adoption barriers (scale-up, market acceptance, regulation). Desired electrode features are also solicited to guide R&D road-mapping.
- **Sustainability and energy transition**. The survey asks respondents to rate the importance of climate-neutral approaches, judge contributions to EU sustainability goals, identify environmental risks (waste, critical materials, production energy), and recommend strategies for improvement (recycling, alternative materials, stricter regulation, etc.). This frames the social discourse in the broader sustainability transition.
- **Barriers to adoption and technology transfer**. Items probe the need for greater industry involvement and the efficacy of enabling tools—public funding, research-industry collaborations, open-access data, and specialized training—to accelerate scale-up and societal embedding.

**Measurement approach and intended use**

Using a mix of dichotomous, multiple-choice, and Likert-type items plus open prompts, the survey captures both structured judgments and emerging ideas from domain experts. The resulting evidence base informs S-LCA interpretation by highlighting expected social benefits/risks at scale, surfacing design features that matter for acceptance, and identifying policy/market levers to align technological innovation with just, inclusive outcomes—particularly salient for GRAPHERGIA's smart-textile and battery demonstrators.

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### 3.1.4 Survey Distributions

The distribution of the three S-LCA surveys officially started in March 2025 (M18). At this stage, the main channel employed was the presentation of a QR code during dissemination and networking events, particularly in online formats such as webinars, conferences, and project-related workshops. This approach ensured that the surveys could be shared quickly with a large and heterogeneous audience, while also allowing for real-time engagement with participants interested in the social sustainability dimension of GRAPHERGIA. The QR code strategy was complemented by short explanatory interventions during events, highlighting the importance of worker, company, and research perspectives in shaping the sustainability profile of advanced graphene-enabled technologies. Although participation was voluntary and self-administered, this method fostered a first wave of responses that now constitute the basis for the preliminary results presented in this deliverable.

In the coming months, the consortium will progressively intensify and diversify survey distribution in order to secure a representative dataset by the project's conclusion (M48). Several actions are foreseen:

- **Extended online dissemination**: The QR codes and direct survey links will be included in project newsletters, shared through social media channels (e.g., LinkedIn, Twitter/X), and embedded on the GRAPHERGIA website, ensuring broader visibility among targeted stakeholders.
- **Targeted outreach to project partners' networks**: Industrial and academic partners will be directly engaged to circulate the surveys within their professional and institutional circles, particularly towards textile and energy-storage companies, research labs, and clusters of workers involved in relevant value chains.
- **On-site promotion at conferences and fairs**: As in-person events gain momentum, printed materials (flyers, posters) with survey QR codes will be distributed at sector-specific exhibitions, scientific conferences, and stakeholder meetings. Short presentations or side sessions will be organized to motivate participation and clarify the utility of the surveys.
- **Direct engagement with companies and associations**: Selected companies and industry associations will be approached bilaterally to encourage them to disseminate the questionnaire internally among their employees or members, increasing the reach to both workers and enterprises in the graphene, textile, and energy domains.
- **Academic distribution**: For the university/research survey, contacts with European research groups, doctoral schools, and thematic networks will be leveraged to recruit

respondents. Calls for participation may also be launched through scientific mailing lists and research community platforms.

This multi-channel strategy is designed to ensure coverage across the three stakeholder groups (workers, companies, universities/research institutes) and across different geographical regions. By maintaining survey collection active until the end of the project, the consortium will be able to monitor response rates, identify potential gaps, and undertake corrective measures (e.g., focused campaigns in under-represented sectors or countries).

By Month 48, the project aims to deliver a robust and diversified dataset, enabling a comprehensive Social LCA of GRAPHERGIA demonstrators. The distribution strategy therefore not only supports quantitative adequacy but also maximizes qualitative richness by ensuring the inclusion of multiple voices across the innovation ecosystem. The final analysis will combine these perspectives to provide solid, evidence-based recommendations for improving the social sustainability of advanced graphene-enabled energy technologies.

## 3.2 The Social Hotspot Database

As part of the S-LCA methodology applied in GRAPHERGIA, the SHDB was selected as a core data source for identifying and assessing potential social risks associated with the life cycle of graphene-based value chains. The SHDB is a comprehensive global database covering over 140 countries and 57 economic sectors, aggregating more than 200 social risk indicators across themes such as labour rights, human health and safety, governance, and community infrastructure [44] [45]– see **Figure 1**.

The decision to integrate SHDB into the GRAPHERGIA S-LCA framework reflects its status as one of the most widely recognised tools for social impact screening in both academic and professional contexts. It draws from internationally respected sources such as the International Labour Organization (ILO), World Bank, Freedom House, and the United Nations Development Programme (UNDP), ensuring methodological transparency and credibility of the data used [48] [39][43].



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**Figure 1.** Graphical representation of the SHDB structure. Source: SHDB Website

## Risk Indicators and Assessment Categories

The SHDB organises its social risk indicators into five main impact categories, Labour Rights & Decent Work, Health & Safety, Society, Governance, and Community, and 30 subcategories. Indicators range from wage fairness and workplace safety to community infrastructure, corruption risk, and access to essential services.

Each indicator is assigned a qualitative risk level (low, medium, high, or very high risk) based on the statistical distribution of risks in a given country–sector combination (**Figure 2**). This enables the identification of systemic risks that may not be apparent at the individual company or facility level.

The qualitative scores are then combined into risk matrices, which provide a visual and analytical basis for prioritising social "hotspots". These matrices help focus further investigation and guide stakeholder engagement in areas with the highest potential for negative impacts [45].

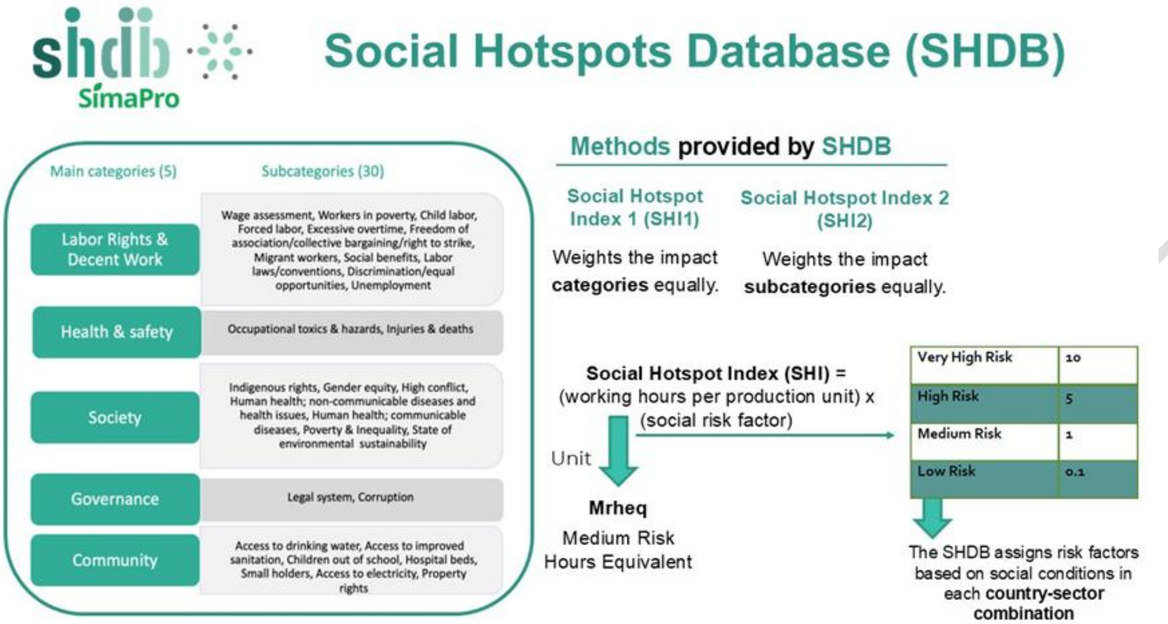


**Figure 2.** SHDB categories, methods and unit. NTT elaboration based on SHDB website information

## Strengths and Limitations

The use of SHDB in GRAPHERGIA's S-LCA allowed for the early detection of potential social risks along the graphene value chain, supporting rapid screening in the early stages of assessment where primary data may be scarce. Its standardised global coverage is particularly valuable for cross-sectoral benchmarking and for providing a structured basis to compare risks across different supply chain stages.

However, SHDB relies on macro-level, country–sector data derived from official statistics and aggregated sources. This means it cannot capture all local variations, informal labour dynamics, or specific working conditions in niche industries. As such, SHDB outputs should be viewed as indicative rather than definitive.

To ensure robustness, GRAPHERGIA combines SHDB analysis with primary survey data, stakeholder consultations, and targeted qualitative research. This hybrid approach enhances the contextual relevance of findings, supporting more nuanced and credible assessments of social performance along graphene-based production and innovation pathways.



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# 4 GRAPHERGIA S-LCA LIBs state of art

The current state of the art in S-LCA of lithium-ion batteries (LIBs) (Demonstrator #3) is mainly reflected in three key studies available in the literature: those by [49][51][50].

Accardo et al. [49] present a holistic sustainability evaluation of a 75-kWh lithium-ion battery pack (NMC811 chemistry) designed for electric vehicle (EV) applications. The study adopts a Life LCSA framework, which integrates three distinct dimensions of sustainability: environmental (LCA), economic (LCC), and social (S-LCA). By applying a cradle-to-grave approach, the analysis captures impacts from raw material extraction to end-of-life recycling, and it also assesses multiple geographical scenarios involving both European countries and key resource-supplying regions.

The Social Life Cycle Assessment identifies significant social risks in the supply chain, particularly in the upstream extraction of raw materials from non-European countries. The most concerning hotspot is the Democratic Republic of the Congo (DRC), where cobalt is sourced. The DRC is characterized by:

- A 15.1% prevalence of child labour
- 94.8% of the population lacking social protection
- Serious deficiencies in occupational health and safety

Other raw materials also pose high social risks. Nickel and manganese, sourced primarily from Australia and South Africa, and graphite from China, all score "high to very high" across key social indicators such as:

- Fair wages
- Health and safety
- Forced labour
- Social security coverage
- Freedom of association

In contrast, the use and end-of-life phases, which occur predominantly in European countries, present low to moderate social risks, largely thanks to better labour standards, governance, and regulatory oversight.

The most socially sustainable configuration involves battery use in Germany and recycling in Sweden, which minimizes social risks across nearly all assessed categories. The only exceptions include medium risks associated with excessive working hours and relatively weak public commitments to sustainability in certain sectors.

The study by Koese et al. [51] presents a comparative S-LCA of two battery energy storage technologies: the Vanadium Redox Flow Battery (VRFB) and the LIB. The assessment is conducted in line with the UNEP/SETAC 2020 guidelines and utilizes the PSILCA v.3 database, which integrates social indicators across global supply chains based on a multi-regional input-output model.

The goal of the study is to assess potential social risks throughout the life cycle of these technologies, focusing on three stakeholder groups: workers, local communities, and society. The functional unit for comparison is 1 kWh of electricity delivered over the battery's lifetime.

