Deliverable Report

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1 Summary

The cooperation of the three projects Gov4Nano, NANORIGO and RiskGONE, aims to strengthen risk governance toward a safe and sustainable development of nanomaterials and advanced materials. The projects developed a proposal for new organizational forms to promote risk governance (joint Deliverable 5.5), based on the principles of trustworthiness, inclusiveness, trans-disciplinarity, openness and transparency, data FAIRness and adaptability. Understanding how and which stakeholders to engage in the process to put in practice these principles is one of the first steps to design and build such structure.

When stakeholder engagement is done effectively, it improves communication channels between the different parties, creates and maintains support for the design and development of new innovations, reduces the potential for conflict and enhances the overall research and development process.

The project analysis on barriers and needs related to risk governance shows the still limited connection of the risk governance and safety community with research and innovation activities and initiatives across key industrial and economic sectors in Europe.

This report uses a value chain and innovation eco-system approach to explore six of the most relevant industrial sectors for the application of nanomaterials and advanced materials. It provides an indicative analysis of the applications, and socio-economic factors driving innovation in these sectors, and the perspectives and context in which stakeholder operate. It identifies initial suggestions on research and development activities, and safe and sustainable aspects to focus on future risk governance actions.

The analysis shows the diversity and complexity of the different sectors analysed. Though with different approaches and goals, the need to strengthen safety and sustainability aspects emerge as a cross-cutting issue in all sectors.

Based on these findings, we developed a roadmap describing the type of stakeholders to engage and network with to strengthen the actions and impact of the nano-safety community (actors and organizations dealing with nano-safety research) toward a safe and sustainable development of nanomaterials and advanced materials.

The roadmap provides a model to build an effective stakeholder engagement strategy with stakeholders of different innovation eco-systems (science, industry, policy and regulation, end-user, and society) for organizational forms dealing with risk governance of nanomaterials and nano-related products.

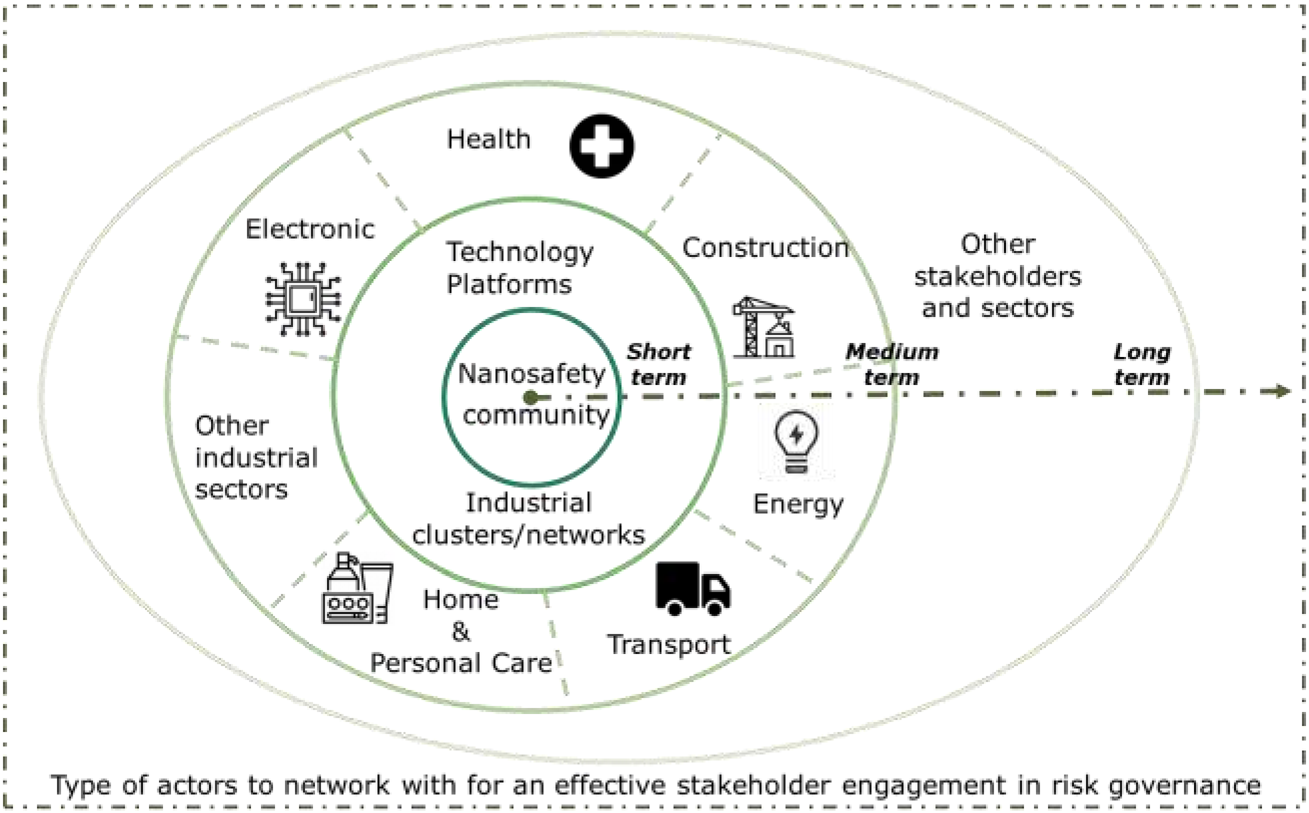

Figure 1. Sketch of a roadmap to purse an effective stakeholder engagement strategy within organizational forms dealing with risk governance of nanomaterials and nano-related products.

2 Description of task

WP6 (task 6.4) will work all along the project with WPs 3 and 5 to ensure stakeholders are represented and engaged in developing and testing the conditions for an organisational form for Nano Risk Governance (D6.1 and D6.8 are all designed to contribute to this aim). In particular, a roadmap (D6.8) of stakeholder engagement with the prospective organisational form for Nano Risk Governance will be prepared based upon the work within these three WPs, aiming to set a path to ensure inclusive, representative and credible operations of the organisational form for Nano Risk Governance.

3 Background

The three NMBP-13 projects have worked extensively with stakeholders to understand the needs and challenges they face and to elaborate on possible solutions to master current and future (nano) advanced materials safety, in line with most recent policy initiatives at the EU level. A proposal for a set of risk governance actions and options to develop structures to review and monitor the implementation of such actions has been designed within the joint "deliverable D5.5. Development of conditions for an organizational form for Nano Risk Governance".

D5.5. highlight the importance of connecting with innovation players in Europe, and specifically refer to the most recent initiatives to promote advanced materials in Europe, such as the draft 2030 materials roadmap[1].

[1] https://www.ami2030.eu/roadmap/

Starting from this background, this report explores the characteristics and key players active in innovation eco-systems representing significant areas of application of nanomaterials, and more broadly advanced materials.

The report provides information for future stakeholder engagement activities to better connect the nano-safety community with research and innovation players.

The deliverable includes:

- A description of selected innovation eco-system,
- An analysis of key stakeholders, their roles, and reasons to network with
- A roadmap for stakeholder engagement in risk governance

It integrates the D5.5 blueprint. It builds on the joint milestones, analysis of the type of stakeholders engaged in NMBP-13 and Gov4Nano projects, and reflections on relevant stakeholders to engage concerning Safe and Sustainable by Design (SSbD) and the Chemical Strategy for Sustainability (CSS).

4 Description of work

The European Green Deal policy and its underlying strategies including the EU Chemicals Strategy for Sustainability and the Zero Pollution Action Plan have put higher demands for the development of innovative (advanced nano) materials and, at the same time, have increased the ambitions to address safety and sustainability in terms of 'toxic free environments' and 'zero pollution. These demands have added complexity to the already existing challenges concerning the risk analysis of nanomaterials.

Nanomaterials are now generally seen in the context of innovation toward advanced materials, as they have in common several safety and innovation challenges. A recent work from OECD[2], classifies the term "advanced materials", including in the working description materials such as biopolymers, composites, porous materials, metamaterials, particle systems, advanced fibres, advanced polymers and smart nanomaterials. It is quite evident as nanomaterials play a relevant role in most if not all these categories.

It is increasingly important that the community of scientists and practitioners dealing with the safety of nanomaterials and nano-related products better network and integrate its action into the (complex and diverse) landscape of EU innovation players dealing with advanced materials.

Scientific developments in identifying and addressing nano-specific issues should be shared more broadly, and connected to policy goals, harmonization and standardisation processes and strategic priorities within industrial innovators.

Innovation based on nanotechnology and nanomaterials requires a strong synergy between different stakeholders to be effectively developed and implemented and address the potential risk associated with their use.

For this reason, an analysis of "innovation ecosystems" has been performed to understand the main actors involved in developing and promoting nanomaterials and nano-based products. An innovation eco-system can be defined as

> *an evolving system of organizations, people, activities, and resources, that are important with regards to specific innovation, including their intangible and qualitative interactions and relationships. An innovation ecosystem could in other words include an actor system with collaborative (complementary) and competitive (substitute) relations with or without a focal firm, and artefact system with complementary and substitute relations.*[3]

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[2] OECD Environment Directorate, Advanced Materials: Working Description, ENV/CBC/MONO(2022)29

[3] Source: Innovation ecosystems: A conceptual review and a new definition, Ove Granstranda, Marcus Holgerssonb, University of Cambridge, Chalmers University of Technology.

We use this approach to identify and analyse industrial sectors for the use and application of nanomaterials and nano-related products, discuss relevant implications concerning implementation of safe and sustainability approaches within the sector, and identify key players to engage with on risk governance.

4.1 Methodology

This document is based on desk analysis and inputs from a series of stakeholder engagement activities (those described in both Deliverable 6.3 – Force field analysis and D5.6 risk governance case studies of the Gov4Nano project) involving research and innovation players active in different areas of application of nanomaterials.

The need to widen the number and type of actors interested in risk governance, and as well the limited connections between nano safety research and other safety and innovation communities it is a clear gap emerged from the Gov4Nano analysis.

In this report we started to look at the nano-safety community, based on results from the analysis of Joint milestone 6. We then focused the analysis to identify other communities that should be engaged in nano safety research. In the first place, these are the research and innovation actors dealing with (nano) advanced materials.

We thus used as a key reference the work the activities of European Technology Platforms dealing with advanced materials, grouping stakeholders in a widespread range of technological contexts where nanomaterials could play a key role.

Several industrial sectors, where the development of innovative technologies for nanomaterials and the aspects related to Safe & Sustainability are strategic, emerged because of these analyses and interactions. More specifically, the sectors selected for the purposes of this report are: building and construction, energy, transport and mobility, health and medical, home and personal care, electronic appliances

The above list is exemplary of several different fields, hence we found it instructive to investigate their innovation eco-systems before extending the dialogue to other sectors and engaging more stakeholder groups.

For each sector, the report explores the innovation ecosystem by discussing specific applications of nanomaterials and advanced materials, identifying the innovation areas, and by analysing the type and the most relevant active players. The description of each sector is structured in three sections: i) socio-economic; ii) scientific-technical; iii) safety and sustainability. The analysis considered specific issues related to European policies and their specific value chain.

The analysis is meant to provide a qualitative and indicative selection of topics and stakeholders to engage with for organization forms dealing with risk governance of nanomaterials and nano-related products. A more detailed and specific analysis would be required to start practical networking and cooperation activities with stakeholders related to the sectors identified.

4.2 Classification of stakeholder

Stakeholders are divided into a set of four main areas (as defined in the Joint NMPB-13 milestone 6), and a subset of more specific classes with respect to the role they play in the research and innovation value chain of nanomaterials and nano-related products, from research, to design, control & oversight, production and commercialization and use:

Table 1. Types of stakeholders.

