Navigating Impact

A Roadmap for Sustainable Drying and Dewatering Technologies

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A Roadmap for Sustainable Drying and Dewatering Technologies

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Summary

The SOLIDARITY project was dedicated to the development and implementation of three innovative and sustainable technologies aimed at revolutionizing drying and dewatering processes within industrial settings:

- Pervaporation for glycol dewatering
- Electrodialysis with bipolar membranes for brine reuse
- Simulation of drying and dewatering in paper production

These technologies collectively target a reduction in industrial heat demand by transitioning energy sources from heat to electricity. Such a transition holds immense potential for substantially lowering greenhouse gas emissions, particularly when powered by sustainable electricity, supporting the Netherlands' goal to be climate neutral by 2050. Moreover, the commercialization of these technologies can foster the competitive position of the Dutch industry, driven by sustainable values, over the next twenty-five years.

The SOLIDARITY project has underscored the significant potential of these technologies in achieving these impactful goals. However, it has also identified various challenges, including enhancing cost-effectiveness, incentivizing end-users to invest in these technologies, and scaling up their application to other industrial domains. To tackle these challenges, this report presents an impact roadmap delineating the essential steps toward realizing the project’s intended impact.

Outlined in the impact roadmap (see page 10) are:

- Impact goals for drying and dewatering technologies to be achieved by 2050.
- Desired outcomes or transformations necessary to achieve the intended impact.
- Outputs expected from SOLIDARITY partners, in collaboration with others, by 2030.
- Activities to be conducted over the next fifteen years to realize these outputs.
- Required inputs for executing these activities over time.

The report highlights the necessity of maintaining a delicate balance between the environmental benefits these technologies offer to society and the economic gains they provide to the economy, industry, and companies. Additionally, widespread adoption depends on the further development of the technologies alongside addressing socioeconomic factors, emphasizing the importance of collaboration among stakeholders.

Drawing from the impact roadmap, five crucial next steps have been identified:

1. Identify and secure new sources of financing.
2. Develop impact monitoring and evaluation tools.
3. Strengthen stakeholder engagement and collaboration.
4. Continue technology development.
5. Enlarge focus on socioeconomic factors.

By following this action agenda, SOLIDARITY project partners will be better equipped to effectively carry out the key activities detailed in the impact roadmap. This will ensure the successful development, implementation, and adoption of innovative drying and dewatering technologies by 2030, thereby fully contributing to environmental preservation and economic growth by 2050.

Contents

1 Introduction

In the SOLIDARITY project, three promising sustainable technologies were developed for drying and dewatering in the process industry. These technologies include:

- **Pervaporation for glycol dewatering:** This process separates liquid mixtures through selective evaporization via a membrane.
- **Electrodialysis with bipolar membranes for brine reuse:** This method removes, concentrates, and converts salt into its corresponding acid and base, combining electrodialysis for salt separation with water splitting.
- **Simulation of drying and dewatering in paper production**: Various techniques, such as impulse drying and airless drying, are simulated for more efficient dewatering and drying.

These technologies, despite their differences, share a common potential to significantly reduce heat demand in industrial processes in the Dutch transition towards climate neutrality in 2050. By transitioning the energy source from heat to electricity, they can substantially lower CO_2 emissions, particularly when powered by sustainable electricity sources. Additionally, these technologies can enhance the competitive position of the Dutch industry through the use and export of sustainable technology over the next twenty-five years.

For these technologies to have a substantial impact, widespread adoption in industrial practices is essential. Although the three-year research project demonstrated their technical feasibility, challenges remain in improving cost-effectiveness, convincing end-users to test, adopt, and invest in them, and scaling up for the selected use cases and to other application areas. As the project concludes, it is crucial to identify the necessary steps to address these challenges.

Mapping these activities is important to fully realize the potential impact of these three promising technologies by 2050. To this end, this report presents an impact roadmap aimed at scaling up SOLIDARITY's drying and dewatering technologies. The roadmap details the necessary actions to achieve this goal, with a particular emphasis on generating significant outputs by 2030. It addresses the decisions required for successful scale-up, uncertainties related to technology and investments, and the roles of various stakeholders and organizations.

The impact roadmap is based on the Theory of Change, see Box 1, which provides a detailed explanation of how and why the intended change is expected to occur in a particular context. The roadmap was developed in collaboration with partners working on the three technologies, who initially created individual technology roadmaps that were successively integrated into an overall roadmap for this report, see Box 2.