The findings indicate that raw material extraction is the primary source of social risk for both LIB and VRFB. This phase consistently contributes the highest risks, followed by the chemical production sectors. Among stakeholders, workers are the most impacted group, especially in terms of indicators such as fair wages, association rights, and employment regulation violations.

A significant variable in social risk is the geographic location of the supply chain. Batteries produced in Germany are associated with lower social risks than those produced in China, due to better labour conditions and environmental controls. However, some risks, like "fair salary" and “trade union density”, remain even in Germany due to national wage structures and union dynamics.

The study compares two types of LIB cathode chemistries: LMO (Lithium Manganese Oxide) and NMC (Nickel Manganese Cobalt Oxide). The results show that NMC cathodes involve significantly higher social risks, mainly because of cobalt mining in the DRC, a sector often linked to child labour, poor working conditions, and environmental degradation. In contrast, LIBs using LMO cathodes show considerably lower risks and are thus more favourable both socially and environmentally.

Similarly, different configurations of VRFB supply chains reveal variations in social risk. An increase in vanadium prices, for example, leads to higher social risk scores due to the cost-sensitivity of



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the PSILCA method. This reflects a core limitation of the approach: risks are scaled to economic value, which may not accurately capture real-world social impacts.

Another important aspect considered is the End-of-Life (EoL) phase of the batteries. VRFBs present a clear advantage, as their design allows for electrolyte reuse and component maintenance, potentially reducing the need for new raw materials and minimizing EoL risks. LIBs, on the other hand, pose challenges in this regard. Recycling may prevent environmental harm but introduces its own social risks, especially in unregulated or informal sectors. Landfilling, which remains a common disposal method, is associated with high social and environmental risks due to leaching, toxic emissions, and waste export to vulnerable regions.

While S-LCA offers valuable insights, the authors also highlight several methodological limitations. First, many PSILCA indicators rely on country-level averages, which may not reflect actual practices within specific sectors or companies. Second, the methodology is highly sensitive to cost, potentially misrepresenting risk when price fluctuations occur. This is particularly problematic for emerging technologies like VRFBs, which are still undergoing cost reductions through innovation and scale-up. Third, S-LCA via PSILCA tends to emphasize negative social impacts, with limited recognition of positive contributions, such as increased energy access or local economic development.

Despite these limitations, the study provides valuable guidance for more socially responsible battery technology development. Key takeaways include the recommendation to prioritize LIBs with LMO cathodes over NMC alternatives due to lower social and environmental risks, and the potential benefits of localizing production within regions like Europe, where supply chain conditions are generally more regulated and socially sustainable.

The last study is by Thies et al. [50] that conduct a focused S-LCA of the lithium-ion battery supply chain, with particular attention to the social sustainability of lithium extraction. Using the SHDB and the open-source software openLCA, the authors assess a 52.9 kWh lithium-ion battery pack (NMC-Graphite chemistry) from cradle to gate. Their approach quantifies social risks in terms of risk-weighted labour hours, applying indicators such as child labour, corruption, occupational hazards, and poverty. The study evaluates several geographically distinct supply chain configurations, including those centered in China, Germany, and responsible sourcing from low-risk countries. The findings clearly identify raw material extraction, especially in regions such as Zambia (used as a proxy for the DRC), as the dominant contributor to social risk. Materials such as graphite, cobalt sulphate, and nickel sulphate are particularly problematic due to high scores in child labour prevalence, poor occupational health standards, and limited social protections.



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The risk profiles improve substantially when the production of cells and packs is relocated to Germany, where labour standards and regulatory enforcement are stronger. Moreover, sourcing critical materials from countries with lower social risk, such as Canada for nickel or Australia for lithium, leads to significant reductions in the total risk burden. This highlights the importance of geographically differentiated supply chain design as a strategy for minimizing social harm. Although the study does not include the use or end-of-life phases, it makes a compelling case that responsible sourcing and localized manufacturing can play a pivotal role in enhancing the social sustainability of lithium-ion battery technologies.

In summary, S-LCA can play a critical role in guiding just and equitable energy transitions, ensuring that progress in environmental sustainability does not come at the expense of human well-being across global supply chains.

The following **Table 3** resumed all the information of the studies discussed before.

Despite the growing attention to sustainability in smart textiles, the literature reveals a significant lack of studies applying S-LCA frameworks to this sector.

These studies clearly highlight the need for more in-depth analyses and experimental applications in order to obtain a more comprehensive and robust understanding of the social impacts associated with emerging technologies. Moreover, the methodologies employed to assess S-LCA vary significantly across literature, with only Thies et al. [51] applying the SHDB, the same framework used in the GRAPHERGIA project. This variation further underscores the necessity for methodological alignment and standardization to enable meaningful comparisons and consistent evaluations across different studies.

### Scope limitation and outlook for other GRAPHERGIA demonstrators

It is important to note that, at this stage of the project (M24), the in-depth literature-based analysis presented in Chapter 4 focuses primarily on the lithium-ion battery (LIB) demonstrator. This choice reflects the higher availability and methodological maturity of existing S-LCA studies in the battery sector, which allow for a consistent and comparable state-of-the-art assessment.

For the other GRAPHERGIA technologies—such as smart textiles and self-powered sensor demonstrators—the information currently available remains fragmented, mostly qualitative, and insufficiently structured to support a robust S-LCA interpretation. These technology lines are, however, fully included in the ongoing data collection process through targeted surveys and SHDB-based screening. Their detailed social assessment will be developed in the final phase of WP6, once a more comprehensive evidence base is available and the integration with environmental and economic datasets (LCA/LCC) can ensure methodological consistency across all demonstrators.



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| Author(s) | Scope | S-LCA Methodology | Stakeholders | High Risk Areas | Social Hotspots | Use Phase Social Risk | EoL Phase Social Risk | Best Scenario (S-LCA) |
|---|---|---|---|---|---|---|---|---|
| **Accardo et al. [49]** | 75 kWh NMC811 EV battery pack, cradle-to-grave | UNEP Guidelines, ISO 14075, reference scale approach | Workers, Society, Consumers | Cobalt (DRC), Manganese (South Africa), Nickel (Australia), Graphite (China) | Fair pay, Health and safety | Low (1–2), higher public sustainability risk | Generally low; medium risk in France (safety), Hungary (fair pay/corruption) | Scenario 2-1: Use in Germany, Recycling in Sweden |
| **Thies et al. [50]** | 52.9 kWh NMC-G battery pack, cradle-to-gate | SHDB database, openLCA, social risk hours | Workers, Local Communities, Society | China, Zambia (proxy for DRC), graphite, cobalt and nickel sulfate production | Child labor, Occupational hazards, Corruption, Poverty | Not included | Not included | German production + low-risk raw material sourcing |
| **Koese et al. [51]** | 1 kWh energy delivered (LIB NMC, LIB LMO, VRFB), cradle-to-grave | UNEP/SETAC Guidelines, PSILCA v3 database | Workers, Local Communities, Society | Cobalt (DRC), Chemical sectors, Vanadium sourcing | Fair salary, Right of association, Pollution, Employment violations | Low for all systems | Low for VRFB (reuse); LIB recycling risks in unregulated environments | LIB with LMO cathode, German production |

**Table 3.** Comparative Review of Lithium-based Battery Technologies for S-LCA

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# 5 PRELIMINARY RESULTS

At this stage (M24), the D6.3 presents preliminary results limited to survey distribution analytics—namely reach, channels, timing, and respondent profiles for the Workers' and Universities/Research surveys. The SHDB-based S-LCA results are intentionally deferred to the final deliverable at M48, when the LCC work within WP6 will have produced complete economic inventories and cost allocations across all demonstrator components. Applying SHDB prior to full LCC coverage would imply partial system boundaries, unbalanced cost/flow normalization, and biased risk weighting across sectors and geographies, thereby undermining comparability and interpretability of social performance indicators.

This report therefore focuses on methodological readiness (questionnaire design, sampling strategy, QA/QC) and on mapping items to SHDB stakeholder sub-categories to ensure traceable integration later on. By M48 we will integrate finalized LCC datasets with SHDB characterization to compute stakeholder-specific indicators (with uncertainty ranges) and triangulate them with worker, company, and academic evidence. This staged approach preserves scientific rigor, avoids premature inference from incomplete data, and ensures decision-relevant, end-to-end conclusions.

## 5.1 Survey Results

The results of the social LCA questionnaire are shown below, based on the responses received to date. The questionnaire was aimed at three categories of stakeholder: workers (6 responses), companies (currently zero responses), and researchers from universities and public and/or private research centres (9 responses). The survey results are presented in an edited, summarised version. For a comprehensive overview of the questions and responses received, please refer to Chapter 8 – Appendix.

### 5.1.1 Worker Survey

Figures 3 and 4 show, respectively, the geographical origin and gender of the workers who answered the survey (now a total of 6 responses were received).



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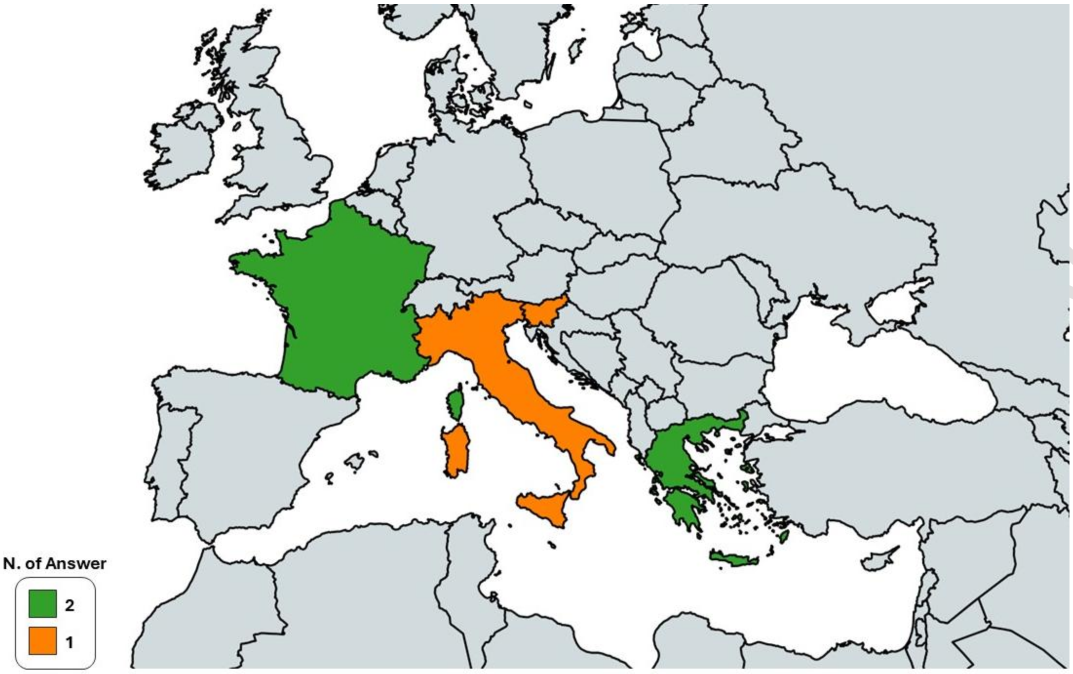