Type of stakeholders	Description
SCIENCE	**Scientific research and academic institutions -** providing education and performing research and development on nanomaterials (including nano-safety research and research infrastructures).
INDUSTRY	**Industry & business -** manufacturing & production, suppliers, equipment, services, use and distribution, trade and industrial association. This includes organizations doing research and innovation on nanomaterials and doing business with nanomaterials (e.g., professional users).
POLICY AND REGULATION	**Regulatory bodies, policy makers, and standard bodies -** (at national, EU and international levels), with the role to design, implement, monitor and enforce regulation (regulatory and inspection bodies); design, develop, implement policies and strategies and provide funding for research and innovation (policymakers); develop voluntary standards and good practices (e.g., ISO, OECD).
CSOs/END-USERS	**Civil society Organizations and end-users -** (citizens, consumers): labour associations and trade unions, consumers, environment and advocacy/user organizations, local communities, media, citizens/consumers.
OTHERS	**Other stakeholders -** Insurance & liability (insurance and re-insurance, lawyers, accreditation bodies); innovation networks (innovation agencies, tech platforms, etc.); investors, projects.

Once the stakeholders of the sector were identified, they were grouped according to the level of influence and interest in the sector of relevance:

1. **Primary Stakeholders:** actors that stand to be directly affected, either positively or negatively, by the innovation, e.g., Company, researchers, innovators, R&I partners, suppliers, manufacturers, industrial associations (hands-on managing, producing, and developing innovation).
2. **Secondary Stakeholders:** actors stand to be indirectly affected, either positively or negatively, by the innovation, e.g., Policy makers and regulators at the international, EU and national level, public procurers, investors & funders, professional users, citizens and public including vulnerable groups, civil society organisations engaged in investigating impacts of new technologies (influence: regulate, purchase, investing, using), research ethics committees and integrity bodies.
3. **Contextual Stakeholders:** those who will be impacted the least, e.g., EU, national and local authorities, government, territories, trade unions, advocacy groups, media, and other societal actors (other actors that could use or indirectly influence the development and use of the innovation).

5 Stakeholder communities to engage with

5.1 Materials for Building and Construction

The building and construction sector represents an interesting case study for both nano-based innovations and stakeholder engagement processes, due to different reasons. On one side, the building and construction sector is one of the primary sources of waste while the built environment is one of the major contributors to a city's pollution and GHG emissions. Increased citizens' requests for sustainability, and upcoming policies at the national and EU level, such as the European Renovation Wave, will push the demand for innovative (even disruptive) solutions, and these will include the use of advanced materials and processes. On the other side, the sector still largely relies on traditional methodologies, it is highly fragmented, and the introduction of disruptive solutions will require deep changes across the whole value chain, and all the stakeholders will be affected. Moreover, innovation in the building environment also impacts people's everyday life and this requires alignment with their needs and concerns, also from the safety and sustainability point of view.

5.1.1 Applications of advanced materials in the construction sector.

Advanced materials are expected to contribute to increasing the durability of buildings and components, reduce the materials consumption and waste, reduce the externalities in terms of both CO2 and pollution, contribute to energy efficiency and energy transition, enable industrial (off-site) production and advanced manufacturing.

Table 2. Drivers and challenges of the building sector, connected innovation areas and technologies[4]

BUILDING SECTOR DRIVERS/CHALLENGES	INNOVATION AREAS	TECHNOLOGIES
Urban regeneration, land use	• Urban planning, shared models, modularity and durability, selective deconstruction	• IoT, Satellite technologies, drones, AI, advanced materials, advanced manufacturing systems
Reducing material consumption and waste	• Modularity and durability Selective deconstruction • Industrial (off-site) production • New materials	• IoT, blockchain and AI, also associated with BIM (Building Information Modelling) methodologies, Advanced materials (e.g., self-healing and self-sensing materials, recycled materials, etc…)
Waste management	• Traceability	• AI, robotics, blockchain
Reducing externalities (pollution, CO_2 emissions, …)	• Energy efficiency • New materials • Industrial production	• IoT, Advanced materials, Advanced manufacturing
Energy efficiency and transition to renewable energy	• Smart control • Deep optimization • New solutions for energy production and storage	• IoT, AI • Advanced materials
Comfort, quality	• Smart control	• IoT
Duration and security	• Predictive maintenance	• IoT, AI

Advanced materials are expected to allow extension of the life cycle or to allow for an extended life cycle (e.g., self-healing and self-sensing materials), improve sustainability performances and energy efficiency (e.g., bio composites materials, ultra-performing), contribute to the reduction

[4] Contents from the report: Mapping of key enabling technologies innovation eco-systems: circular economy in the building and construction sector in Italy: towards sustainable production and consumption, Mar 2020, SocKETs project (GA958277) - https://sockets-cocreation.eu/

of pollution (e.g., materials capturing or absorbing pollutants) and resource consumption (recycled materials). One example is paints combining high capability to reflect solar light with photocatalytic and self-cleaning.

However, considering *their whole life cycle with respect to the use they are intended for, and assessing their actual convenience* is essential. One practical example are the materials for thermal insulation: in this case, several regulatory frameworks are now pushing for buildings with thermal insulation, but insulating materials may have a limited duration with respect to the building and may generate a growing waste stream: it is thus crucial to make balanced choices, considering both the environmental performances provided by the innovative material (for example in terms of energy efficiency) and its environmental cost throughout the whole life cycle (including end-of-life).
There is also an increasing interest in the sector toward advanced materials based on natural materials or secondary raw materials. One interviewee described how innovative mortars have been developed by using recycled plastic and glass to enhance mechanical and thermal properties. Recycled materials are also used in aggregates and in thermal insulating panels (with up to 100% recycled materials). However, there is also a diffused scepticism with respect to the quality and duration of recycled materials.

5.1.2 Socio-economic and scientific-technical aspects

The building and construction sector is related to several societal and economic issues. First of all, the built environment impacts on the everyday lives of all the people living, at least, in urban areas. Affordability and sustainability of housing is, for example, a major issue in many areas across EU, in particular in European cities (as demonstrated by the ESCO report on Housing affordability and sustainability in the EU), where housing affordability issues are growing (due, for example, to the rapid attraction of skilled workers by economic growth centres, to trends such as the emergence of the digital and the sharing economy - e.g. Airbnb- , or the globalisation of labour). Growing issues related to housing affordability are exacerbating societal division and limiting social and economic mobility.

The construction sector is also strategic for EU economy, generating almost the 9% of gross domestic product (GDP) alone and providing 18 million of direct jobs (ESCO, "Stimulating favourable investment conditions, Analytic report, 2018). In some EU countries, the burst of the housing bubble triggered, together with the financial crisis, severe drops in the demand, however policies such as the EU Renovation Wave (and other policies at national level), aiming at providing answers to the increasing request for energy efficiency and sustainability, may push for a rapid increase in the sector. Looking, for example, at the impacts of Italian financial incentives for renovation works in 2017, Fassa Bortolo and Symbola Foundation found that they "led to the investments of over 28 billion euros, and created more than 418,000 direct and indirect jobs, improving the construction entrepreneurial system and reducing energy consumption, pollution and household bills" (Fassa Bortolo, Fondazione Symbola, 2019). They also found that "between 2014 and 2017, more than 34,000 companies in the construction sector, 20.8% of the total, invested in green products and technologies", meaning that at least part of the Italian industrial system is interested by the benefits associated to these technologies.

5.1.3 Safety and sustainability aspects

The issue of sustainability in the building and construction sector is prominent, due to its large impacts on environment (e.g., in terms of high energy consumption, resource consumption, waste production). Safety is also crucial for building and construction, from different perspectives: for the workers involved in the construction process, for the citizens that will live throughout the built environment (e.g., in the cities), and for the people living and working inside buildings.

From the sustainability point of view, a lot of work has been recently done on ways to assess and certificate different sustainability aspects: evaluation of embodied carbon, certifications such as those for Near Zero Energy Buildings, ore LEED (Leadership in Energy and Environmental Design) certification, Energy Labels, etc. A further step forward may come from the development and progressive introduction of materials passport, such as those developed in the EU project BAMB – Buildings as Materials Banks[5]. In this case, the materials passport is thought to be "a one stop shop for material information describing defined characteristics of materials in products that give them value for recovery and reuse" with "the aim to: Increase the value or keep the value of materials, products and components over time; Create incentives for suppliers to produce healthy, sustainable and circular materials/building products; Support materials choices in Reversible Building Design projects; Make it easier for developers, managers and renovators to choose healthy, sustainable and circular building materials; Facilitate reversed logistics and take back of products, materials and components". The final objectives identified for all the building materials in this project could also represent an important starting point when dealing with advanced or nano- materials in many other sectors.

This kind of initiative will be eventually crucial to highlight safety aspects related to materials in a sector where a major part of safety issues is now related to workers safety, to occupational accidents in construction sites.

5.1.4 Stakeholder involved

Innovation in the building and construction sector involves several actors. The primary stakeholders of the innovation ecosystem (those who are directly involved in the work to develop of new technologies, applications and approaches) include a large part of the building and construction value chain. In particular:

1. Construction, materials/chemicals, manufacturing, tech (ICT-IoT-AI) companies: providing the products that constitute the building and all its systems. They are affected by almost all kind of innovation that could be relevant to buildings sustainability.
2. Professionals and associations of professionals (e.g., Architects, Engineers, etc.): designing the building and its systems, they also supervise the construction phases. They can take active part to the innovation development or simply participate by setting requirements.
3. Research organizations, research centres: providing knowledge to generate innovation and supporting both the technology and the knowledge transfer towards companies and professionals

[5] https://www.bamb2020.eu/topics/materials-passports/

4. Utilities companies: in some cases, they invest in R&D and/or take part to technology development. The services they provide can have a crucial role in solutions for building automation.

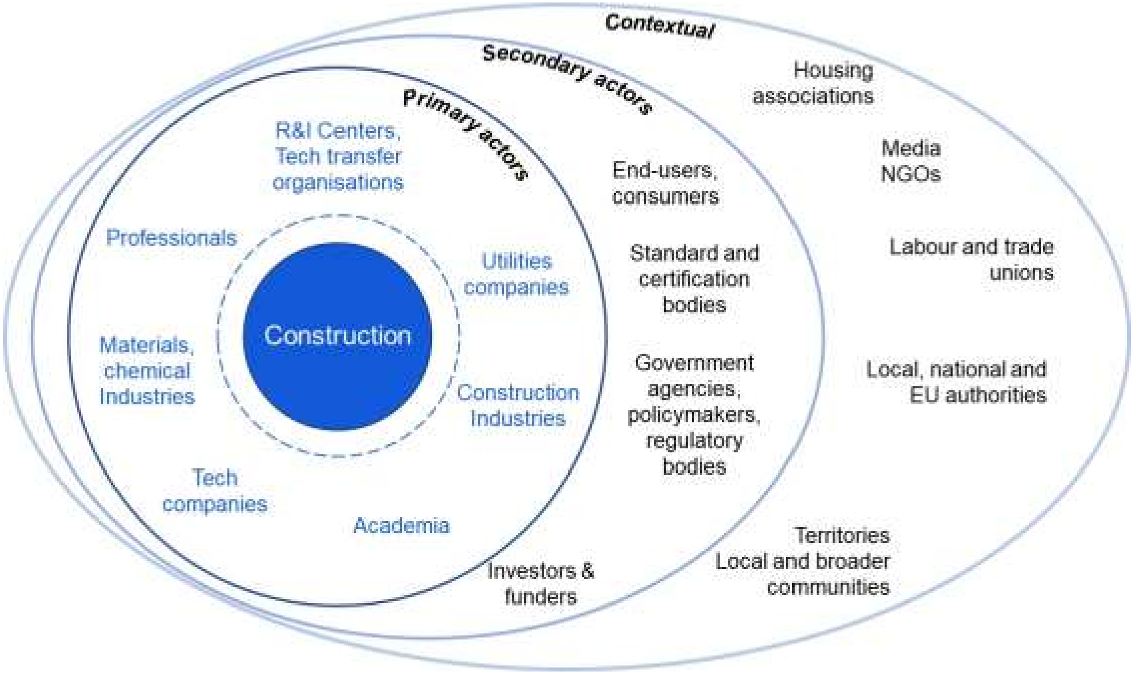

Figure 2. Innovation eco-system and stakeholder involved for Sustainable Construction Materials.