The following sections provide a brief overview of the SOLIDARITY project and the technologies, followed by a visualization and detailed description of the impact roadmap. From this description, three key conclusions are drawn:

- **Societal transformation:** The primary goal of SOLIDARITY's drying and dewatering technologies is to reduce greenhouse gas emissions and stimulate economic growth in the Netherlands through added value. This implies that decisions regarding these technologies should consider both environmental and economic factors.
- **Technological and socioeconomic development:** While ongoing technological development is crucial for widespread industrial application, equally important are the socioeconomic changes needed for adoption. Research and development activities should therefore focus on both technological and socioeconomic advancements.

- **Collaborative efforts:** Extensive collaboration with various industry stakeholders is essential to effect the necessary changes. An ecosystem perspective is required for future development, as individual actions may not lead to optimal decisions.

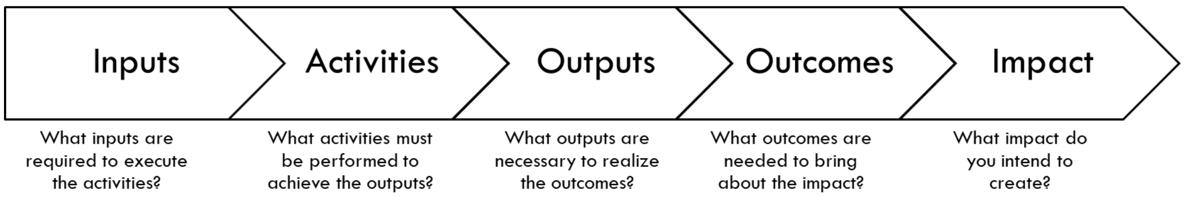
To address these points, this report, based on the impact roadmap, formulates a five-point action agenda aimed at ensuring the SOLIDARITY project successfully scales up its drying and dewatering technologies. This agenda is designed to maximize their potential impact by 2050, with significant milestones and outputs achieved by 2030. By adhering to this action agenda, the project will be strategically positioned to take its next steps in driving innovation, environmental sustainability, and economic growth.

Box 1. Understanding the Theory of Change

The Theory of Change is a comprehensive framework used to describe and illustrate how and why an intended change or impact is expected to occur within a specific context, as illustrated in the figure below. It is a strategic planning tool that maps the pathway from inputs to impact, ensuring that all necessary components are considered and aligned for achieving the desired outcomes.

Recognizing that societal impact is neither automatic nor easy, the Theory of Change emphasizes the need for deliberate effort to overcome challenges. It provides a concrete, shared vision for collaboration between organizations, offering clear direction and focus. Additionally, it guides the development of strategic plans by identifying the necessary next steps and interventions to achieve desired outcomes as depicted in the accompanying figure.

The Theory of Change starts with the desired impact and then works backward to determine the necessary outcomes, outputs, activities, and inputs. This reverse-engineering approach ensures that every step of the process is purposefully aligned with achieving the ultimate goal. It is particularly effective for creating impact roadmaps, which are strategic plans that outline the pathway to achieving significant societal changes.



2 SOLIDARITY's drying and dewatering technologies

In the MOOI project SOLIDARITY, Process Efficient Solid and Liquid Dewatering and Drying, ten public and private partners collaborated to demonstrate cost-effective drying and dewatering in the process industry. The project initiative aimed to help the industry meet climate targets by enhancing the efficiency of industrial processes. The project achieved this by combining technologies and innovations in solid-liquid and liquid-liquid separations, leading to reduced heat usage, increased use of clean electricity, and improved process efficiency. Below, the three developed technologies are explained in detail.

Box 2: Project partners

2.1 Pervaporation membrane for glycol dewatering

TNO and Pervatech, a membrane and module producer, have developed a pervaporation process to dewater glycol. Technip FMC, an EPC contractor and key player in systems and processes for natural gas processing, sees a big advantage of this technology to improve natural gas dehydration as well as making the process more sustainable. Natural gas contains large amounts of water depending on the location where it is sourced, while the market demands water-free gas. The common method to dehydrate natural gas involves adsorption of water with glycol at high pressure. The recovery of the glycol requires high temperatures that results in large amounts of fossil fuel-based distillation energy. Pervaporation membranes are seen as an energy-efficient alternative to perform the water-glycol separation.

Lab-scale tests conducted by TNO and Pervatech demonstrated that HybSi® membranes are a suitable candidate for the pervaporation process to dehydrate glycol. These membranes showed good selectivity's and permeances under the tested conditions, with performance only dropping when the water contains high amounts of salt. Nevertheless, it proved difficult to convince potential end-users to serve as locations for field tests within the project's scope. End-users demand proof of the technology's performance, but a field test is necessary to collect that proof. Additionally, the business case analysis revealed that the current membrane module design is probably too costly for end-users. The membrane surface area is still high, requiring 5 to 6 membrane modules, making the construction large and consequently costly. Furthermore, the application of membranes is largely unknown to the field and may be perceived complex.