**Figure 3.** Geographical origin of the respondents to the workers' survey

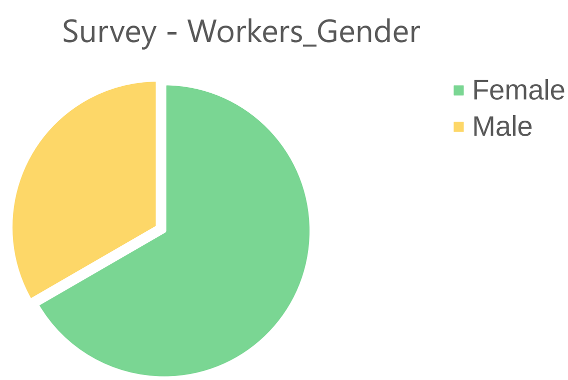


**Figure 4.** Gender distribution of the respondents

**Table 4** and **Figure 5** show some of the main results from the survey of companies operating in the project sectors of textiles, packaging, and fertilisers. The survey aimed to evaluate aspects relating to social sustainability through direct interaction with workers and company owners.

| # | Question | No | Yes |
|---|---|---|---|
| **6** | Is your wage sufficient for you (as an individual or your family) to meet basic needs and maintain a modest but decent standard of living? | 33% | 67% |
| **7** | Have you ever received a bonus payment? | 83% | 17% |
| **8** | Have you worked extra hours? | 50% | 50% |
| **9** | Were you compensated for the extra hours worked? | 83% | 17% |
| **11** | Have you received **training** in the field of **security** and safety in the workplace? | 33% | 67% |
| **13** | Is personal protective equipment (**PPE**) supplied to workers? | 33% | 67% |
| **14** | Have you undergone a **health check** in your workplace? | 83% | 17% |
| **16** | Are you aware of existing **preventive measures** and protocols with regards to accidents and injuries at your workplace? | 50% | 50% |
| **17** | Have you experience an **accident** during your work shift? | 100% | 0% |
| **18** | Are you aware of existing preventive measures and protocols with regards to **chemical exposure** at your workplace? | 67% | 33% |
| **19** | Have you received any **social benefits** as an employee (e.g. unemployment benefits, health insurance, pension, etc.)? | 33% | 67% |
| **21** | Have you received **medical assistance** related to work issues? | 83% | 17% |
| **22** | Do you have access to **parental leave** and/or special leave (for disability, bereavement, etc.)? | 17% | 83% |
| **23** | Does your **employer influence** the decision to take parental leave or any other special leave? | 50% | 50% |
| **24** | Do you have **flexible working** hours? | 50% | 50% |
| **25** | Are your **working conditions documented** (e.g., regular contracts)? | 33% | 67% |
| **26** | Are you a **permanent worker**? | 67% | 33% |
| **29** | Are you aware of your right to **freedom of association** in the workplace? | 33% | 67% |
| **30** | Do you have **easy access to information** about labour rights and the activities of labour organizations in your workplace? | 50% | 50% |
| **31** | Do you believe that all **employees**, regardless of union membership, are **treated fairly** in the workplace? | 50% | 50% |
| **32** | Do you know **how to file a complaint** or raise doubts about any action by management that violates non-discriminations? | 50% | 50% |

**Table 4**. Summary of the Yes/No answers_Worker survey – value in percentage



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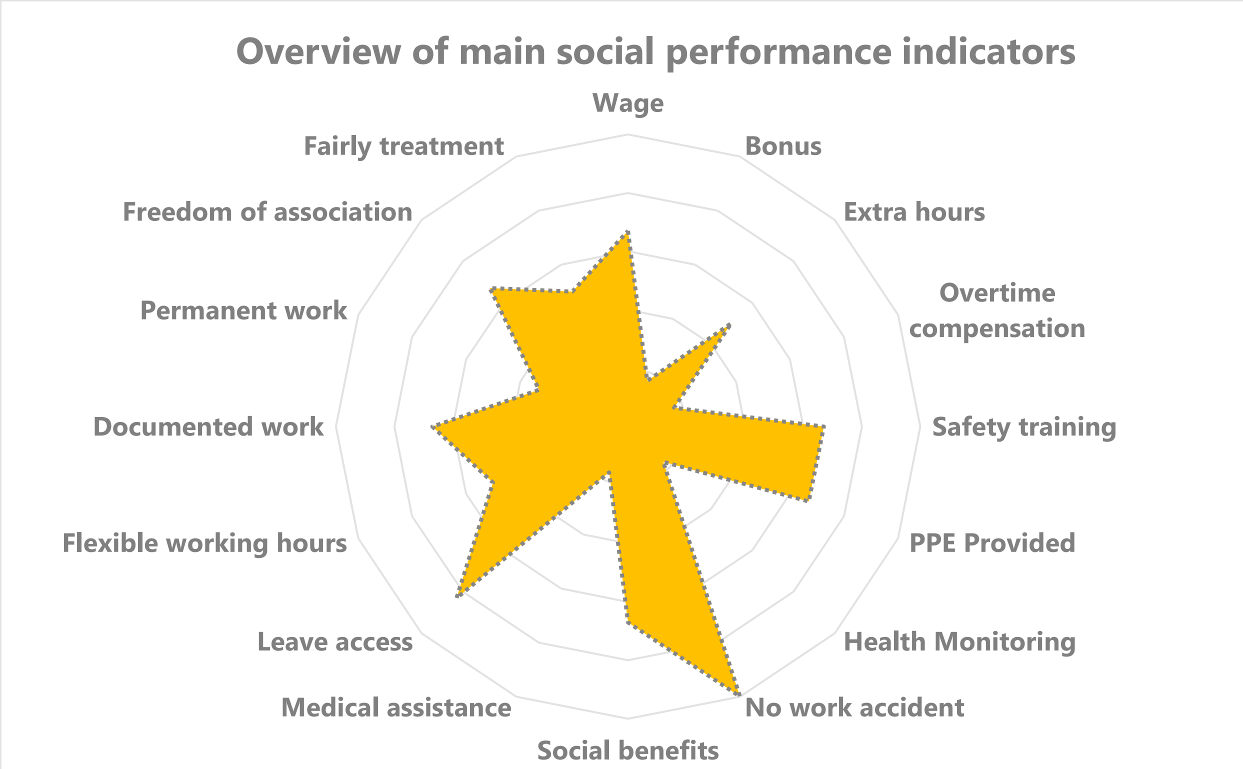


**Figure 5.** Overview of the main social performance indicators_Worker survey



As part of the Social LCA component of the GRAPHERGIA project, a worker-oriented questionnaire was distributed to companies belonging to sectors relevant to the value chain addressed by the project. The purpose of this evaluation is to collect sectoral insights into labour-related conditions, challenges, and good practices. At the current stage of the project (M24), six completed questionnaires have been received. While this represents a very limited sample size, it offers a first exploratory picture of key issues in the sector and provides a baseline against which future responses (expected to increase by M48) can be compared.

The questionnaire was structured around a series of questions addressing different aspects of social performance at the worker level, including fair wages and compensation, occupational health and safety, social protection and work–life balance, employment relationship, and freedom of association and non-discrimination. The following discussion interprets the percentages obtained so far, highlighting strengths, weaknesses, and implications.

## Fair wages and compensation

Preliminary results suggest that two-thirds of respondents (67%) consider their wages sufficient to cover basic needs and enable a modest standard of living. This finding is positive in relative

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terms, yet the fact that one-third of workers perceive their wage as insufficient highlights the persistence of gaps compared with living-wage benchmarks. These results are particularly relevant given ongoing debates on wage adequacy across European sectors with global supply chain exposure.

Incentive mechanisms appear uncommon: only 17% of respondents reported ever receiving a bonus. Moreover, while 50% reported having worked extra hours, only 17% stated they were compensated for overtime. Even accounting for the small dataset, this discrepancy is noteworthy. It suggests that a significant proportion of overtime work may remain uncompensated or that compensation mechanisms are not perceived as fair or transparent. This is an important hotspot, as unpaid overtime is directly linked to decent work deficits and undermines the principle of fair remuneration.

### Occupational health and safety

The responses concerning occupational health and safety (OHS) reveal a mixed picture. On the positive side, two-thirds of respondents indicated that they had received training on safety and security, and the same share confirmed that personal protective equipment (PPE) is provided. Such findings suggest that basic OHS practices are being implemented across the responding companies.

Nevertheless, the survey also highlights critical weaknesses. Only 17% of workers reported undergoing routine health checks, and awareness of chemical-exposure preventive measures was acknowledged by only one-third (33%). In addition, while half of respondents said they were aware of preventive protocols for accidents and injuries, this leaves a considerable share without clear knowledge of safety procedures. The absence of reported accidents is encouraging, but given the limited number of responses, this result should be interpreted cautiously and cannot be taken as evidence of low accident risk in the sector.

The very low percentage of workers receiving medical assistance related to occupational issues (17%) further underlines a possible under-provision of occupational health services or a lack of awareness among workers about existing channels for support. This area requires particular attention given the technological focus of GRAPHERGIA and the likelihood that advanced materials or processes may entail specific health and safety challenges.

### Social protection, leave and work–life balance

Social protection mechanisms appear to be relatively well established among respondents, with 67% confirming access to social benefits such as unemployment insurance, health coverage, or pensions. A large majority (83%) also reported having access to parental and special leave.

However, half of respondents perceived that employers influence the decision to take such leave, raising concerns about implicit pressure or cultural barriers that limit the actual exercise of formal entitlements.

Flexible working arrangements were available to 50% of respondents, which indicates progress compared with more rigid past practices but also shows that flexibility is not universally accessible. This represents an opportunity for improvement, as flexibility is increasingly recognised as a determinant of job satisfaction and work–life balance.

### Employment relationship and stability

The questionnaire suggests that employment terms are generally documented: 67% of respondents confirmed the existence of formal documentation of their working conditions. However, only one-third indicated that their employment was permanent. This result points to significant reliance on temporary or non-standard contracts. Employment precarity can exacerbate vulnerabilities in other domains (for instance, willingness to report unsafe practices, or confidence in claiming entitlements).

### Freedom of association and non-discrimination

When asked about rights related to freedom of association, 67% of respondents confirmed they are aware of this entitlement, yet only half indicated that they have easy access to information about labour rights and union activities. Responses were also evenly split on whether workers are treated fairly regardless of union membership and whether they know how to file a complaint about discrimination. These 50/50 distributions are telling: they suggest that while basic rights exist in principle, awareness and trust in the mechanisms for their enforcement are inconsistent.

### Cross-cutting interpretation

Even with a limited dataset, several patterns emerge.

**Strengths identified so far:**

- A majority of workers report sufficient wages for basic needs.
- Documented contracts and access to social protection are relatively common.
- Training and PPE provision are implemented in most cases.
- Parental and special leave are formally accessible to the majority of respondents.