Even if not directly connected to the innovation development, public authorities and policy makers are seen crucial because they are seen as an "enabler": they have the possibility to support innovation giving competitive advantage both through regulation and Green Public Procurement. On the other side, their inertia or wrong choices have the effect to stop innovation.

The role of professionals (e.g., designers) and professional associations (mainly architects and engineers) is essential in implementing innovative solutions. Several of them are small (or individual) professional studios, which usually do not have resources (mainly in terms of time and people) to learn and train themselves on new developments.

Since most of the "products" are designed to last several decades after their construction or renovation, the list of actors that will have a stake on the product during its life cycle is broaden than what could be expected in other industrial sectors. This is also one of the main reasons for the importance of collection and availability of information about materials, systems and components: this kind of knowledge will allow future generations to intervene on buildings and infrastructures in a more efficient way with respect to what we are able to do nowadays.

A "special" stakeholder is, thus, represented by future generations as described by Feige et al. (Feige, Wallbaum, & Krank, 2011). Even if they cannot take part to the innovation process, they should be one of the main targets of the transition towards a circular economy, in particular in a sector where products are designed to cross generations. Examples of European stakeholders are resumed in Table 3[6].

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[6] https://single-market-economy.ec.europa.eu/sectors/construction/construction-transition-pathway_en

Table 3. Relevant European stakeholders in the Sustainable Construction Sector.

Type of stakeholders	Organization
SCIENCE	**Politecnico di Milano,** Fraunhofer-Gesellschaft**,** Buildings Performance Institute Europe, Ecole Nationale Supérieure d'Architecture de Strasbourg, Instituto Español del Cemento y sus Aplicaciones, TECNALIA Research & Innovation, Università degli Studi di Brescia, VTT Technical Research Centre of Finland, CETMA, STRESS
INDUSTRY	ANCE (Italian National Association of the Building and Construction Sector), Italcementi, Autodesk, HeidelbergCement AG, SCHNEIDER ELECTRIC, SOPREMA, Industrial Minerals Association, Architects' Council of Europe, Federation of the European Precast Concrete Industry, Build Europe, CEMBUREAU, Cerame-Unie, Construction Products Europe, European Manufacturers of Expanded Polystyrene, European Insulation Manufacturers Association, Eurobitume, European Builders Confederation, European Industrial Hemp Association, European Network of Construction Companies for Research and Development, European Confederation of Woodworking Industries, European Construction Industry Federation,
POLICY AND REGULATION	ISO, CEN, KlimaHouse, EU BIM Task Group, Kosovo Energy Efficiency Fund,
CSOs/END-USERS	World Green Building Council, Legambiente, Anpar, Eurocities, European Council of Civil Engineers, Housing Europe, Environmental Coalition on Standards, European Environmental Bureau, Open Contracting Partnership

5.2 Materials for Energy

The energy sector is the first responsible of the greenhouse gas emissions, with around 75% of the global emission. To achieve the global objective to become net zero CO2 emission by 2050[7], a complete transformation of the way in which we produce, use, deliver and consume energy is required. In achieving such objectives, a rapid development and deployment of technologies and materials are required to bring innovation to the market in time.

Today, around 500 million tonnes of CO2/year are emitted from key materials industry, such as steel, refinery, fertilisers, cements and chemicals, which correspond to 14% of the EU emission. To reduce such amount, the EU aims to adopt renewable energy sources and materials. In this scenario, cooperation between the different stakeholder will be necessary to achieve the sustainability goals and bring into the market the most cutting-edged technologies and materials to boost already present technologies, energy from wind, solar, bioenergy, geothermal, nuclear sources, and hydro energy, fossil fuels mixed with alternative fuels) or enable new solutions, such as carbon capture, use and storage technologies (CCUS).

5.2.1 Applications of advanced materials in energy sector

The transition of the energy system will be based on the reduction of the overall energy demand and making the energy supply side climate neutral. New and advanced materials are the priorities for the energy transition with the goal to produce and integrate higher shares of renewable power in the energy system, to reduce the carbon footprint of energy-intensive industries. The priorities can be divided in: advanced materials for renewable and low-GHG-emission energy production technologies (Solar PV, CSP, wind, bioenergy, geothermal…); surface treatments to enhance solar adsorption, anti-erosion, anti-ice and anticorrosion protection and thermal barrier coatings; Advanced materials for energy storage that facilitate the integration of renewable energy; Advanced materials for hydrogen generation, conversion and use and advanced batteries. Advanced materials for sustainable transformation of energy-intensive industrial processes, such as new technologies and new sustainable processes, such as Carbon Capture, Storage and Utilization (CCSU) or the electrification of energy-intensive processes.

5.2.2 Socio-economic and scientific/technical aspects

The EU industrial strategy[8] has as a main objective to reinforce Europe's industrial landscape to increase autonomy and leadership in strategic value chains through industrial alliances and new cooperation approaches based on dynamic industrial innovation ecosystems, advanced solutions for energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy. This strategy is continuously supporting the energy sector in concomitance with Industrial Alliances (for Batteries, Hydrogen and Energy-Intensive Industries) and the European Raw Materials Alliance (access to primary and secondary raw materials and the development of Europe's own value chain), toward the successful transition to a climate-neutral and circular economy EU industry.

The EU commissions is looking to create a more affordable, secure, and sustainable energy industry to support the EU's energy independence by accelerating the deployment of renewables and ensuring the affordability and security of energy supply. The developments of new materials for solar applications, might enable the development of upcoming technologies (e.g., high-efficiency crystalline silicon, post silicon solutions, flexible photovoltaics (PV), tandem, BIPV) that might reduce the ecological footprint and increase the recyclability of module components. The costs of wind energy might decrease due to rising turbine size and capacity factors, reducing friction and optimising wind farms control and operation, using sensors for advanced maintenance. Current requirements on the gas composition of CO2 and H2 for the safety of the transport and storage infrastructure, with high impact on CO2 capture cost will require new materials for energy intensive industries.

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7 https://www.iea.org/reports/net-zero-by-2050

8 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en

5.2.3 Safe and sustainable aspects

Advanced materials and innovations based on sustainable-by-design approach could enable the transition to the decarbonisation of the energy in industrial sectors. The current need to tackle down environmental impact is creating new opportunities for industries to reduce energy and resource consumption, decarbonise production processes, and protect the environment. In this matter, switching from a linear model of production and consumption to a fully circular one can aid to reduce the billions of tonnes of waste that go to landfill every year due to the huge volumes of materials used in batteries, solar panels, wind blades, e-motors, etc. Another innovation to lower environmental footprint is related to the potential advantages of green hydrogen production over pink hydrogen (produced from nuclear) or blue hydrogen (produced from fossil fuels with later carbon capture). The go-to-market of green or pink hydrogen will be guided by decarbonization trends and the rising price of fossil fuels (green or pink hydrogen production could be cheaper than blue hydrogen by the early 2030s). Higher efficiency of solar panels, capable of generating more energy per square meter and thus requiring less overall area, will result in a lower levelized cost of energy (LCOE), reduced carbon footprint, and improve EU energy sovereignty for electricity generation, with a reduced usage of critical raw materials.

5.2.4 Stakeholders involved

The supply chain in the energy sector is represented by the different steps and processes involved to produce energy services, from the raw materials to the energy of our houses and is represented in Figure 3.

Figure 3. Representation of energy supply chain.

Considering the new trends in energy production, the supply chain is changing. The EU can build its energy strategy based on a strong industrial benchmark of advanced material and technology players as well as start-ups. However, there is a strong global competition in electrolysis technology with USA and Asia in the lead. EU-based players further down the value chain are eager for EU technologies manufactured at scale and reducing EU's vulnerabilities and dependencies (in frame of EU's open strategic autonomy). EU-based research organizations have relevant activities in the field of electrolysis technologies and can support fast-track technology development in the EU. In the Energy sector, different subjects can be identified that act together or separately, collaborating or competing. The level of influence/interest in the sector is represented in the Figure 4.

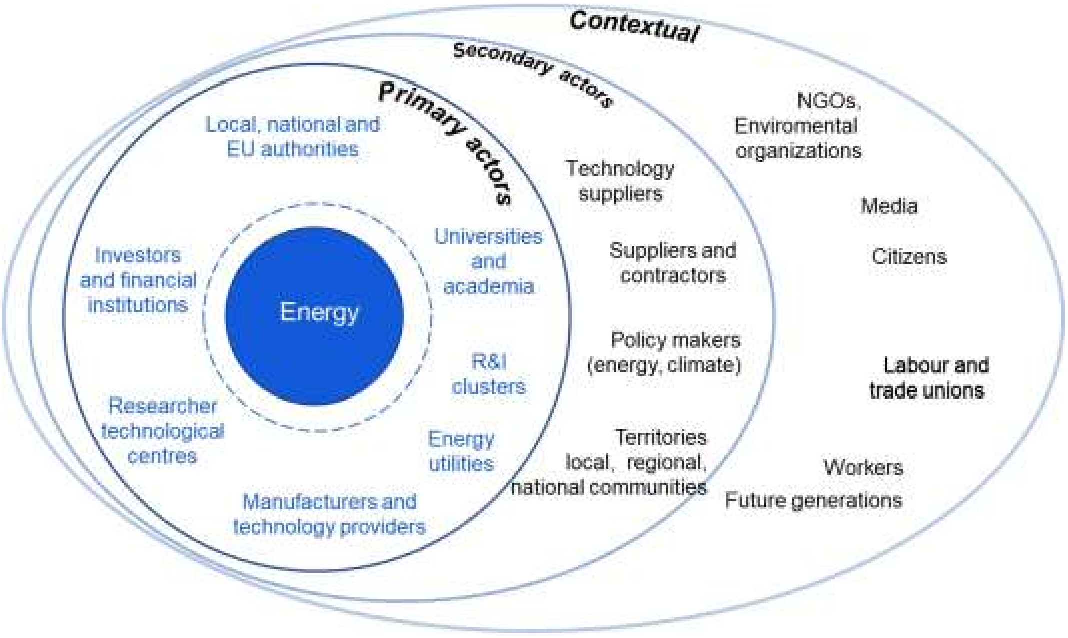

Figure 4. Innovation eco-system and stakeholder involved for materials in the Energy sector.

Examples of stakeholders involved in the Energy sector promoting new advanced materials are resumed in Table 4, classified according to the Gov4Nano categories and their relevance/influence: Science, Industry, Policy and Regulators, CSO/end-users.

Table 4. Relevant European stakeholders in the Energy Sector.