Therefore, directing efforts towards refining the membrane design and identifying appropriate sites for field testing will be pivotal in ensuring the successful commercialization of this promising technology.

2.2 Electrodialysis with bipolar membranes for Brine Reuse

Wageningen University & Research and WaterFuture have developed electrodialysis with bipolar membranes (EBDM) technology, achieving TRL 5-6, to produce acid and base in the recovery of salt from industrial wastewater streams. Currently, this technology is being tailored for the chemical industry, specifically for Carbogen AMCIS, a fine chemical company that extracts high-quality cholesterol compounds from sheep's wool fat for cosmetics and Vitamin D3 production. Carbogen AMCIS is looking for a sustainable solution for its sodium sulfate-containing aqueous wastewater stream, which is currently largely diluted with groundwater and discharged into the sewer. Given the broader advantages of EBDM—reducing wastewater discharge, removing salt by producing acid and base for reuse, and lowering heat consumption—WaterFuture has also been involved to explore alternative applications.

The lab-scale screening and field test of the EBDM technology have demonstrated its high potential to provide a stable circular supply of acid, base, and water. The technology can be integrated within current production systems and lacks competitive technologies. These advantages have generated interest from the industry, but actual buy-in remains limited. The main challenge is that the business case is not yet profitable due to the high costs associated with the production of high-quality (lifetime) and complex membranes, the need to pre-treat the waste stream, and the technology's inability to provide high concentrations of acid and base as originally applied in the key process. Legislation prohibiting the discharge of salt in industrial waste streams may serve as a significant driver for the commercialization of this technology.

With continued technological and market development and supportive legislation, EBDM technology has the potential to become a widely adopted, sustainable solution for industrial wastewater treatment.

2.3 Simulation of drying and dewatering in paper production

TNO and Huhtamaki have translated various dewatering technologies (displacement press, impulse drying, and heat cap) and drying technologies (intensified, airless, and electric drying) into simulation models for application in paper production processes. VNP, the Royal Dutch Association of Paper and Cardboard Manufacturers, provided advice and feedback concerning the applicability of the developed models. In collaboration with industrial end-users Huhtamaki and ESKA, experiments were conducted to test the models' performance for molded and sheet paper on existing machines or specifically designed test facilities. These technologies are essential building blocks towards an all-electric paper mill, significantly improving energy efficiency and enabling the paper industry to meet climate goals while remaining competitive.

The partners have developed a comprehensive set of tools to simulate the drying and dewatering processes in paper production. They have demonstrated that modeling these processes is challenging, but the accuracy of forecasts significantly improves when actual material characteristics are used as input rather than generic parameters. This suite of tools enables more focused experimentation with drying and dewatering technology, reducing both the time and resources required for such trials. Consequently, there has been increased industry engagement and support for adopting these technologies in the paper sector. However, the evidence supporting their performance remains insufficient to justify investment decisions.

Moving forward, further validation and field testing are crucial to provide the necessary proof of performance and drive broader adoption and investment in these promising technologies.

3 Impact roadmap

SOLIDARITY's impact roadmap outlines a strategic pathway aimed to drive significant societal transformations across economic and ecological domains in the Dutch transition towards climate neutrality by 2050. Key to this roadmap are the outcomes, urging both private and public stakeholders to adapt/coordinate their behaviors, relationships, and actions. These outcomes rely on the future outputs of the project partners, a collection of direct insights and developments within their control, targeted for achievement by 2030. To actualize these outputs, specific research tasks and action – activities – must be undertaken in the coming years, bolstered by the necessary resources, materials, and information – inputs. Together, these elements lay the groundwork for SOLIDARITY's concerted effort to realize its intended impact. Below, explore the visualization of this strategic roadmap as we delve into its components.

Box 3: Design method

TNO Vector, the center for societal innovation and strategy at TNO, offers guidance to both public and private entities in addressing the significant societal developments and challenges of our era. It formulated the impact roadmap for SOLIDARITY through a systematic four-step process:

1. **Introduction interviews:** In January 2024, initial online meetings were conducted with the work package leaders of the three technology lines to outline TNO Vector's approach to impact road mapping and gain a broad understanding of the technologies in development.
2. **Individual workshops:** In February 2024, separate workshops were held with the partners of each technology to identify the activities conducted within SOLIDARITY and the resulting outputs.
3. **Joint workshop:** A joint workshop took place during the SOLIDARITY progress meeting in March 2024. Partners first focused on developing comprehensive impact roadmaps for their respective technologies, followed by presentations of these roadmaps to each other. This allowed for the identification of similarities and differences in elements, connections, stakeholders, and conditions across the roadmaps.
4. **Reflection sessions:** Building upon the similarities identified in the roadmaps, TNO Vector synthesized an overall impact roadmap. This roadmap was validated and refined with work package leaders in April 2024 and with all project partners in May 2024. The final version of the roadmap is detailed in this report.