**Hotspots and challenges:**

- Overtime compensation practices appear highly problematic, with a strong mismatch between the share of workers reporting overtime and the share reporting compensation.
- Awareness of chemical safety measures and routine health checks is strikingly low.
- Employment precarity is significant, with two-thirds of respondents not holding permanent positions.
- Freedom of association and non-discrimination practices are inconsistently understood, with only half of respondents reporting knowledge of procedures or confidence in equal treatment.
- Perceived employer influence over leave-taking may undermine the effectiveness of formal rights.

## Limitations and next steps

Several limitations need to be explicitly acknowledged at this stage:

- **Sample size:** Only six responses have been collected as of M24. This number is far too low to support generalisation across the sector. The percentages presented should therefore be considered purely indicative and exploratory. By M48, the project anticipates a larger dataset, which will enable more robust statistical analysis and greater confidence in the representativeness of the results.
- **Sectoral diversity:** The questionnaire was distributed across companies in different but related industrial sectors. With such a small number of responses, it is not possible to compare practices between sectors or company types. Future rounds of data collection could enable more granular comparisons.
- **Temporal limitation:** Given that data collection is ongoing, the current results represent only a momentary snapshot at the halfway point of the project. Subsequent responses may alter the overall distribution of answers, either confirming these initial patterns or providing a more balanced picture.

Although based on a very limited number of responses, the preliminary findings provide valuable indications of social sustainability conditions in the sectors relevant to GRAPHERGIA. The survey suggests that certain fundamentals—such as wage sufficiency for the majority, documentation of contracts, and access to social benefits—are in place. However, it also highlights several important challenges, including overtime practices, low levels of occupational health surveillance, employment precarity, and inconsistent awareness of labour rights and grievance mechanisms.

These insights, even at an early stage, underline the importance of continued monitoring of worker-level conditions throughout the remainder of the project. Expanding the dataset will be crucial to validate or adjust these preliminary observations. By M48, with a larger and more representative sample, GRAPHERGIA will be able to provide a more robust sectoral assessment and to translate the findings into actionable recommendations for enhancing social sustainability across the value chain.

### 5.1.2 University/Research-Institute Survey

This section analyses responses from a questionnaire administered to people working in research across sectors relevant to GRAPHERGIA's value chain. The aim is to capture perceptions from R&D-facing professionals about opportunities, risks, and enabling conditions for e-textiles, self-powered sensors, and next-generation LIB electrodes.

At M24, the dataset comprises nine completed questionnaires; results are therefore preliminary and should be treated as indicative signals rather than statistically robust evidence. Data collection will continue until M48; we expect the patterns reported here to be refined or re-weighted as the sample grows.

**Figures 6 and 7** show, respectively, the type of institution to which respondents belong (universities or public and/or private research centres) and the geographical distribution of institutions (headquarters, in the case of multiple locations).

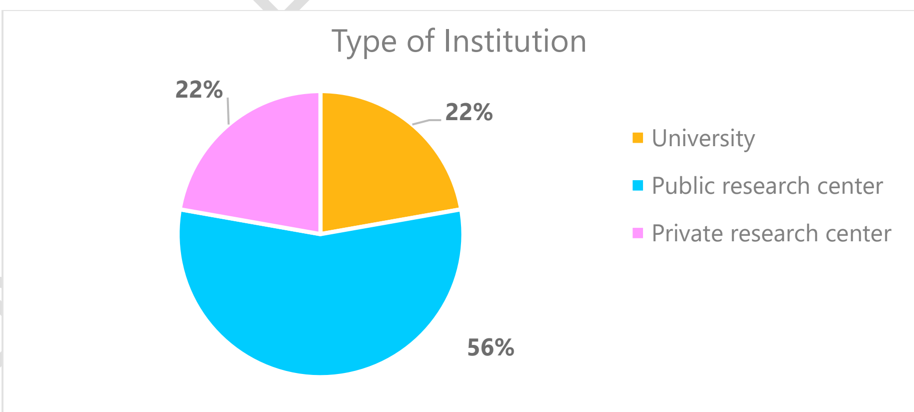


**Figure 6.** The type of institutions of the interviewees

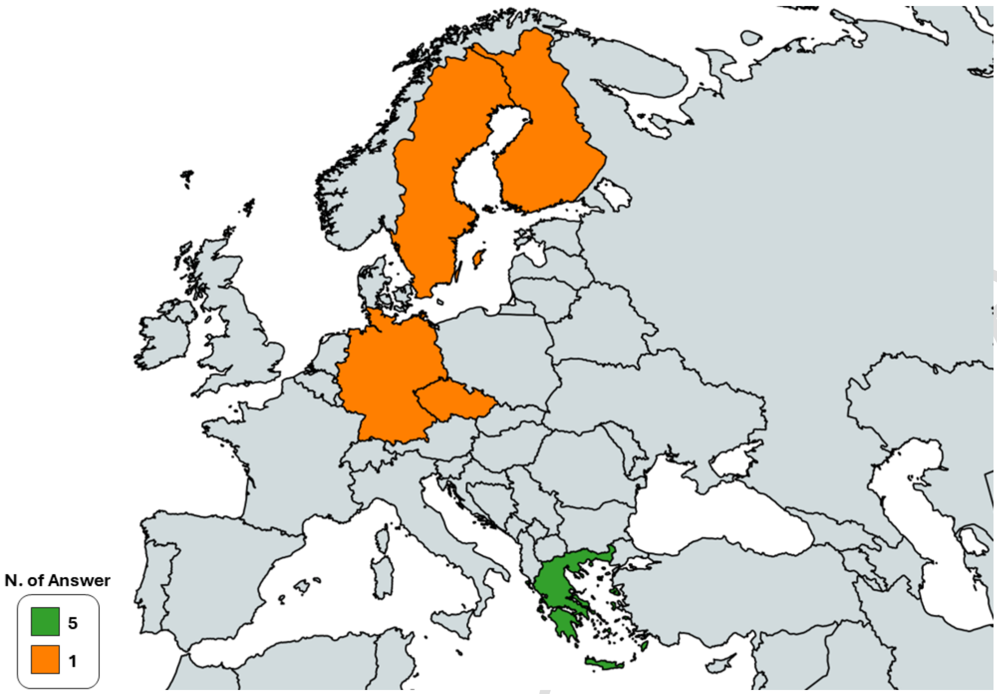


**Figure 7.** Geographical origin of the respondents to the Researchers' survey

**Figure 8** shows the type of role held by the respondent within the institution (the answer 'researcher' includes the answer 'Postdoctoral Researcher'; 'Researcher' and 'Staff scientist').

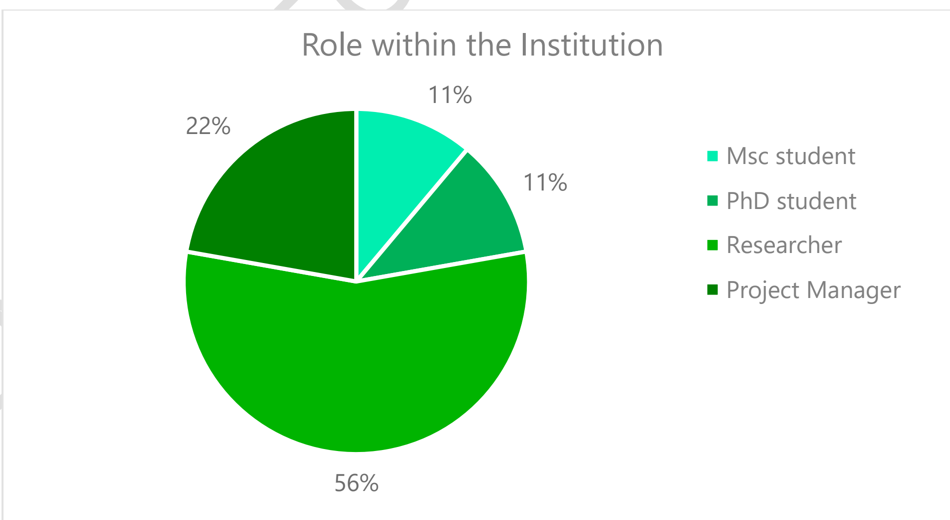


**Figure 8.** Role held by the respondent within the institution

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**Table 5** lists all the questions (along with their corresponding acronyms, 'Q*x*') whose results are reported in **Tables 6–9**. In these tables, the questions are only listed by their acronym due to space limitations.

| Q | Question |
|---|---|
| Q5 | What is your **field of research**? |
| Q6 | Have you ever heard of **e-textiles for wearable** power supply and self-powered sensors? |
| Q7 | **In which sectors** do you see the **greatest impact** of e-textiles? |
| Q8 | Do you think **self-powered sensors could improve** health and safety monitoring? |
| Q9 | What do you think are the **main social benefits** of large-scale adoption of e-textiles? |
| Q10 | What do you think are the **main challenges** in implementing e-textiles in society? |
| Q11 | How important is the **aesthetic design of e-textile** products to you? |
| Q12 | How do you think **e-textiles will impact on the traditional textile** industry? |
| Q13 | Have you **ever heard of next-generation electrodes** for lithium-ion batteries? |
| Q14 | What are the **main limitations of current lithium-ion batteries**, in your opinion? |
| Q15 | Do you think **next-generation electrodes** could improve battery efficiency and sustainability? |
| Q16 | In which **areas** do you see the **greatest impact of batteries** improved with these electrodes? |
| Q17 | What could be the main challenges to the widespread adoption of these new electrodes? |
| Q18 | What features would you like to see in **future Lithium-Ion Battery Electrodes?** |
| Q19 | **How important** do you consider the **climate-neutral approach** adopted for these products? |
| Q20 | Do you think these products could **contribute to the EU's sustainability goals**? |
| Q21 | What **environmental risks** do you see associated with these technologies? |
| Q22 | What **strategies could improve the sustainability** of these products? |
| Q23 | Do you think **greater industry involvement is necessar**y to ensure the adoption of these technologies? |
| Q24 | **What tools could facilitate** the technological transfer of these innovations to the market? |

**Table 5.** Questions 5-24 and related acronyms

| Q | Yes | No | Not Sure |
|---|---|---|---|
| Q6 | 100% | 0% | / |
| Q8 | 100% | 0% | / |
| Q13 | 89% | 11% | / |
| Q15 | 100% | 0% | / |
| Q20 | 78% | 0% | 22% |
| Q23 | 89% | 0% | 11% |

**Table 6.** Questions with answer "Yes/No (and Not sure in some case)"

| Q | Answer |
|---|---|
| Q12 | **Answer 1:** High demand and public interest will have a strong impact on the traditional textile industry.<br>**Answer 2:** Not (in the near future).<br>**Answer 3:** Multidisciplinary collaboration with other industries; New standards/regulations; Advanced textile materials or traditional materials with enhanced properties.<br>**Answer 4:** Boost the textlie industry and open new working positions<br>**Answer 5:** New commercial possibilities<br>**Answer 6:** They will need to be implemented in all new lines, clothes or athletic clothes etc. but not complete overtake it will be a niche.<br>**Answer 7:** Advanced technologies, cycle economy, sustainability. |
| | |
| Q18 | **Answer 1:** Long life cycle and capacity.<br>**Answer 2:** Raw materials with lower environmental and social impact, high recyclability<br>**Answer 3:** Size, sustainability,<br>**Answer 4:** Faster charging, more capacitance<br>**Answer 5:** Fast charge, reusable<br>**Answer 6:** Push the limit of theoretical capacity<br>**Answer 7:** Use of recyclable materials, reuse of components |