Type of stakeholders	Organization
SCIENCE	Politecnico di Milano; Politecnico di Torino; Aalborg University; Technical University of Denmark; Delft University of Technology; Federal Institute of Technology Lausanne; Norwegian University of Science and Technology; EUREC; Institute for Renewable Energy - Eurac Research;
INDUSTRY	Brookfield Renewable Partners L.P.; Tesla Inc.; First Solar Inc.; Stem Inc.; Plug Power Inc.; Clearway Energy; NextEra Energy (NEE); ENI; ENEA; Audi
POLICY AND REGULATION	The Federal Energy Regulatory Commission; Office of Gas and Electricity Markets (Ofgem); Council for Environmental Quality (CEQ); National Renewable Energy Laboratory (NREL); European Energy Union; European Energy Research Alliance (EERA); European Energy Centre; Council of European Energy Regulators (CEER); European Union Agency for the Cooperation of Energy Regulators (ACER); International Energy Agency (IEA)
CSOs/END-USERS	International Institute for Sustainable Development (IISD); African Climate Reality Project; Asociación La Ruta del Clima; Uplift UK; Arab Watch Coalition; Christian Aid; Oil Change International; Climate Action Network International; Alliance of Civil Society Organisations for Clean Energy Access (ACCESS); CAFOD, ENERGIA International Network on Gender and Sustainable Energy, Greenpeace, HIVOS, the International Institute for Environment and Development (IIED), Practical Action, and the World Wildlife Fund (WWF)
OTHERS	SE4ALL initiative; SCCALE 203050; Community Energy for Energy Solidarity (CEES); Life LetsGo4Climate; REScoop VPP; COMER RES; RE/SOURCED; OneNET;

5.3 Materials for transport and mobility

The transition towards a sustainable transport world will require an improvement on the vehicles efficiency as well as adopting zero/low carbon automobiles and fuel technologies. New materials and innovation in this sector might accelerate the transition by reducing costs, boosting technology learning, reducing materials weight, and improving performance of both conventional and zero-emission vehicles (alternative fuels, hybrid, battery, or fuel cell electric).

The European Commission set the transport sector as a key pillar for EU competitivity in the world through a sustainable transport system able to increase the region economic, create more jobs and increase the people's quality of life. The EU industry has employed around 10 million people, accounting for 4.5% of total employment in the EU and creating also 4.5% of gross domestic product (GDP). Efficient and functional transport connections are also vital to the EU's economy in terms of its exports — shipping carries 90 % of the EU's foreign trade. Many European companies are world leaders in infrastructure, logistics and the manufacture of transport equipment. EU households today spend 13.5 % of their income on transport-related goods and services, such as season rail tickets and holiday or business flights, making transport the second-largest item in their household budgets after house-related expenditure.

5.3.1 Applications of advanced materials

Growth in the need for improved safety and enhanced performance of the vehicle and stringent regulations for fuel economy and automotive emission is driving the growth of the global automotive lightweight materials market. This is due to the rising adoption of automotive lightweight materials and growing need for fuel efficient automotive solutions.[9] Considering the typical number of light-weighting materials in the aircraft structures for each aircraft category (small, medium, and long-range, typically 10, 20 and 30 tons/aircraft), it is possible to assume that approx. 500.000 tons of lightweight materials for aeronautical structures will be produced. Additionally, the new aeronautic propulsion systems to be developed (i.e., hybrid-electric and hydrogen-based), will demand new materials and production processes beyond the limits of the current technology at both ends: cryogenic and very high temperature. The development of these materials and process technology, rather than a quantitative issue, is an enabler for the development of new propulsion technologies.

Sustainability in transportation, logistics and individual mobility involves additional aspects besides CO_2 and energy. Liveable cities, green habitats, and citizen-friendly living areas of the future require a re-thinking of multi-mode mobility with less ownership of cars, fewer parking areas, and environmentally friendly personal autonomy. Smart Cities will in future provide full information and mobility services: offering optimal multi-mode transport for citizens, extensive public transport including autonomous vehicles, transport-on-demand, shared vehicles, optimized logistics (delivery, collection etc.) – also in rural areas. Public acceptance of autonomous vehicles is growing. A pre-condition for this scenario is availability of 5G or 6G communication between infrastructure, vehicles, controllers, and users. Equally, safe (semi-) autonomous vehicles need fast, comprehensive, affordable sensors all around. Advanced sensors and communication materials will pave the way for the broad introduction of smart mobility. Major benefits of sustainability, footprint, but also advanced mobility opportunities for sensitive groups (disabled or ill, children and old-age citizens) can be expected.

5.3.2 Socio-economic and scientific/technical aspects

The main challenges in this industrial area are fundamentally related to producing and promoting zero-emission vehicles through the development of light-weighting materials and structures, power electronic devices and innovative batteries. These challenges, or opportunities, are of great importance in the sector to produce more efficient vehicles, ships and aircraft with a huge impact in energy consumption. New and advanced materials can be the drivers for innovation and progression in the next generation of more sustainable transportation with lightweight materials and lower environmental footprint. Competitive transport systems are vital for Europe's ability to compete in the world, for economic growth, job creation and for

[9] The Airbus Global Market Forecast 2021 – 202. https://aircraft.airbus.com/sites/g/files/jlcbta126/files/2021-11/Airbus%20Global%20Market%20Forecast%202021-2040.pdf

people's everyday quality of life. The benefits of digitalization and efficiency in transportation via intramodality, connectivity and hybrid private-public transport, include reduced noise and air pollution, thus driving towards a more Sustainable mobility.

5.3.3 Safe and sustainable aspects

The transport industry, that relies mostly on motor vehicles, produce the most greenhouse gas emissions among different industry sectors. Hence, a keyway to reduce these environmental impacts and boosting public transport and rail freight is promote a more environmentally friendly transport system. To do so, the transport sector needs to be based on three fundamental pillars: (i) energy-efficient and fossil-free vehicles, (ii) a higher proportion of renewable fuels for operating the vehicles, and (iii) a more transport-efficient society. Lightweight materials play an important role in this sense, for every 45,4kg weight reduction, fuel efficiency increases by 1-2%. Other field of material innovation is based on using hydrogen-fuelled transport that might be a great impact on global emissions. Hybrid propulsion systems are under study where co-generation is the main technical development. The Fuel Cells (FC) are used in combination with a gas or steam turbine to use the FC heat produced during use.

However, there exist some materials challenges that can improve sustainability, these are:

a) Increasing energy efficiency in transport reduction friction and increasing materials durability
b) Shifting to electrical vehicles including batteries with higher durability and autonomy
c) Changing to fast charging fuel cell technologies, improving infrastructure deployment,
d) Moving towards, automatic/start stop with novel materials for automatic transmissions
e) Improving maintenance, including sensors and aftertreatment systems,
f) Alternating fuels, with low friction and high durable materials,
g) Reducing particle emissions from engines, brake and tyres and use self-healing materials.

The future outlook of the sustainable sector involves:

- Increased sensing, connectivity and intramodality
- Lightweight materials, to reduce fuel consumption
- Additive manufacturing for spare parts
- Alternative fuels and lubricants, energy efficiency and durability
- Fuel cells, batteries and charging infrastructures
- Monitoring and reducing emissions (catalyst, engine component design)
- Predictive sensing and predictive maintenance.

5.3.4 Stakeholder involved

The industrial value-chain for the transport and mobility sector is represented by different actors involved directly and indirectly in the progress and innovation of technologies and materials in this sector. The sector is a very complex articulation of subjects, organizations, entities, and businesses (as represented in Figure 5), all of them participating or collaborating for shares and market opportunities.

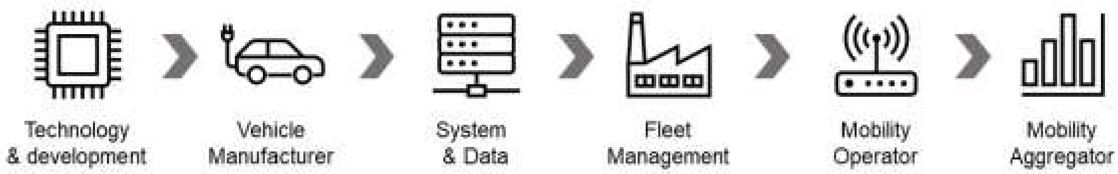

Figure 5. Representation of Material for Sustainable mobility supply chain.

In the transport and mobility sector, different actors could act together or separately, collaborating or competing to promote the innovation ecosystem, all of them involved in services and facilities. The level of influence/interest in the sector is represented in the Figure 6.

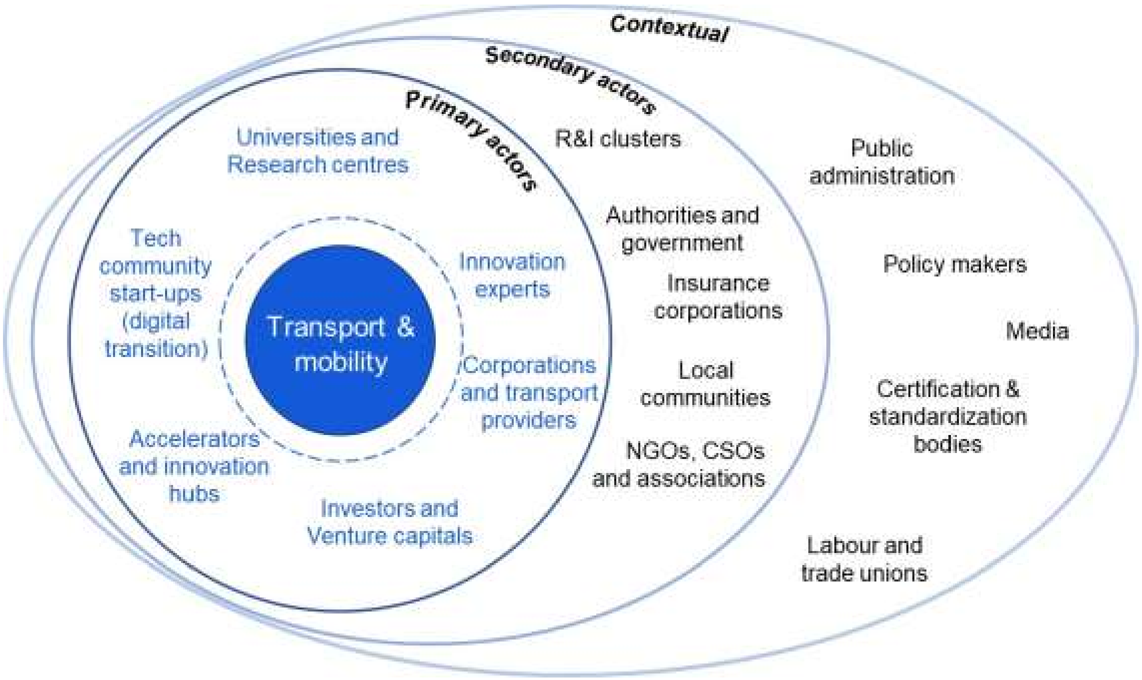

Figure 6. Innovation eco-system and stakeholder involved for materials in the transport and mobility sector.

Stakeholders involved in the transport and mobility sector, can be resumed in 4 main categories, according to the Gov4Nano classification and their specific relevance/influence: Science, Industry, Policy and Regulators, CSO/end-users. Examples of European stakeholders are reported in Table 5.

Table 5. Relevant European stakeholders in the Sustainable Transport and mobility sector.