**Table 7.** Open-ended questions



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| Rating Scale | Question | |
|---|---|---|
| | Q11 | Q19 |
| 1 | 22% | 0% |
| 2 | 0% | 0% |
| 3 | 22% | 11% |
| 4 | 44% | 22% |
| 5 | 11% | 67% |

**Table 8.** Questions with rating scales of 1-5

| Q | Answer | |
|---|---|---|
| Q5 | Electronics | 11% |
| | Energy | 22% |
| | Environmental sciences | 11% |
| | Bioengineering, Tissue Engineering, Biodegradable and natural polymers | 11% |
| | Advanced materials | 11% |
| | Innovation | 11% |
| | Bioengineering | 22% |
| | | |
| Q7 | Defence | 22% |
| | Healthcare | 56% |
| | Sports | 22% |
| | | |
| Q9 | Improved quality of life | 56% |
| | Increased workplace safety | 11% |
| | Greater accessibility to technology | 33% |
| | | |
| Q10 | Technology durability | 11% |
| | High cost | 33% |
| | Regulations | 44% |
| | All of them maybe cost could be mitigated | 11% |
| | | |
| Q14 | Lifespan | 56% |

| | | |
|---|---|---|
| | Environmental impact | 33% |
| | Cost | 11% |
| | | |
| Q16 | Electric mobility | 33% |
| | Renewable energy storage | 67% |
| | | |
| Q17 | Challenges in large-scale production | 78% |
| | Regulations | 11% |
| | all the above | 11% |
| | | |
| Q21 | Use of critical materials | 44% |
| | Energy consumption in production | 11% |
| | All above, and increased difficulty to sort and recycle | 11% |
| | Waste production | 33% |
| | | |
| Q22 | Alternative materials | 22% |
| | Recycling | 33% |
| | Stricter regulations | 22% |
| | low environmental footprint materials with reuse process as the end-of-life scenario | 11% |
| | Both recycling and alternative materials | 11% |
| | | |
| Q24 | Research-industry collaborations | 78% |
| | all the above | 11% |
| | Open access data and collaborations between research-industry | 11% |

**Table 9.** Closed-ended questions



## Respondent profile and topical awareness

The sample spans multiple research domains—Energy (22%), Bioengineering (22%), Electronics (11%), Environmental sciences (11%), Advanced materials (11%), Innovation (11%), and an additional bioengineering-related category (11%). This distribution suggests a predominantly science- and technology-oriented audience with direct exposure to materials, devices, or application development.

Awareness of the focal technologies is very high. All respondents (100%) have heard of e-textiles for wearable power and self-powered sensors, and 89% have heard of next-generation electrodes

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for lithium-ion batteries. This aligns with the respondents' research roles and sets a useful context for interpreting subsequent judgments about impacts, benefits, and risks.

## E-textiles and self-powered sensors

### Perceived impact areas and benefits

Respondents see the greatest impact of e-textiles in healthcare (56%), followed by defence (22%) and sports (22%). The emphasis on healthcare is consistent with wearables' established value propositions in patient monitoring, rehabilitation, and assisted living, while defence and sports reflect performance and safety use-cases.

When asked about the main social benefits from large-scale adoption of e-textiles, respondents prioritised improved quality of life (56%), greater accessibility to technology (33%), and increased workplace safety (11%). The ordering suggests that researchers are currently more attuned to end-user utility and inclusivity (quality of life, access) than to workplace-specific prevention gains, although the latter remains part of the perceived benefit portfolio.

Notably, 100% believe self-powered sensors could improve health and safety monitoring, underscoring confidence that embedded, maintenance-light sensing can enhance real-time oversight and reduce risk, particularly in settings where battery maintenance is a barrier.

### Barriers to implementation

The main challenges flagged for implementing e-textiles are regulations (44%), high cost (33%), and technology durability (11%), with an additional comment acknowledging that "all of them" matter, even if cost could be mitigated (11%). Regulatory clarity and compliance readiness thus emerge as the single most cited friction at this early stage, closely followed by cost and robustness—two classic hurdles for translation from lab to market.

### Role of aesthetics

On a 1–5 scale of how important the aesthetic design of e-textile products is, responses cluster toward the top end (22% rated "3", 44% "4", 11% "5", with a minority at "1"—22%). In short, over half of respondents (55%) place high importance (4–5) on aesthetics. For consumer-facing wearables, this reinforces that industrial design is not ancillary: adoption and sustained use often depend on comfort, form factor, and visual appeal, not only functionality.

### Anticipated sectoral effects (open answers)

Open-ended comments on how e-textiles might impact traditional textiles highlight multidisciplinary collaboration, new standards and regulations, advanced (or enhanced) materials, new commercial niches and jobs, and circular-economy and sustainability considerations. Several respondents expect growth without full displacement of conventional lines—a niche expansion that coexists with traditional products rather than an immediate overhaul. This perspective is pragmatic and signals where policy and industry platforms can invest: standards development, interdisciplinary consortia, and market education.

## Next-generation LIB electrodes

### Perceived limitations of current batteries and desired improvements

Respondents identify lifespan (56%), environmental impact (33%), and cost (11%) as the main limitations of current LIBs. This framing sets an expectation that "next-gen" electrodes should tangibly improve durability and environmental performance.

Asked what features they would like to see in future electrodes (open responses), the themes are consistent: long life cycle and capacity, faster charging/higher capacitance, pushing theoretical capacity limits, and use of recyclable or lower-impact materials with high recyclability/reuse. These priorities mirror the limitation set: users want performance and longevity gains delivered without environmental trade-offs.

A linked 1–5 rating about desired features shows a strong skew toward the top of the scale (67% rated "5", 22% "4", 11% "3"; none chose 1–2), indicating very high importance placed on feature advancement by this research cohort.

### Expected benefits and application domains

100% of respondents believe next-generation electrodes could improve battery efficiency and sustainability, and they see the largest system-level impact in renewable energy storage (67%), followed by electric mobility (33%). The storage emphasis suggests respondents associate electrode innovation with grid-scale or distributed energy applications where cycle life, efficiency, and sustainability credentials can compound system benefits over long horizons.

### Adoption challenges

The chief obstacle to widespread adoption is challenges in large-scale production (78%), with regulations (11%) and an "all of the above" acknowledgement (11%) rounding out the picture. Scale-up complexity—process control, yield, quality consistency, and cost—again appears as the dominant translational bottleneck, a point highly consistent with responses on e-textiles.

## Sustainability, risks, and enablers across both technology families

### Alignment with EU sustainability goals and perceived risks

Asked whether these products could contribute to EU sustainability goals, 78% answered Yes, with 22% unsure. While this is a strong endorsement, the "Not sure" share is non-trivial and likely reflects legitimate questions about life-cycle impacts, critical raw materials, and end-of-life management.

Consistent with that interpretation, the principal environmental risks cited are use of critical materials (44%) and waste production (33%), with energy consumption in production (11%) and a combined "all above + increased difficulty to sort and recycle" (11%) also noted. These responses are a clear reminder that technical performance gains must be matched by material circularity and responsible sourcing to achieve net sustainability benefits.

Regarding mitigation strategies, respondents emphasise recycling (33%), followed by alternative materials (22%) and stricter regulations (22%). Additional suggestions include low-footprint materials with reuse pathways at end-of-life (11%), and a combined approach (recycling + alternative materials, 11%). The overall message is unambiguous: design-for-circularity, supply-risk management, and regulatory alignment should be built into R&D roadmaps from the outset.

**Technology transfer**

On the enablers of adoption, the research cohort strongly favours greater industry involvement (89% Yes) and identifies research–industry collaborations (78%) as the primary tool for market transfer, with additional references to open-access data and "all of the above". This indicates a clear appetite for co-development models, shared datasets, and pre-competitive platforms that accelerate Technology Readiness Level (TRL) maturation while de-risking scale-up.

## Cross-cutting synthesis

**Strength signals (early stage):**

- High awareness and positive expectations for both e-textiles/self-powered sensors and next-gen electrodes across a technically informed sample.
- Healthcare stands out as the leading e-textile application, with quality of life and accessibility as the headline social benefits.
- For batteries, respondents expect efficiency and sustainability improvements, prioritising longevity, fast charging, and recyclability.
- Design matters for e-textiles: more than half rate aesthetics as highly important, reinforcing the need to integrate industrial design into R&D programs.



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- Collaboration with industry is viewed as essential for technology transfer, consistent across both families of innovations.

**Hotspots and tensions to monitor:**

- Regulatory readiness is the most cited barrier for e-textiles, and manufacturing scale-up is the bottleneck for next-gen electrodes—together, they define the translation frontier.
- Critical materials and end-of-life are top sustainability risks. Mitigation requires materials substitution where feasible, circular design, and clear sorting/recycling pathways.
- Evidence for EU-goal alignment is broadly positive but not unanimous (22% unsure), signalling a need for robust LCA/S-LCA evidence and transparent trade-off communication.

## Limitations and next steps

**Sample size and timing.** The analysis now is based on nine responses. With such a small number of answers, percentage swings are sensitive to individual responses, and findings cannot be generalised to the whole sector. Continued data collection to M48 is essential for representativeness and for robust sub-group analysis (e.g., field of research, application focus).

**Respondent composition.** Because all respondents are research professionals, the dataset may exhibit translation optimism (confidence in technical solutions) and underrepresentation of downstream constraints (e.g., user training, service models). Future rounds should seek broader stakeholder coverage (manufacturing engineers, procurement, clinicians, athletes/coaches, H&S officers, recyclers).

At this mid-project checkpoint, research stakeholders convey high awareness and optimism about the social and environmental value of e-textiles, self-powered sensors, and next-generation battery electrodes, while candidly acknowledging the translation bottlenecks—regulation for e-textiles and scale-up for electrodes—and the sustainability guardrails that matter most (critical materials, waste, and circularity). The signal on healthcare primacy for e-textiles and renewable-energy storage for batteries offers a practical guide for piloting and stakeholder engagement. As responses accumulate toward M48, the project will be able to convert these preliminary insights into evidence-backed priorities for design-for-circularity, regulatory alignment, and industry-ready manufacturing, thereby maximising the likelihood that the anticipated social benefits—improved quality of life, accessibility, and safety—are realised at scale.



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# 6 Conclusions

This deliverable sets the foundations for a rigorous S-LCA pathway across GRAPHERGIA's three demonstrators—self-charging textile systems, self-powered aerospace sensors, and graphene-based Li-ion battery modules for space—by aligning early evidence gathering with UNEP/SETAC guidance and the project's broader LCSA framework. It operationalises a multi-method design that combines stakeholder surveys with database-supported risk screening, with the explicit intent to inform design choices and supply-chain decisions before lock-in occurs. In doing so, it strengthens GRAPHERGIA's commitment to develop high-performance solutions that are socially equitable and consistent with the European Green Deal's just transition objectives.