Type of stakeholders	Organization
SCIENCE	EARTO, Tekniker, CIDETEC, CIC Energigune, ITE, Fraunhofer, VTT, TNO, CEA, Aalto Univ., AIT
INDUSTRY	ArcelorMittal, BASF, Covestro, Lyondellbasell, Solvay, Thyssenkrupp, Evonik, Hydro Aluminium, Fiat & Chrysler, CRF, BMW, Ford, Volkswagen, Mercedes Benz, Leonardo, BOSCH, Balzers Oerlikon, SKF, Leonardo, Airbus, CAF, BatteryPLAT, CIE Automotive, Unilever, Repsol, Northvolt, Verkor, BASF, ACC, AVL, EDP, ABEE, Unilever, Arkema, ITP, Armor, Aspilsan
POLICY AND REGULATION	National Transportation Policy; European Parliament, the Council of the European Union, and the European Commission; CIT; transport policy;
CSOs/END-USERS	The International Association of Public Transport (UITP); International Air Transport Association (IATA); CitiZEN Sustainable Mobility for Citizens in Europe; CIVITAS initiatives; U-MOB
OTHERS	S.T.R.E.E.T. Project; Sustainable Transport Infrastructure in the Strategic urban region Eurodelta (STISE); Public Engagement for Sustainable Public Transport (PE4Trans); Physical Activity Through Sustainable Transport Approaches (PASTA); Sustainable Transport E-Planner to Upgrade the IT-HR mobility (STEP-UP); Urban Innovative Actions (UIA); Sustainable Policy RespOnse to Urban mobility Transition (SPROUT);

5.4 Materials for Health and Medical

The EU aims to enhance and strengthen the health and well-being of citizens. The COVID outbreak in 2020 showed how a united community can face difficult social times, but it also highlighted some shortcomings in the medical system and therapies. Hence, the EU is promoting new initiatives in these matters to improve the medical system and be able to respond more quickly and accurately to eventual medical contingencies, from local to large scale. The EU has a huge potential in research and industry innovation (e.g., personalized medicine), which needs to be further developed on the European scale through synergies across national and regional programmes.

Advanced materials are demanded to satisfy the rising demand for new applications in the medical field. The most important characteristics of future materials are associated with their biocompatibility and their antibacterial properties. The research and industrial interest in new materials with the aforementioned characteristics is rising. Indeed, the market of new and advanced materials for the medical sector is projected to reach € 26.1 billion by 2025 from € 14.4 billion in 2020, at a CAGR (compound annual growth rate) of 13.0% during the forecast period. In this frame, advanced materials based on nanotechnology can boost the development of new medical devices and products in areas such as advanced drug delivery, tissue engineering, diagnostic systems and personalized medicines, amongst others.

5.4.1 Applications of advanced materials

Advanced surfaces for health and medical applications with improved functionality and biocompatibility, increased performance, sensing and durability, include:

- surface nano structuring and functionalization to increase materials' added value.
- surface texturing to improve cell growth and tissue anchorage, with stimuli-response adhesion properties for tissue recovery in mild conditions.
- surfaces with antimicrobials, anti-inflammatory, antifouling, anticorrosive, anticoagulating, or healing properties.
- surfaces with drug delivery function, which can also be stimuli responsive.
- surfaces able to reduce friction and wear without the risk of delamination or debris release.
- surfaces able to prevent ageing, corrosion, or tribo-corrosion failures.

Through surface functionalization and coatings, new material properties can be achieved. Biologically inspired materials can support tissue growth and healing.

Functional materials are essential for the development of the medical devices of the future. The basis is material science and biology. The future comprises regenerative medicine, cell therapy, nanomedicine, rehabilitation, and several other technologies at the interface of materials science, biology, and biomechanics among other areas. The functionality of biological structures (joints, muscles, nerves) or even complex solutions with function and structure integration, such as pro-angiogenesis solutions with tissue healing effects can be enabled. Other applications for functional materials are wearable devices for biomedical applications, advanced monitoring of heart rate and heart activity using flexible electronics, new sensors for monitoring temperature, oxygen saturation, blood pressure, activity level and calories burned, and integration into a universal sensor front end with multiple sensors for monitoring these parameters. Finally, materials adapted to new sterilization techniques such as X-Ray need to be developed to avoid the use of ethylene oxide.

Europe is a strong player in this sector at a scientific level but getting developments to market is very challenging for companies due to the cost involved in product certification, the lack of suitable standards and suitable collaborations between low TRL players, industry, and clinicians. The development of efficient TRL multistage consortia, a relevant supply chain, appropriate standards and the training of notified bodies will be the basis of success.

5.4.2 Socio-economic and scientific/technical aspects

The COVID-19 outbreak demonstrated cooperation between the different stakeholders can be a crucial point for rapidly promoting, developing and implementing new medical devices and approaches, and helping to develop life-saving treatments. However, one weakness has been identified: European scientific knowledge (solutions and devices) is not strongly disseminated and exploited among stakeholders. Strategies should be adopted to enhance the availability of qualified materials and processes to develop new medical devices for diagnosis or implants and shorter the go-to-market time. These main strategies might be:

- Enhancing the availability and lifetime of materials to support processes and design of medical devices.
- Develop multi-functional materials to target specific applications, such as regenerative medicine, cell therapy, tissue engineering, drug delivery, sensing, and combinations of them.
- Incorporate material science at all stages of medical device development to reach their full potential.
- Foster the presence of the entire supply chain in development programs and promote communication between clinicians, medical doctors, industry, and researchers as a key to ensure that materials and products are developed with the required needs and performance to cut down access time to the market.
- Incorporate more top-down approaches coming from surgeons, nurses, hospitals, and industry in our research programs.
- Promote authorities' awareness and facilitate access to as well as promote the training of notified bodies to advance with the development of adapted standards and regulations.

As mentioned, the scientific know-how of the EU is strong, and many cutting-edge medical devices and other high-value products have been promoted in the region, as witnessed by the use of 3D printing to produce tailor-made devices for respiratory purposes in hospitals. However, in general, we have also observed how many of the consumable materials for the medical sector were imported, especially from China. There exists a gap between the scientific know-how and the business and market regarding the transferring and implementation of new and advanced materials for prostheses and devices, among others. Closing this gap (e.g., promoting an increase in TRL across SMEs or facilitating documentation for insurance and finance request), it is important for the deployment of high-performing products and services, supporting a more competitive EU industrial landscape.

As identified in the Materials 2030 roadmap**,[10] the main barriers** to overcome in the sector are:

- **The healthcare social security systems** are increasing the price pressure across all nodes of the value chain, reducing the profit margins, leaving fewer opportunities for small and middle-sized players to survive, and decreasing the interest of big players in less profitable devices, leaving rare pathologies without solutions.

- The **new Medical Device Regulation or MDR** establish more stringent guidelines for companies that are looking to bring medical devices into the market, compared to the previous norms. The MDR demand a thorough study and evidence to support new medical devices, hence, some companies are stopping their activities in new medical device development or are partially abandoning many of the product portfolios without renewing them. The MDR regulation is challenging the entry into the market of many new products, as only highly profitable companies and projects can emerge.

5.4.3 Safety and sustainability aspects

The reduction of the environmental footprint of medical devices and products is an increasingly important aspect of product development in the health and medical field. EU should adopt circular approaches to handle and reduce single-use medical waste, which can be challenging considering that waste can contain infectious substances. Today, most of the used medical devices are incinerated after use, hence it is necessary to implement new approaches to either, reduce the usage of single-use medical devices or recycle the used ones. Developing new procedures to sterilise materials, creating new material separation protocols, optimising the

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[10] The draft Materials 2030 roadmap, June 2022, https://www.ami2030.eu/roadmap/

energy efficiency and increasing the amount of recycled material during the production steps are among the main strategies to reduce the environmental footprint in the medical sector. There is also a need to develop specific advanced materials (plastic, metals and composites) with greater mechanical characteristics to be periodically used properly and for a longer time, as well as presenting good antimicrobial and biocompatible properties. The medical ecosystem is moving toward this, promoting the development of new and greener fabrication procedures for medical devices (e.g., 3D printing) and materials from natural sources and renewable.

In this frame, the Safe- and Sustainable-by-design approach could be key attempt to reduce the environmental footprint and guaranteeing the introduction of safe health products in the market. A medical product like implants should be designed to reduce the number of patient interventions. In general, more tests should be carried out to assess the lifetime of a medical product or process and tools in a real-life situation. Before thinking about sustainable materials, one should reflect on the sustainability of the supply chain. As mentioned, new materials and processes can enable the future of the health and medical sector and concomitant with other enabler technologies such as digital and robotics to mitigate global and local health risks. To achieve these objectives, it is required a more participative process from stakeholders to include the different needs in the development of new technologies for the health and medical sector. Ideally, this process should be executed from the very initial stages of design and research to the end-users.

5.4.4 Stakeholder involved

The industrial value chain or supply chain for healthcare is the representation of the various processes involved in producing goods and services, starting with raw materials and ending with the delivered product. The supply chain is changing, especially after the COVID-19 outbreak, adopting a different approach in the value chain interactions such as patient consumerism, care delivery and payment methods, and industry consolidation, among others. The Healthcare industry is a very complex articulation of subjects, organizations, entities, and businesses (as represented in Figure 7), all of them participating or collaborating for shares and market opportunities for human health.

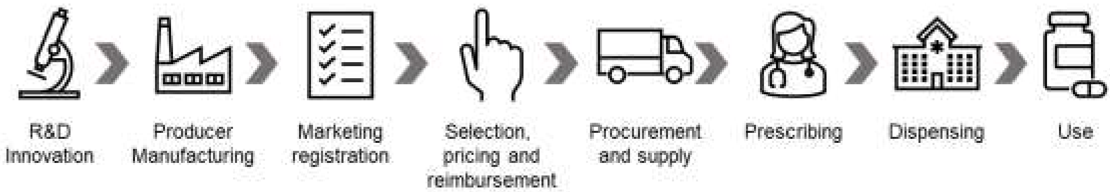

Figure 7. Representation of Healthcare supply chain. Modified from UN: The Pharmaceutical Value Chain.

In the Health and Medical sector, different subjects, acting together or separately, collaborating or competing, can be identified, such as **pharmaceuticals, equipment manufacturers, insurance companies, employers, big technology providers, intermediaries, private and public entities, NGOs, service providers, and several branches of government**, all of them involved in healthcare services and facilities. The level of influence/interest in the sector is represented in Figure 8.

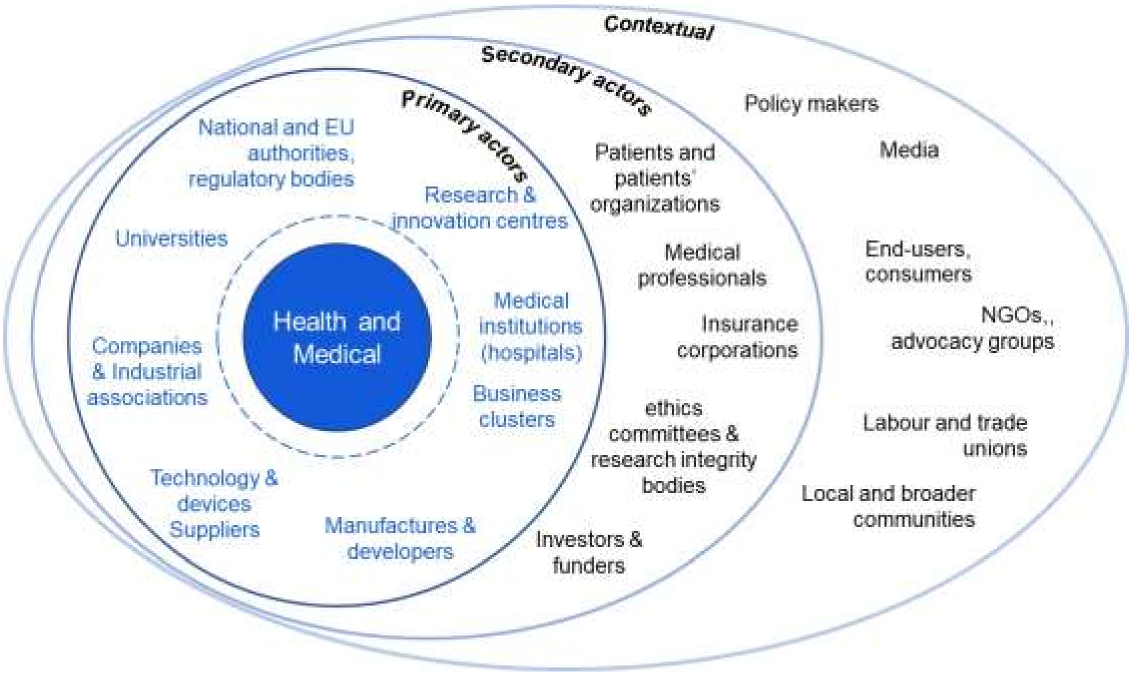

Figure 8. Innovation eco-system and stakeholders involved for materials in the health and medical sector.

In general, the stakeholders involved in the health and medical sector can be resumed using the 4 main stakeholder categories identified by the Gov4Nano project, according to their relevance/influence: Science, Industry, Policy and Regulators, CSO/end-users. Examples of relevant European stakeholders are reported in Table 6.

Table 6. Relevant European stakeholders in the Health and Medical Sector.

Type of stakeholders	Organization
SCIENCE	BRTA, Fraunhofer, Politecnico di Torino, Dechema, CNR, IMDEA, CSIC, University of Salerno, Politecnico Milan, Cidetec, Inmat, Vito, Tekniker.
INDUSTRY	Zimmer, Medtronic, Stryker and Microdent, Stryker, Steris, Roche, Novartis, GE, B. Braun and Intuitive Surgical, Heraeus for antibiotics surfaces, Rescoll,
POLICY AND REGULATION	European Medicines Agency (EMA), Medicine and Healthcare products Regulatory Agency (MHRA), Notified Bodies; European Agency for Safety and Health at Work; European Centre for Disease Prevention and Control and, most recently, the European Chemicals Agency.
CSOs/END-USERS	MedTech Europe, Red cross, The European Institute of Molecular Medicine (EINUMM), Foundation for the Development of Internal Medicine in Europe (FDIME), European Federation of Internal Medicine (EFIM)
OTHERS	EU4Health, Digital Europe Programme, European Regional Development Fund (ERDF), HealthTech4EU, Insurance Canopy, Veracity insurance, Chubb insurance, Horizon Europe, New Enterprise Associates, SOSV venture capital firm, EIT health, Y combinator, Hiventures, Almi invest Crista Galli ventures, Scottish Enterprise, Parkwalk Advisors, Oxford Science Enterprises, Bpifrance, High-Tech Gründerfonds

5.5 Materials for Home & Personal Care

Home and personal care refer to tools and household products (e.g., cosmetics) and it covers also cleaning products that help people to stay healthy, control allergies, provide anti-bacterial surfaces or even medical home appliances. The European home care market size was valued at € 76.8 billion in 2019 and is expected to grow at a compound annual growth rate (CAGR) of 7.6% from 2020 to 2027. The growing geriatric population in the EU region, coupled with the rising incidence of chronic diseases is the key factor driving the market for home care in the region. A major issue faced by manufacturers during the COVID-19 situation was the disruptions caused to supply chains, especially for cosmetics, during lockdown. As a result, manufacturers and exporters were facing high competition, however, the sales through online retail channels majorly supported the market penetration.). A movement from Business to Business to Business to Customer with more personalized products will be a major driver in the future.

The European cosmetics and personal care market is the largest market for cosmetic products in the world. The largest national markets for cosmetics and personal care products within Europe are Germany (€14 billion), France (€11.5 billion), the UK (€9.8 billion), Italy (€9.7 billion), Spain (€6.4 billion) and Poland (€3.8 billion).

5.5.1 Applications of advanced materials

The market combines several important aspects, e.g., sustainability, safety and supporting health and wellbeing. Therefore, the development of new advanced materials as the starting point in the value chain is very challenging. Actual activities of the industry are focused on the following technological priorities:

1. Alternative active and non-active ingredients based on natural and sustainable substances
2. Materials and design for circularity and re-use
3. Renewable materials and biotechnology production methods
4. Multi-functional surfaces, coatings, sensor functions

All major players have placed sustainability as key element of their development strategies, with several small and medium enterprises entering the market thanks to specific sustainable solutions. A trend in this regard is the sourcing of raw materials, the production of active and non-active ingredients and their final formulation with fulfilling the complete LCA. The demand of sustainable solutions as well the trend of personalized products leads to one of the major challenges of whole value chain. Transparent reporting and communication on the type of materials and their characteristics over the value chain is important to optimize use of resources, reduce the overall environmental impact and as well properly communicate to the end user.

5.5.2 Socio-economic and scientific/technical aspects

The market pull in personal and home care markets is typically driven by business-to-business market needs but is increasingly moving towards business-to-customer needs. The functionality of the product comes first in citizens preferences, and end users would like to know if the personal and home care products they use are sustainable and have a low environmental impact. The risk of customer acceptance is in balance with the additional costs of the sustainable solution.

5.5.3 Safe and sustainable aspects

To minimize the impact to the environment, the portfolio of ingredients should change from non-biodegradable products to biodegradable products with fast degradation timelines and based on sustainable natural biobased resources. The use of 2nd or 3rd generation biomass[11] has a big potential for environmental-friendly production.

A key aspect is to design sustainable materials and production processes (e.g., fermentation, environmentally friendly coating processes, 3D printing), and to evaluate the overall LCA along the whole value chain to quantify and reduce the environmental impact. As an example, the use of renewable energy or mixtures (e.g., natural gas/hydrogen) in the production energy mix,

[11] 2nd generation biofuels are derived from cellulosic biomass such as perennial grasses. 3rd generation biofuels are to be made from algae. Plant & Soil Sciences eLibrary, 2022

could further reduce the environmental footprint. Providing sustainable advanced materials by using new feedstock solutions, is also an important element. Advanced materials developed by new and sustainable chemical processes or new feedstock solution play a crucial role for closing the carbon loop and therefore act as a basis for a sustainable value chain. Novel properties such as enhanced multifunctionality, durability during use and recyclability are other solutions to find using advanced materials. Processing industry must develop and implement sustainable process steps, for example water treatment and reuse. The evaluation of positive social effects at the development phase of the product will help reach consumer confidence and will facilitate the introduction of the product in the market. Carbon footprint calculations and passport card of the product will facilitate information for selecting the recycling pathway.

5.5.4 Stakeholder involved

The industrial value-chain of materials for home and personal care industry is represented by different actors involved directly and indirectly in the progress and innovation of technologies and materials in this sector, all of them participating or collaborating for shares and market opportunities, as represented in Figure 9 according to the level of influence/interest in the sector.

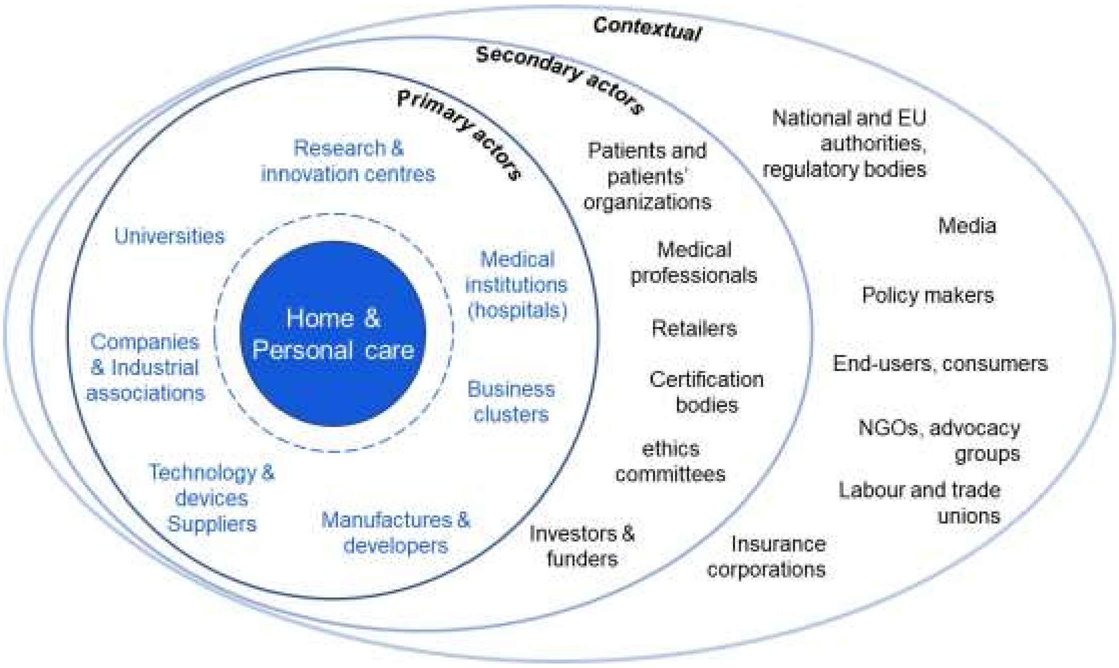

Figure 9. Innovation eco-system and stakeholder involved for materials in the home and personal care sector.

In general, the stakeholders involved in the home and personal care industry, can be resumed in 4 main categories, according to their relevance/influence: Science, Industry, Policy and Regulators, CSO/end-users. Examples of relevant European stakeholders are resumed in Table 7 and pushed mainly by chemical industries.

Table 7. Relevant European stakeholders in the Home and Personal Care sector.

Type of stakeholders	Organization
SCIENCE	BRTA, Leitat, Fraunhofer; Henkel Beauty Care Research & Development; University of Bocconi; Università degli Studi di Milano; Università di Verona; International Cosmetics Science Centre (ICSC); Union Cosmetics.
INDUSTRY	Henkel, L'Oreal, Chanel, Beiersdorf, Unilever, Healthcare at Home, Bayada Home Health Care, Ashfield Health care, Accredo health Group, Heritage independent Living, Mears Group PLC, BASF, EVONIK, AVON, P&G, Palmolive, Sephora, Ives Rocher, Intercors group
POLICY AND REGULATION	The Kosmetikverordnung (KVO); CosIng; Cosmetic Products Enforcement Regulations; European Medicine Agency (EMA); Ceway - Cosmetics Regulatory Services
CSOs/END-USERS	Personal Care Council; Cosmetics Europe – the personal care association; Global Cosmetics Cluster; DETIC; International Beauty Industry Trade Association (IBITA); Independent Beauty Association (IBA)
OTHERS	InnCoCells project; INGREEN project

5.6 Materials for Electronics appliance

The electronics sector is huge and enabling across most economical sectors. All types of chemicals and materials are used in this sector and would be difficult to provide a complete overview. This section thus includes only an initial analysis of some aspects of materials development for electronic appliances.

Europe's Consumer Electronics Market size crossed € 230 billion in 2020 and is anticipated to exhibit a CAGR of 8% from 2021 to 2027. According to other sources, 2022 consumer electronics revenue amounted to more than € 0,92 trillion worldwide and € 188,6 billion in Europe according to November 2021 update of Statista. In the Electronics segment, the number of users is expected to amount to 469.4million users by 2025. User penetration will be 46.0% in 2022 and is expected to hit 55.3% by 2025. The average revenue per user (ARPU) is expected to amount to 441,7€.