Methodologically, the work clarifies scope, stakeholder coverage, and data architecture for subsequent iterations. The approach integrates five stakeholder groups (workers, consumers, local communities, society, and value-chain actors) and combines primary data from tailored questionnaires with secondary risk intelligence (notably SHDB) to enable both bottom-up insight and top-down screening. This dual lens is essential in emerging materials systems where site-specific practices can diverge from country-sector averages, and where early design choices have long-tail social implications.

The preliminary evidence assembled at mid-project (M24) yields actionable signals, while also surfacing clear limitations that the consortium is already addressing. On the worker side (n=6), strengths include documented contracts (67%), reported wage sufficiency for basic needs (67%), the presence of safety training (67%) and PPE provision (67%), and access to social benefits (67%) and leave (83%). At the same time, pronounced hotspots emerge: only 17% report routine health checks; awareness of chemical-exposure protocols stands at 33%; and a sharp mismatch appears between reported overtime (50%) and overtime compensation (17%). Moreover, only one-third report permanent contracts, indicating notable employment precarity. These findings, while based on a small sample, point directly to priority improvement areas around occupational health surveillance, transparent and fair compensation for overtime, and employment stability.

On the research/innovation side (n=9), respondents express high awareness of social value and sustainability imperatives for both e-textiles/self-powered sensors and next-generation battery electrodes. They prioritise healthcare as the leading e-textile domain and see energy-storage longevity, fast charging, and recyclability as key social-environmental levers for batteries. The principal translation bottlenecks crystallise as regulatory readiness (e-textiles) and manufacturing scale-up (electrodes). These insights provide an early compass for design-for-acceptance and design-for-circularity choices in the demonstrators and for coordinated engagement with standards and regulatory communities.

At the product/value-chain level, the deliverable confirms the role of the SHDB as the screening backbone for upstream and midstream risks to be coupled, at M48, with complete LCC inventories for robust normalisation. This staged approach avoids premature inference from partial system boundaries and cost flows, and guards against mis-weighting of country-sector risks. In line with state-of-the-art analyses of critical materials chains, the baseline expectation remains that upstream stages (feedstocks, graphene production inputs, specialty chemicals) will concentrate higher social risks—spanning labour rights, governance quality, and community well-being—relative to regulated European use and end-of-life phases; this will be tested quantitatively once economic allocations are finalised.

Across these streams, three cross-cutting conclusions stand out:

1. **Early social integration is already shaping design choices.** By pairing worker-level signals with research-side expectations and SHDB screening, the project has identified high-leverage levers: strengthen OHS programmes (with periodic health checks and chemical-exposure protocols), codify fair-work practices (overtime compensation transparency, steps toward contract stability), and build circularity features into product architectures (durability, reparability, disassembly, and clear sorting pathways). These translate directly into WP6 eco-design guidance and will inform demonstrator-specific gate reviews.
2. **Stakeholder engagement must broaden and deepen.** The current sample—especially the absence of company-level responses—limits representativeness. The consortium's multi-channel distribution plan (QR-code campaigns, partner networks, sector fairs, bilateral outreach to companies/associations, academic lists) is appropriate to close gaps by M48 and to capture diverse geographies and roles (operators, H&S officers, procurement, recyclers). Scaling this effort is indispensable both for triangulation and for credible, context-aware conclusions.
3. **Governance and transparency are enabling conditions.** As the demonstrators progress, publishing social KPIs alongside technical metrics—e.g., training hours, OHS leading/lagging indicators, supplier audit coverage and closure rates, local procurement shares, gender and diversity metrics—will support comparability, due-diligence alignment, and trust with regulators, investors, and communities. Embedding these metrics in open, machine-readable formats will also facilitate future Digital Product Passport integration and value-chain traceability.

**Limitations** of the present assessment are explicit. Survey sizes are small (especially at company level), the analysis intentionally defers SHDB quantification until LCC datasets are complete, and not all demonstrator processes have stable supply-chain configurations yet. These constraints justify the project's staged design and underline the need for continued recruitment and QA/QC as scale-up proceeds.

**Next steps** are clear and time-bound within WP6 and cross-WP integration:

- **Data consolidation and representativeness (→ M48):** Intensify worker, company, and research recruitment; pursue sectoral balance (textiles, energy storage, aerospace), roles and geographies; implement response-quality checks and de-duplication; and document non-response patterns to assess bias.
- **OHS and fair-work action plan (rolling):** Draft and pilot a minimal common programme across partner facilities covering (i) periodic medical surveillance, (ii) chemical-exposure procedures and training, (iii) overtime tracking and compensation transparency, and (iv) pathways toward contract stability. Monitor uptake via a small core indicator set tied to WP6 dashboards.
- **Design-for-circularity requirements (next design gates):** For e-textiles and sensors, specify washability/repairability tests, fibre/component disassembly features, and labelling/traceability hooks; for battery modules, prioritise durability, second-life potential where relevant, and recycler-ready material segregation. Link these to the SHDB-informed hotspot map to ensure that material substitutions and supplier selections reduce upstream social risks, not only environmental footprints.
- **SHDB × LCC integration (analysis window to M48):** Merge finalised cost inventories with SHDB to compute stakeholder-specific indicators with uncertainty ranges; test alternative sourcing and localisation scenarios; and report trade-offs transparently (including sensitivity to economic normalisation).
- **Transparency and external alignment (ongoing):** Map emerging metrics to EU policy signals relevant to advanced materials (e.g., Green Deal, Fit for 55) and to anticipated data schemas for Digital Product Passports; prepare concise, public-facing summaries to accompany technical deliverables and demonstrator showcases.

In conclusion, D6.3 achieves its primary objective: it establishes a credible, stakeholder-centred S-LCA scaffold for GRAPHERGIA, identifies early hotspots and opportunities, and lays out a disciplined pathway to decision-relevant, end-to-end conclusions by the project's close. The combination of survey-based ground truth, structured risk screening, and explicit coupling to environmental and economic pillars equips the consortium to make anticipatory, ethically informed choices from lab to pilot line to application. As data density grows and circularity features mature, the project is well-positioned to demonstrate that cutting-edge graphene technologies can advance performance while measurably improving worker well-being, strengthening communities, and enhancing fairness and resilience across global value chains.



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# 8 Appendix

## 8.1 Social-LCA Survey

Below is an example of the survey text which was developed and disseminated for the evaluation of the social LCA related to the three stakeholder categories evaluated: Workers, Companies and Researchers.

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The overarching aim of GRAPHERGIA is to develop a new science-based, holistic approach, implementing new advances to achieve one-step, laser-assisted synthesis, processing, functionalization and simultaneous integration of graphene-based materials and graphene nanohybrids, directly into relevant energy harvesting/storage devices.

WP6 - Life cycle assessment, sustainability and ecodesign approach

Objectives: (i) To assess the environmental burdens through the identification/quantification of energy and raw materials, and benefits of material components and processing technologies employed. (ii) To determine Life Cycle Cost and cost-feasibility of the different stages associated with the development of the target products. (iii) To identify and assess social aspects and overcome any possible related issues. (iv) To define an ecodesign strategy to minimize future waste in the technological development process.

Social LCA (S-LCA) will be employed to address social and socio-economic benefits of GRAPHERGIA processes and products. With this document we would like to involve you through a simple survey that we kindly ask you to complete about the perception and the knowledge on the production of smart textiles and batteries.

Thank you for taking part in our research on social sustainability. Your response will be part of the GRAPHERGIA project that develops novel laser-assisted graphene production methods for energy harvesting and storage. In parallel, intends to address the social impact along the life cycle of smart-textiles products and battery production.

**For companies:**

The questionnaire counts with 4 main sections. The first one addresses general data about the product. The second one addresses the working conditions within the company. The third one refers to the relationship the company has towards the local community. The fourth section addresses the relationship the company has with suppliers and other main actors along the supply chain. Once again thank you very much for your participation. Your input is the most valuable factor of this research.

**For workers:**

The questionnaire comprises multiple inquiries that delve into social aspects such as wages, working conditions, health, and safety in the workplace, among others. Your honest responses are crucial for obtaining valuable and accurate insights. Thank you for your sincerity in providing feedback.

**For University/Research institute**

The questionnaire comprises multiple inquiries that delve into social aspects related to applicability and Social Impact of project demonstrators, design, future challenges and research topics for products improvements. Once again thank you very much for your participation. Your input is the most valuable factor of this research.

*GRAPHERGIA team*



## WORKERS QUESTIONNAIRE

### GENERAL INFORMATION

1. What country do you currently reside in? (List)
2. What is your gender? (M/F/Other)
3. To which industry do you belong? (Select one option)
    - Waste treatment & disposal
    - Textile
    - Distribution
    - Transport
    - Logistics
    - Raw material producer
    - Product design
    - Product manufacturing

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- Other

**WAGES**

4. Please, indicate your average monthly wage (in Euro, gross):
   - < 1.000
   - 1.000 - 2.000
   - 2.000 - 3.000
   - 3.000 - 4.000
   - 4.000 - 5.000
   - > 5.000
5. Is your wage sufficient for you (as an individual or your family) to meet basic needs and maintain a modest but decent standard of living? (Yes/No)
6. Have you ever received a bonus payment? (Yes/No)
7. Have you worked extra hours? (Yes/No)
8. Were you compensated for the extra hours worked? (Yes/No)

**WORKING HOURS**

9. Please, indicate your number of hours in a normal working week:
   - < 30
   - 30-35
   - 35-40
   - > 40

**HEALTH AND SAFETY**

10. Have you received training in the field of security and safety in the workplace? (Yes/No)
11. <u>(Selection: Yes)</u> How many hours did you spend on safety training in the last year? (number hours/year)
    - < 8
    - 8 – 12
    - 12 – 24
    - 24 – 40
    - > 40
12. Is personal protective equipment (PPE) supplied to workers?
13. Have you undergone a health check in your workplace? (Yes/No)
14. <u>(Selection: Yes)</u> how many periodic health checks for employees have you had in the last year? (Number per year)
    - 1
    - 2

- 3
- 4
- > 4

15. Are you aware of existing preventive measures and protocols with regards to accidents and injuries at your workplace? (Yes/No)
16. Have you experience an accident during your work shift? (Yes/No)
17. Are you aware of existing preventive measures and protocols with regards to chemical exposure at your workplace? (Yes/No)

**SOCIAL BENEFITS**

18. Have you received any social benefits as an employee (e.g. unemployment benefits, health insurance, pension, etc.)? (Yes/No)
19. (Selection: Yes) Please, indicate which ones:
    a. Health insurance
    b. Pension fund
    c. Child care
    d. Dormitories
    e. Canteen
    f. Transport to work place
    g. Scholarships
    h. Others
20. Have you received medical assistance related to work issues? (Yes/No)

**WORKING CONDITIONS**

21. Do you have access to parental leave and/or special leave (for disability, bereavement, etc.)? (Yes/No)
22. Does your employer influence the decision to take parental leave or any other special leave? (Yes/No)
23. Do you have flexible working hours? (Yes/No)
24. Are your working conditions documented (e.g., regular contracts)? (Yes/No)
25. Are you a permanent worker? (Yes/No)
26. How many labour days per year do you have as holidays? (Number of labour days/ year)
    - < 10
    - 10 – 20
    - 20 – 30
    - 30 – 35
    - > 35

**27.** How much time do you spend commuting daily?
  - < 10 min
  - 10 - 20 min
  - 20 - 40 min
  - 40 - 50 min
  - 50 - 60 min
  - > 60 min

**FREEDOM OF ASSOCIATION AND COLLECTIVE BARGAINING**

**28.** Are you aware of your right to freedom of association in the workplace? (Yes/No)

**29.** Do you have easy access to information about labour rights and the activities of labour organizations in your workplace? (Yes/No)

**DISCRIMINATION**

**30.** Do you believe that all employees, regardless of union membership, are treated fairly in the workplace? (Yes/No)

**31.** Do you know how to file a complaint or raise doubts about any action by management that violates non-discriminations? (Yes/No)

## COMPANY QUESTIONNAIRE

GENERAL INFORMATION

1. Where is your company located? (List)
2. Do your company have other facilities apart from the headquarters? (Indicate where) (List)
3. Which market sector do the company's products belong to?
   - E-Textile
   - Energy-storage
   - Sensors
   - 2-D materials
   - Other

- (Selection: E-textile) E-textile sector. What is/are the end product(s) of the company?
  - sports & fitness
  - medical & healthcare
  - wellness
  - military
  - fashion

- automotive
- Other(s)

- (Selection: Other(s)) E-textile sector. Please specify the other product(s) of the company. (open answer)

4. Please describe the production process of the relevant plant. In the description, include only those process steps that relate to the product sold:______________________________________________________________________________________________________
5. What is the selling price of the end-product produced by the company? (USD or EUR/unit)
   - < 10
   - 10 – 20
   - 20 – 50
   - 50 – 100
   - > 100

**WORKERS AS STAKEHOLDERS**

**1. HEALTH AND SAFETY**

1. Does the company ensure the availability and use of Personal Protective Equipment (PPE) for its employees? (Yes/No)
2. Is the company/site in compliance with applicable local health and safety regulations? (Yes/No)
3. Does the company have contingency plans established for emergency situations, such as fires? (Yes/No)
4. Does the company have a dedicated Committee of Health and Safety actively involved in maintaining a safe workplace? (Yes/No)
5. Can you specify the number of accidents related to the use of harmful substances within the past year? (number/year)
   - 0
   - 1
   - 2
   - 2 - 5
   - 5 – 10
   - > 10
6. How often are employees subjected to periodic health checks? (number/year)
   - 1
   - 2

- 3
- 4
- > 4

**7.** How many hours, on average, are dedicated to safety and health training for workers each year? (hours/year)
- < 8
- 8 – 12
- 12 – 24
- 24 – 40
- > 40

## 2. WAGES

**8.** Can you provide the average monthly gross salary of employees within the company? (euros/month)
- < 1.000
- 1.000 - 2.000
- 2.000 - 3.000
- 3.000 - 4.000
- 4.000 - 5.000
- > 5.000

**9.** What is the lowest monthly gross salary paid at the company? (euros/month and full-time work shift)
- < 500
- 500 – 700
- 700 – 1.000
- 1.000 – 1.200
- 1.200 – 1.500
- > 1.500

**10.** In average, what is the current overtime hours at the company? (hours/week or month)
- < 10
- 10 – 20
- 20 – 50
- 50 – 100
- 100 – 200
- > 500

**11.** Do employees receive additional compensation for overtime worked within the company? (Yes/No)



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## 3. SOCIAL BENEFITS

**12.** Are any of the following social benefits provided to full-time workers at the company?
   a. Health insurance
   b. Pension fund
   c. Child care
   d. Dormitories
   e. Canteen
   f. Transport to work place
   g. Scholarships
   h. Others

## 4. WORKING CONDITIONS

**13.** In average, how many hours per week does a full-time employee work at the company? (hours/week)
   - < 30
   - 30-35
   - 35-40
   - > 40

**14.** What percentage of employees have flexible working hours within the company? (%)
   - 0 - 25%
   - 25% - 50%
   - 50% - 75%
   - 75% - 100%

**15.** Are working conditions documented (e.g., through regular contracts)? (Yes/No)

**16.** What percentage of workers are classified as permanent employees within the company? (%)
   - 0 - 25%
   - 25% - 50%
   - 50% - 75%
   - 75% - 100%

**17.** On average, how many days of holidays do employees receive per year (labour days)? (number days/year)
   - < 10
   - 10 – 20
   - 20 – 30

- 30 – 35
- > 35

**18.** Have you got rotating shifts? (Yes/No)
**19.** Have you got night working shits? (Yes/No)

## 5. DISCRIMINATION

**20.** Does the company hire workers independently of their religion, nationality and sexual orientation? (Y/N)
**21.** What percentage of the labour force consists of women employed by the company?

- 0 - 25%
- 25% - 50%
- 50% - 75%
- 75% - 100%

**22.** How many complaints related to discrimination have been identified by the company in a year? (number of complaints/year)

- 0
- 1
- 2 -4
- 4 – 10
- > 10

**23.** Does your company have a gender equality plan? (Yes/No)

## 6. TRAINING

**24.** Are employees given appropriate training before entering employment with the company? (Yes/No)
**25.** What percentage of employees participated in at least one training program in the past year?

- 0-33%
- 33-66%
- 66-100%

## 7. FREEDOM OF ASSOCIATION AND COLLECTIVE BARGAINING

**26.** Do employees have the right to form associations within the company? (Yes/No)
**27.** Are you aware of any association or committee formed by the workers at the company? (Yes/No/In progress) If your answer is yes or "in-progress", please go to questions a) to c).

a. How many affiliates does the workers association/committee have?
    - 0 - 25%

- 25% - 50%
- 50% - 75%
- 75% - 100%

b. Has the company ever had to negotiate a specific issue with this workers association/committee? (Yes/No/In progress)

c. Is the workers association's/committee's representative invited to participate in the company's decisions? (Yes/No/In progress)

**28.** Do employees have the right to organize collective bargaining activities? (Yes/No)

**29.** Do employees have the right to strike? (Yes/No)

**LOCAL COMMUNITY AS STAKEHOLDERS**

**1. HEALTH AND SAFETY**

**30.** Have there been any accidental affecting the environment as a result of the company's activities? (Yes/No)

**31.** Has the company contributed to the improvement of local infrastructure (e.g., telecommunications, road network, energy, and water supply) to support its activities? (Yes/No)

**32.** Has the company played a role in education and knowledge of the local population? (Yes/No)

**33.** Does your company propose specific programs in place to enhance health and safety for the local community? (Yes/No)

**2. LOCAL EMPLOYMENT**

**34.** How many new jobs are created each year directly through the enterprise's activities? (number of new jobs/year (ideally last one))

- 0
- 1 – 5
- 5 – 10
- 10 – 20
- 20 – 50
- > 50

**35.** Have the company's activities generated business and employment opportunities in other sectors (e.g., waste management)? (Yes/No)

**36.** Does the company manage any policy/regulation that gives priority to hire or do business with local employees/suppliers? (Yes/No)

**3. SUSTAINABILITY**

**37.** Does the company measure and report on its sustainability performance and progress? (Yes/No)

38. Is it publicly available? (Yes/No)
39. Are there any external certification or standards that your company adheres to in sustainability matters? (Yes/No)
40. Which of the following does your company comply to:
    - ☐ ISO 14001
    - ☐ ISO 50001
    - ☐ EU Ecolabel
    - ☐ Carbon Trust Standard
    - ☐ Leadership in Energy and Environmental Design (LEED)
    - ☐ SA8000
    - ☐ Eco-Management and Audit Scheme (EMAS)
    - ☐ Global Reporting Initiative (GRI)
    - ☐ None

### 4. VALUE CHAIN ACTORS AS STAKEHOLDERS

41. Is the company member of any social responsible initiative? (Yes/No)
42. (Selection: Yes) If yes, can you name this organization/initiative?

## UNIVERSITY/RESEARCH INSTITUTE

### 1. General Information about the Respondent

43. Which type of institution do you belong to? (Public research center, Private research center, University, Other)
44. Where is your institution located? (List)
45. What is your role within the institution? (Researcher, Professor, PhD student, Project manager, Other)
46. What is your field of research? (Advanced materials, Energy, Electronics, Environmental sciences, Bioengineering, Other)

### 2. Applicability and Social Impact of E-Textiles

47. Have you ever heard of e-textiles for wearable power supply and self-powered sensors? (Yes/No)
48. In which sectors do you see the greatest impact of e-textiles? (Healthcare, Sports, Defense, Industry, Other)
49. Do you think self-powered sensors could improve health and safety monitoring? (Yes/No/Not sure)
50. What do you think are the main social benefits of large-scale adoption of e-textiles? (Improved quality of life, Increased workplace safety, Greater accessibility to technology, Other)
51. What do you think are the main challenges in implementing e-textiles in society? (High cost, User acceptance, Regulations, Technology durability, Other)

52. What features would you like to see in future e-textile products (e.g., washable electronics, flexible displays)?
53. How important is the aesthetic design of e-textile products to you? (Scale from 1 = not at all important to 5 = Extremely important)
54. How do you think e-textiles will impact the traditional textile industry?

**3. Applicability and Social Impact of Lithium-Ion Battery Electrodes**

55. Have you ever heard of next-generation electrodes for lithium-ion batteries? (Yes/No)
56. What are the main limitations of current lithium-ion batteries, in your opinion? (Cost, Lifespan, Environmental impact, Other)
57. Do you think next-generation electrodes could improve battery efficiency and sustainability? (Yes/No/Not sure)
58. In which areas do you see the greatest impact of batteries improved with these electrodes? (Electric mobility, Consumer electronics, Renewable energy storage, Other)
59. What could be the main challenges to the widespread adoption of these new electrodes? (Challenges in large-scale production, Market acceptance, Regulations, Other)
60. What features would you like to see in future **Lithium-Ion Battery Electrodes**?

**4. Impact on Sustainability and Energy Transition**

61. How important do you consider the climate-neutral approach adopted for these products? (Scale from 1 to 5)
62. Do you think these products could contribute to the EU's sustainability goals? (Yes/No/Not sure)
63. What environmental risks do you see associated with these technologies? (Waste production, Use of critical materials, Energy consumption in production, Other)
64. What strategies could improve the sustainability of these products? (Recycling, Alternative materials, Stricter regulations, Other)

**5. Barriers to Adoption and Technology Transfer**

65. Do you think greater industry involvement is necessary to ensure the adoption of these technologies? (Yes/No/Not sure)



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**66.** What tools could facilitate the technological transfer of these innovations to the market? (Public funding, Research-industry collaborations, Open-access data, Specialized training, Other)

## 8.2 Social-LCA Survey – Answers at M24

**Tables 10-14** provide a detailed overview of the responses gathered so far from two of the three S-LCA surveys developed within GRAPHERGIA: the Workers' Survey and the Universities/Research Institutes Survey. The data presented reflects preliminary insights into social aspects as perceived by employees and academic stakeholders.