Concerning semiconductors, it is expected to hit € 552 billion in 2022 and towards 2030, the global semiconductor market might further grow far beyond €910 billion. Today, the EU just accounts for 10% of worldwide semiconductor sales; by means of the Chip Initiative, Europe wants to double this share (20%) (EU Commission). The innovation market for advanced materials is therefore estimated to grow towards €63,7 billion. By 2030 deposition of materials (plating, precursors, sputtering targets) will represent an opportunity of more than €9,1 billion and non-silicon advanced substrates will represent a €4,55 billion opportunity. As far as the electronic market is concerned, besides the traditional silicon-based market, a new growth market is impacting today's technology, where the key targets concern the use of sensing devices with ultra-low power consumption, together with the exploitation of eco-sustainable materials, green technologies and the use of recyclable materials which will create a positive impact in reducing the so-called electronic high-tech trash[12]. Here, flexible and conformable electronics is a vital issue to be considered in the future, where sensing and the electronics required to control, transfer and store information is critical. Indeed, flexible electronics has been one of the world's fastest growing technologies, with A market valued at €21,74 billion in 2019 and projected to reach €39,08 billion by 2027 (CAGR of 7.4 % from 2020 to 2027)

5.6.1 Applications of advanced materials

The challenges concerning flexible/stretchable sensors will be to maintain the integrity of material properties and at the same time to meet the requirement of quality printing. Printing is at a mature stage in development making it suitable for a varied range of applications. The design to production time is reduced, and the direct deposition tool minimizes the material wastage. Additive manufacturing techniques are adopted to fabricate flexible/stretchable tactile sensors with tailored geometries to improve their performance in sensing systems conforming to unstructured surfaces. However, there is need for further development of materials (inks) and additive manufacturing technologies if these sensors are to be mass-produced for large scale mainstream consumer-related applications with emphasis on recyclability. A desirable feature of flexible electronic systems for various smart surfaces, ranging from healthcare to automotive markets, is the combination of multiple sensor arrays, e.g., signal conditioning and processing circuitry, memory, energy harvesting and wireless transmission of information. The challenges regarding ultra-low power sensing are connected to device and systems integration at nanoscale. Flexible and transparent electronics, manufactured using natural and sustainable materials, are of importance for the smart functionalisation of the interior of e.g., vehicles geared with smart-monitoring of passengers and cargo in the car cabin; vehicle user interface (HMI - Human Machine Interface); safety and comfort of passengers.

5.6.2 Socio-economic and scientific/technical aspects

The increasing digitalisation and decoupling of economic growth from resource consumption will change the way people live, work, are entertained and travel, as well as how governments and businesses interact among themselves and with the world. These market drivers are increasing the demand for smarter, lower cost, sustainable and more power efficient electronic devices

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[12] High-tech computer industry effects on the environment, from the raw materials to the chemicals and solvents used to produce silicone chips as well as other persistent organic compounds used to produce high-tech equipment - Environ Health Perspect. 2006 Aug; 114(8): A500.

which can sustain and enable applications such as electric vehicles, energy management and 5G/6G.

5.6.3 Safe and sustainable aspects

Rare-earth metals are key point for the developing of high-tech devices such as mobile phones, computers and many other everyday devices. The increasing demand of these devices will require also an increment of these rare-earth materials, and considering the limited global supply of them, we need to find a way to recover these metals efficiently from discarded products. Rare-earth metals are currently mined or recovered via traditional e-waste recycling. But there are drawbacks, including high cost, environmental damage, pollution and risks to human safety. This is where our ongoing research comes in. An important element to consider is taking advantage of eco-sustainable materials to provide solutions for tomorrow's challenges at a micro and nano scale for smart dynamic sensors. This, in turn, can build the transition towards the next-generation of hyper-trends, applied research needs to be carried out on multifunctional materials for sensing and electronics, chip-less integrated systems, ultra-low power sensing electronic systems, among others. 5G is the engine of the modern society. Enabling the IOT and its massive data flows requires billions of sensors, cameras, antennas, and other electronic devices that need to be designed and assembled. Al these devices need to have a limited environment impact, including the issue of end-of-life (e-waste). This requires increasing their lifetime and ensuring recycling and repairing of these devices, for example by means of advanced assembly and disassembly materials and techniques. Sustainable (Green) polymer material innovation, combined with sustainable design guidelines to facilitate ease of disassembly, repair, and remanufacture. Digital technologies will contribute to decarbonization in the (chemical) value chains, resilience & climate neutrality. Electronics market will facilitate the digitalization that facilitates distance cooperation without transporting persons and goods, reducing energy consumption and thus, carbon footprint.

5.6.4 Stakeholder involved

Industrial and innovation capacities can be built on the strong semiconductor value chain in Europe, covering advanced materials, equipment providers and electronic components. These EU strengths are also complemented with world-class research R&D capabilities and organisations and associations, which support the European semiconductor industry. These leads to possibilities in terms of:

- Technical advantages around improving performance of the semiconductor devices, improved energy efficiency and enabling new applications.
- Economic advantage due to cost-effective material solutions.
- Reduction of energy consumption, thanks to heat management, weight reduction and miniaturization.
- Energy harvesting.

The industrial value-chain or supply chain for electronics appliance is a complex articulation of subjects, organizations, entities, and businesses, all of them participating or collaborating for shares and market opportunities for the electronic market.

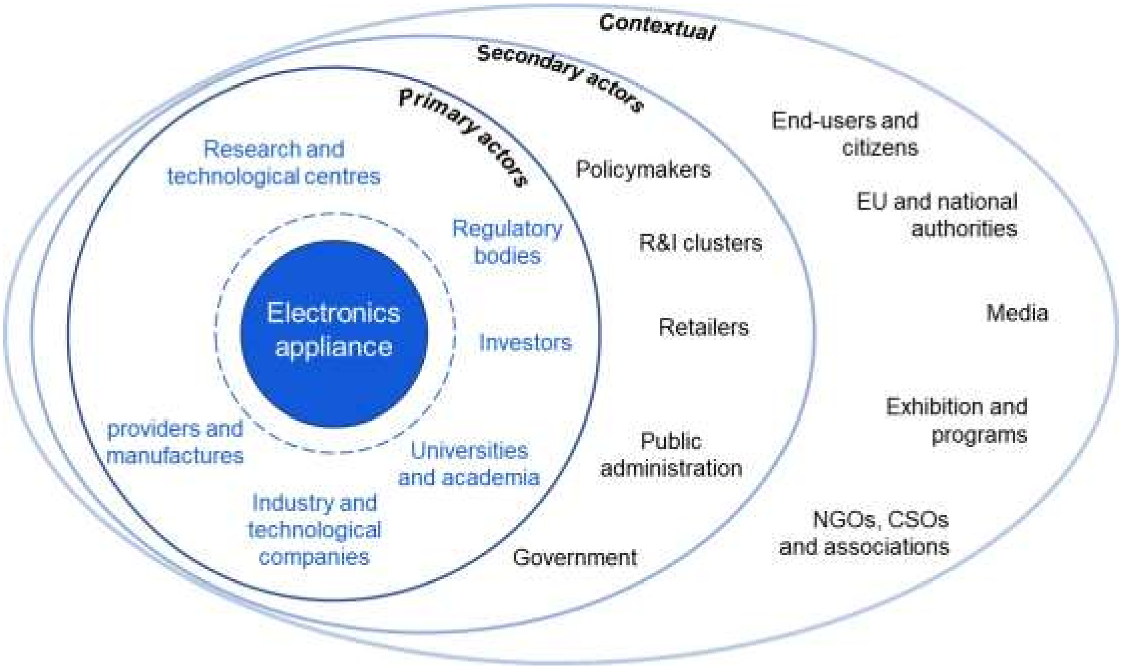

Figure 10. Innovation eco-system and stakeholder involved for materials in the electronics sector.

The stakeholders involved in the electronics sector, can be resumed in 4 main categories, according to their relevance/influence: Science, Industry, Policy and Regulators, CSO/end-users as shown in Table 8.

Table 8. Relevant European stakeholders in the Electronic Sector.

Type of stakeholders	Organization
SCIENCE	IMEC, Leti, Fraunhofer, INL, BRTA; Semiconductors Research Corporation; Semiconductor Physics Research Center; IBM research; Institute for Compound Semiconductors
INDUSTRY	Umicore, BASF, SOITEC, Air Liquide, Merck, Osram Opto Semiconductors GmbH, NXP semiconductors NV, ASML, Zeiss, Besi, EVG, Applied Materials, Obducat, Robert Bosch GmbH, STMicroelectronics NV, Infineon, Philips, Siemens GmbH; STMicroelectronics; Vishay;
POLICY AND REGULATION	Eusemiconductors; Waste from Electrical and Electronic Equipment (WEEE); The Regulation on electronic identification and trust services for electronic transactions in the internal market (eIDAS Regulation)
CSOs/END-USERS	AENEAS, EMIRI, EUMAT, EARTO; Semiconductor Industry Association; IEEE;
OTHERS	Silicon Europe Project

6 A roadmap for stakeholder engagement

6.1 The role of stakeholder engagement in risk governance

Our analysis shows the diversity and complexity of the technical and socio-economic challenges that need to be faced in the different sectors analysed. Ensuring and improving safety and sustainability of processes and products along the sectoral value chains emerged as a common aspect and, depending on the context, it could be seen, at the same time, as a challenge, a need, and a driver for development. Innovation in advanced materials and nanomaterials play an important role in finding solutions to these challenges.

Stakeholder engagement gives opportunities to further align research and innovation practices with societal needs and expectations, helping to drive long-term sustainability. Successful implementation of new products or technology should promote and manage relations with stakeholders and end-users proactively rather than reactively.

The attempt of the Gov4Nano project is to provide advice on how to develop new organizational forms to promote governance of risks of nanomaterials and advanced materials toward a safe and sustainable development (Gov4Nano Deliverable 5.5). Stakeholder engagement is an essential component of this effort. Networking and connecting expertise of different research, development and innovation communities is paramount to share knowledge and work toward a holistic approach along the value chain to implement Safe and Sustainability by design practices[13].

The next section provides a summary of key topics identified in the previous sections. Based on these assumptions, a roadmap has been developed to reach this objective (Figure 11).

6.2 Highlights from the innovation ecosystem analysis

The analysis of this report provides initial suggestions on research and development activities, and safe and sustainable aspects of relevance for each of the different sectors. This could help to identify initial topics and themes to start cooperation amongst the different communities.

- The building and construction sector involve as primary stakeholders both private and public organizations and is characterized by a fragmentation of professionals and small organizations. Decreasing environmental impact of building materials by circular approaches, such as re-use and recycling of construction materials (e.g., disassembly, reverse logistics), and novel materials to increase quality and efficiency, and reduce energy consumption of constructions are some of the most relevant technology development objectives. Safety is also key, both for workers and for citizens living in the built environment.
- The energy sector is looking for solutions for energy efficiency, effective reuse and recycling and green primary production of raw materials, including critical raw materials and circular economy, by accelerating the deployment of renewables and ensuring the affordability and security of energy supply. In this sector, advanced materials and innovations based on sustainable-by-design approach could enable the transition to the decarbonisation of the energy in industrial sectors as well as switching from a linear model of production and consumption to a fully circular one, to reduce the waste that go to landfill every year due to the huge volumes of materials used in batteries, solar panels, wind blades, e-motors, etc.
- The transport and mobility sector are a very articulated field with so many organizations and entities interlinked in activities regarding production, services and facilities. Some key developments concerning advanced materials include light-weighting materials and structures, low friction and high durable materials, functional materials (e.g., self-healing)

[13] Caldeira C., Farcal R., Moretti C., Mancini L., Rasmussen K., Rauscher H., Riego Sintes J., Sala S. Safe and Sustainable by Design chemicals and materials - Review of safety and sustainability dimensions, aspects, methods, indicators, and tools. EUR 30991 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-47560-6, doi:10.2760/879069, JRC127109

power electronic devices and innovative batteries. Safety and sustainability aspects concern materials as such, and broader areas of development, such as energy-efficient and fossil-free vehicles, renewable fuels and a more transport-efficient society. Sustainability in transportation, logistics and individual mobility involve additional aspects besides CO2 and energy. Liveable cities, green habitats, and citizen-friendly living areas of the future require a re-thinking of multi-mode mobility with less ownership of cars, fewer parking areas, and environmentally friendly personal autonomy.