### Worker's Survey

| Q | Question |
|---|---|
| 1 | Category |
| 2 | What country do you currently reside in? (Please specify) |
| 3 | What is your gender? |
| 4 | To which industry do you belong? |
| 5 | Please, indicate your average monthly wage (in Euro, gross): |
| 6 | Is your wage sufficient for you (as an individual or your family) to meet basic needs and maintain a modest but decent standard of living? |
| 7 | Have you ever received a bonus payment? |
| 8 | Have you worked extra hours? |
| 9 | Were you compensated for the extra hours worked? |
| 10 | Please, indicate your number of hours in a normal working week: |
| 11 | Have you received training in the field of security and safety in the workplace? |
| 12 | If yes, how many hours did you spend on safety training in the last year? (number hours/year) |
| 13 | Is personal protective equipment (PPE) supplied to workers? |
| 14 | Have you undergone a health check in your workplace? |
| 15 | If yes, how many periodic health checks for employees have you had in the last year? (Number per year) |
| 16 | Are you aware of existing preventive measures and protocols with regards to accidents and injuries at your workplace? |
| 17 | Have you experience an accident during your work shift? |
| 18 | Are you aware of existing preventive measures and protocols with regards to chemical exposure at your workplace? |
| 19 | Have you received any social benefits as an employee (e.g. unemployment benefits, health insurance, pension, etc.)? |
| 20 | Please, indicate which ones: |
| 21 | Have you received medical assistance related to work issues? |
| 22 | Do you have access to parental leave and/or special leave (for disability, bereavement, etc.)? |



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| | |
|---|---|
| **23** | Does your employer influence the decision to take parental leave or any other special leave? |
| **24** | Do you have flexible working hours? |
| **25** | Are your working conditions documented (e.g., regular contracts)? |
| **26** | Are you a permanent worker? |
| **27** | How many labour days per year do you have as holidays? (Number of labour days/ year) |
| **28** | How much time do you spend commuting daily? |
| **29** | Are you aware of your right to freedom of association in the workplace? |
| **30** | Do you have easy access to information about labour rights and the activities of labour organizations in your workplace? |
| **31** | Do you believe that all employees, regardless of union membership, are treated fairly in the workplace? |
| **32** | Do you know how to file a complaint or raise doubts about any action by management that violates non-discriminations? |

**Table 10.** List of questions for the workers' survey and reference numeric code



The following abbreviations are used in the X and Y tables:

In all questions with 'yes' or 'no' answers, "Yes" is abbreviated to 'Y' and "No" to "N"

Question 2 → Nations are indicated by their abbreviation, based on the definition in ISO 3166-1.

Question 3 → "Female" is abbreviated to "F" and "Male" to "M".

Question 4 → T = Textile; PD = Product Design; O = Other;

Question 5 → values are in thousands, abbreviated to "k"; it must be multiplied by E+03.

Question 20 → H.I. = Health insurance; P.F. = Pension fund; W.T. = Transport to workplace.

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| Q 2 | Q 3 | Q 4 | Q 5 (k) | Q 6 | Q 7 | Q 8 | Q 9 | Q 10 | Q 11 | Q 12 | Q 13 | Q 14 | Q 15 | Q 16 | Q 17 | Q 18 | Q 19 | Q 20 | Q 21 | Q 22 | Q 23 | Q 24 | Q 25 | Q 26 | Q 27 | Q 28 (min) | Q 29 | Q 30 | Q 31 | Q 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FR | F | O | 3-4 | Y | N | Y | N | 30-35 | Y | <8 | N | N | | N | N | N | N | / | N | Y | Y | Y | Y | N | 20-30 | <10 | N | N | N | N |
| IT | F | T | <1 | N | N | N | N | 35-40 | Y | 8-12 | Y | N | | Y | N | Y | Y | H.I. | Y | Y | N | N | Y | N | 20-30 | 40-50 | Y | Y | Y | N |
| FR | F | O | 3-4 | Y | N | N | N | 30-35 | N | / | N | N | | N | N | N | N | / | N | N | N | N | N | N | 10-20 | <10 | N | N | N | N |
| GR | M | O | 1-2 | Y | N | N | N | 35-40 | Y | 8-12 | Y | N | | Y | N | Y | Y | H.I. | N | Y | Y | N | Y | Y | 20-30 | 20-40 | Y | Y | Y | Y |
| GR | F | O | 2-3 | N | N | Y | N | >40 | N | / | Y | N | | N | N | N | Y | H.I. | N | Y | Y | Y | N | Y | 20-30 | 20-40 | Y | N | N | Y |
| SI | M | PD | 2-3 | Y | Y | Y | Y | 35-40 | Y | 8-12 | Y | Y | 1 | Y | N | N | Y | H.I., P.F., W.T. | N | Y | N | Y | Y | N | 10-20 | 20-40 | Y | Y | Y | Y |

**Table 11.** Worker Survey - Total Answers

| Q | Question |
|---|---|
| Q1 | Category |
| Q2 | Which type of institution do you belong to? |
| Q3 | Where is your institution located? |
| Q4 | What is your role within the institution? |
| Q5 | What is your field of research? |
| Q6 | Have you ever heard of e-textiles for wearable power supply and self-powered sensors? |
| Q7 | In which sectors do you see the greatest impact of e-textiles? |
| Q8 | Do you think self-powered sensors could improve health and safety monitoring? |
| Q9 | What do you think are the main social benefits of large-scale adoption of e-textiles? |
| Q10 | What do you think are the main challenges in implementing e-textiles in society? |
| Q11 | How important is the aesthetic design of e-textile products to you? |
| Q12 | How do you think e-textiles will impact the traditional textile industry? |
| Q13 | Have you ever heard of next-generation electrodes for lithium-ion batteries? |
| Q14 | What are the main limitations of current lithium-ion batteries, in your opinion? |
| Q15 | Do you think next-generation electrodes could improve battery efficiency and sustainability? |
| Q16 | In which areas do you see the greatest impact of batteries improved with these electrodes? |
| Q17 | What could be the main challenges to the widespread adoption of these new electrodes? |
| Q18 | What features would you like to see in future Lithium-Ion Battery Electrodes? |
| Q19 | How important do you consider the climate-neutral approach adopted for these products? |
| Q20 | Do you think these products could contribute to the EU's sustainability goals? |
| Q21 | What environmental risks do you see associated with these technologies? |
| Q22 | What strategies could improve the sustainability of these products? |
| Q23 | Do you think greater industry involvement is necessary to ensure the adoption of these technologies? |
| Q24 | What tools could facilitate the technological transfer of these innovations to the market? |

**Table 12.** List of questions for the University/Research-Institute Survey and reference numeric code

The following abbreviations are used in the X and Y tables:

In all questions with 'yes' or 'no' answers, "Yes" is abbreviated to 'Y' and "No" to "N"

Question 2 → U. = University; Pu. = Public Research Center; Pr. = Private Research Center

Question 7 → Def. = Defence; H.C. = Healthcare; Sp. = Sports

| Q 2 | Q 3 | Q 4 | Q 5 | Q 6 | Q 7 | Q 8 | Q 9 | Q 10 | Q 11 | Q 12 | Q 13 | Q 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U. | FI | Staff scientist | Electronics | Y | Def. | Y | Improved quality of life | Technology durability | 3 | / | Y | Lifespan |
| Pu. | DE | Researcher | Energy | Y | H.C | Y | Improved quality of life | High cost | 5 | High demand and public interest will have a strong impact on the traditional textile industry. | Y | Environmental impact |
| U. | CZ | PhD student | Environmental sciences | Y | H.C | Y | Increased workplace safety | Regulations | 1 | Not (in the near future) | Y | Environmental impact |
| Pu. | GR | Post-doctoral Researcher | Bioengineering, Tissue Engineering, Biodegradable and natural polymers | Y | H.C | Y | Improved quality of life | Regulations | 4 | multidisciplinary collaboration with other industries; new standards/regulations; advanced textile materials or traditional materials with enhanced properties | N | Lifespan |
| Pu. | GR | Researcher | Advanced materials | Y | Sp. | Y | Improved quality of life | Regulations | 4 | Boost the textlie industry and open new working positions | Y | Lifespan |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pu. | GR | Project manager | Energy | Y | H.C | Y | Improved quality of life | High cost | 4 | / | Y | Environmental impact |
| Pr. | SE | Project manager | Innovation | Y | H.C | Y | Greater accessibility to technology | High cost | 4 | New commercial possibilities | Y | Lifespan |
| Pr. | GR | Msc student | Bioengineering | Y | Def | Y | Greater accessibility to technology | All of them maybe cost could be mitigated | 1 | They will need to be implemented in all new line clothes or athletic clothes etc but not complete overtake it will be a niche | Y | Cost |
| Pr. | GR | Postdoctoral Resaercher | Bioengineering | Y | Sp. | Y | Greater accessibility to technology | Regulations | 3 | Advanced technologies, cycle economy, sustainability | Y | Lifespan |

**Table 13.** University/Research-Institute Survey - Total Answers_Part A

| **Q 15** | **Q 16** | **Q 17** | **Q 18** | **Q 19** | **Q 20** | **Q 21** | **Q 22** | **Q 23** | **Q 24** |
|---|---|---|---|---|---|---|---|---|---|
| Y | Electric mobility | Challenges in large-scale production | / | 4 | Y | Use of critical materials | Alternative materials | Y | Research-industry collaborations |
| Y | Renewable energy storage | Challenges in large-scale production | Long life cycle and capacity. | 5 | Y | Energy consumption in production | Recycling | Y | Research-industry collaborations |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Y | Electric mobility | Challenges in large-scale production | Raw materials with lower environmental and social impact, high recyclability | 5 | Not sure | All above, and increased difficulty to sort and recycle | Stricter regulations | Not sure | Research-industry collaborations |
| Y | Renewable energy storage | all the above | size, sustainability, | 5 | Y | Waste production | low environmental footprint materials with reuse process as the end-of-life scenario | Y | all the above |
| Y | Electric mobility | Challenges in large-scale production | faster charging, more capacitance | 5 | Not sure | Use of critical materials | Recycling | Y | Research-industry collaborations |
| Y | Renewable energy storage | Challenges in large-scale production | / | 4 | Y | Use of critical materials | Recycling | Y | Research-industry collaborations |
| Y | Renewable energy storage | Challenges in large-scale production | Fast charge, reusable | 5 | Y | Use of critical materials | Alternative materials | Y | Research-industry collaborations |
| Y | Renewable energy storage | Challenges in large-scale production | Push the limit of theoretical capacity | 3 | Y | Waste production | Stricter regulations | Y | Research-industry collaborations |
| Y | Renewable energy storage | Regulations | Use of recyclable materials, reuse of components | 5 | Y | Waste production | Both recycling and alternative materials | Y | Open access data and collaborations between research-industry |

**Table 14.** University/Research-Institute Survey - Total Answers_Part B