- The healthcare value chain is a complex one, with strict regulatory requirements. Some of the most significant R&D activities on advanced materials emerging from our analysis concerns the development of functional and multi-functional materials, coatings and functional coatings, bioinspired materials, with an emphasis on biocompatibility and antibacterial properties. Key SSBD aspects are related to the sustainability issues along the overall value chain, with an emphasis toward the reduction of environmental footprint of medical devices and products. Most relevant phases for SSBD are production and the end of life (waste management).
- The home and personal care sector is replacing non-biodegradable products with biodegradable products with fast degradation timelines and based on sustainable natural biobased resources. A key aspect is to design sustainable materials and production processes (e.g., fermentation, environmentally friendly coating processes, 3D printing), and to evaluate the overall LCA along the whole value chain to quantify and reduce the environmental impact. Advanced materials developed by new and sustainable chemical processes or new feedstock solution play a crucial role for closing the carbon loop and therefore act as a basis for a sustainable value chain.
- The electronics sector is looking for eco-sustainable materials to provide solutions for micro and nano scale devices. This, in turn, can build the transition towards the next-generation of devices, including multifunctional materials for sensing and electronics, chip-less integrated systems, ultra-low power sensing electronic systems, among others. 5G is the innovation that might enable the IoT, as its massive data flows requires billions of sensors, cameras, antennas, and other electronic devices that need to be designed and assembled. Therefore, advanced assembly and disassembly materials will play a key role. Sustainable polymer material innovation, combined with sustainable design guidelines to facilitate ease of disassembly, repair, and remanufacture. Digital technologies are expected to contribute to decarbonization in the (chemical) value chains, resilience & climate neutrality.

7 A roadmap for stakeholder engagement

Previous Gov4Nano activities and stakeholder consultations already highlighted the primary need to connect the community of nano safety research with research and innovation players and stakeholders working in relevant industrial sectors.

Based on the analysis performed, we developed a roadmap describing a viable path to strengthen the network of the nano safety community with research and innovation players along Europe.

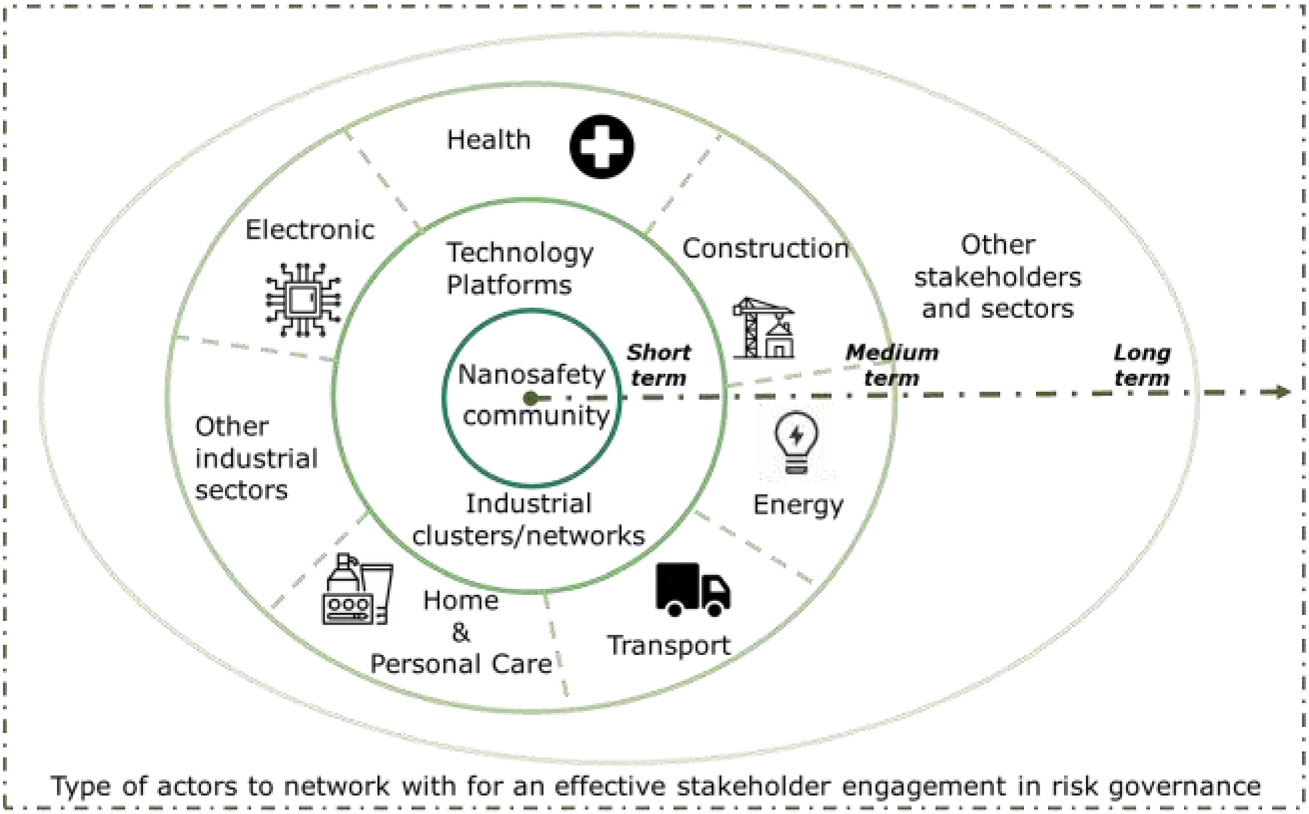

Figure 11. Sketch of a roadmap for an effective stakeholder engagement of organizational forms dealing with risk governance of nanomaterials and nano-related products.

The nano-safety community is identified as a central point of the roadmap. For the purpose of the roadmap, this term includes both informal and formal individuals and groups of researchers working on safety and sustainability issues related with nanomaterials and nano-related products. This community has grown in the recent years thanks to the wide on-going scientific work in the field, and as well activities and cooperation within EU projects and national initiatives in the field (in several cases connected through the Nanosafety Cluster[14]). It can be considered as a relatively wide and long-lasting scientific community.

The engagement process can be broadened by involving the R&D actors of different industrial clusters and technological platforms already dealing with nanomaterials, but not directly involved (or experts) in risk governance, safety and sustainability aspects of nanomaterials. The knowledge about safety and sustainability is relevant for them due to the use of nanomaterials in their technological applications. Gov4Nano identified at least 4 EU Technological Platforms or initiatives that could be relevant for the safe and sustainable development of nanomaterials, based on the work of the AMI 2030 roadmap:

- EUMAT – European Technology Platform for Advanced Engineering Materials and Technologies

[14] https://www.nanosafetycluster.eu/

- Suschem – European Technology Platform for Advanced Engineering Materials and Technologies
- MANUFUTURE Technology Platform
- EMIRI, the Energy Materials Industrial Initiative.

The Technological Platforms provide access to information about the industrial sectors using nanomaterials within their products or processes. For the stakeholders working in these sectors the results of the R&D performed on risk governance of NMs (standards, rules, data, tools among others) might be relevant, for example to address regulatory compliance issues and to increase the acceptance of their products. The analysis performed in this document, highlighted that the discussion with these stakeholders should be informed by a preliminary scanning of the sector characteristics (social, economic, technological aspects) and of the specific safety and sustainability issues.

The final step of this roadmap is the engagement of a broader community comprising other sectors and different types of stakeholders alongside those related to R&D and industry, such as end-users, insurance companies, public authorities, standardization bodies, public opinion.

8 Evaluation and conclusion

This report explores six of the most relevant industrial sectors for the application of nanomaterials and advanced materials, using a value chain and innovation eco-system approach. It provides an analysis of the perspectives of stakeholder groups, and the context in which they operate, within each of the six selected innovation ecosystems, considering the peculiarities of the organisations, application sectors and technologies involved.

It uses these findings to identify the type of stakeholders to engage and network with to strengthen the actions and impact of the nano-safety community (actors and organizations dealing with nano-safety research) toward a safe and sustainable development of nanomaterials. It suggests a stronger relationship between the nano-safety community and stakeholders of the different innovation eco-systems (science, industry, policy and regulation, end-user and society).

A stepwise, gradual approach is proposed.:

- In the short term, by developing liaisons with clusters and networks of industrial actors showing interest (or having a need for) strengthening safe and sustainable by design practices, such as European technology platforms. The goal is to increase awareness, share knowledge, and develop and agree on common and harmonized practices, methods and models;
- In the medium term, by reaching specific stakeholders within each of the innovation eco-systems identified, to provide practical support in implementing safe and sustainable by design strategies;
- In the long term, by creating structured and long-standing partnerships, also with actors in broader areas and sectors of application of nanomaterials and nano-related products

This is sketched in a visual roadmap, aiming to inspire engagement activities to promote and strengthen capacity in risk governance of nanomaterials.

The roadmap provides a model to build an effective stakeholder engagement strategy with stakeholders of different innovation eco-systems (science, industry, policy and regulation, end-user and society) for organizational forms dealing with risk governance of nanomaterials and nano-related products.

All three types of risk governance organizational forms envisaged by the Gov4Nano, NANORIGO and RiskGONE projects (joint deliverable 5.5). could take advantage of this model. A roundtable (option A) could likely address well at least the short-term goal set in the roadmap, creating and maintaining a dialogue between the nano safety community and industrial clusters and network. The house for risk governance (option B) could fit better to address also medium and long terms goals, as connecting with different sectors and with individual actors within each sector might require a more structured approach in terms of resources, competences, cooperation formats. Eventually, the roadmap could serve as a model and source of inspiration for any institution integrating specific risk governance functions (option C).

This report provides a qualitative and synthetic analysis of areas of interest and potential cooperation with actors of different innovation eco-systems relevant for the deployment of nanomaterials and nano-related products. However, a further and more detailed work will be needed to put in practice the activities foreseen in the roadmap.

9 Deviations from the work plan

The deliverable has been postponed to December 2022 to wait for the finalization of deliverable 5.5 and last amendments of the projects.

10 Performance of the partners

Airi has led this activity. All relevant WP and task leaders have been in discussion for the preparation of the deliverable.

11 List of abbreviations/glossary (optional)

AdMa	Advanced Materials
CSS	Chemical Strategy for Sustainability
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
Gov4Nano	Implementation of Risk Governance: meeting the needs of nanotechnology
NM	Nanomaterial
OECD	Organisation for Economic Co-operation and Development
RA	Risk Assessment
R&D	Research and Development
R&I	Research and Innovation
SbD	Safe(r/ty) by Design
SME	Small and Medium Enterprise
SSbD	Safe-and Sustainable by-Design
WP	Work Package