Impact Roadmap for Sustainable Drying and Dewatering Technologies

Inputs

- People with knowledge and experience
- Pilot location and facilities
- Market and technological knowledge
- Collaboration and orchestration based on shared interest
- Funding for development

Activities

Socioeconomic factors

- Advocate for sustainable policies
- Host stakeholder consultations
- Demonstrate energy-saving benefits
- Advocate for renewable electricity incentives
- Share best practices with industry
- Conduct technical assistance sessions
- Develop curricula and training programs
- Organize knowledge hub workshops

Technology

- Elevate technologies' TRL levels
- Optimize process integration
- Conduct business case analysis
- Research alternative application areas

Outputs

- Promoted sustainable policy initiatives
- Advanced sustainable electricity solutions
- Enhanced interest in technologies
- Nurtured expertise in technologies

- Technologies at TRL 6-7
- Seamless integration in existing processes
- Technologies are cost-effective
- Identified alternative application areas

by 2030

Outcomes

- Full realization costs of unsustainable practices
- Increased access to renewable electricity
- Increased investment in sustainable practices
- Rise in pool of skilled workforce

- Widespread adoption of technologies
- Ample of technology suppliers
- Expansion to other application areas

Impact

Industrial resource circularity and emission reduction

Expansion of the Dutch economy driven by values

by 2050

Stakeholders

End-users
Membrane suppliers

Technology providers
Governmental bodies

Financers
Knowledge institutes

3.1 Impact

SOLIDARITY's intended societal impact spans economic and ecological transformations, driven by the knowledge and skills cultivated within the project. Its dual impact goal for 2050 is to enhance industrial resource circularity and reduce emissions, while also fostering the expansion of the Dutch economy driven by values. These goals reflect a unified effort towards a more sustainable and economically robust future.

- **Industrial resource circularity and emissions reduction:**

SOLIDARITY's partners are dedicated to pioneering innovative drying and dewatering technologies aimed at significantly reducing greenhouse gas emissions. These technologies are engineered to minimize the amount of heat, a major contributor to our CO_2 footprint, needed for drying and dewatering substances. They can even further reduce lower CO_2 emissions when powered by renewable electricity sources. For instance, SOLIDARITY's paper drying technology has proven to achieve substantial heat savings.

Furthermore, SOLIDARITY's technologies strive to enhance circularity by increasing the availability of reusable materials. Take the EDBM technology, for example. It not only extracts salts, but also converts it into acids and bases, while cleaning the wastewater, facilitating the reuse of these chemicals and water in producing new products. Similarly, pervaporation enables energy efficient recycling of glycol in the natural gas dehydration process. These approaches foster a more sustainable resource management system and contribute to the advancement of a circular economy.

- **Expansion of the Dutch Economy Driven by Values:**

Beyond its environmental impact, the SOLIDARITY partners aim to stimulate the Dutch economy with a focus on values. While cost reduction currently dominates the Dutch economy, there is a growing movement towards a value-based economy, where environmental, social, and economic values are balanced.

By positioning Dutch technology providers as global leaders in sustainable drying and dewatering technology, SOLIDARITY seeks to enhance the economy both financially and sustainably. This leadership not only generates job opportunities within the Dutch economy but also establishes a social license to operate for businesses under increasing pressure from market demands and regulatory requirements to operate sustainably.

In conclusion, through the development of innovative technologies that reduce greenhouse gas emissions and promote resource circularity, SOLIDARITY's partners aim to actively contribute to environmental preservation and the advancement of a value-based economy. Its efforts foster a society where economic prosperity is intertwined with environmental stewardship, paving the way for a more sustainable future.

3.2 Outcomes

To achieve the desired impact, both private and public stakeholders must alter their behavior, relationships, actions, and activities – known as outcomes. While these changes are not entirely within the control of SOLIDARITY's partners, they determine the outputs that should result from their future activities.

Firstly, the outcomes pertain to the development and commercialization of the drying and dewatering technologies. The three technologies must become widely adopted in industrial practice to make an impact. It is not sufficient when only a few technology and material providers, such as Huhtamaki, TechnipFMC, WaterFuture, and Pervatech, commercialize the technology. To ensure widespread adoption, many technology providers need to be willing and able to sell the technology globally, seeing both demand from customers and long-term profitability.

Moreover, industrial applications should extend beyond the oil and gas, chemical, and paper industries to include other sectors, like pharmaceuticals. In this industry, drying and dewatering technologies could be used for solvent recycling or drug component purification.

Secondly, besides technology development, various socioeconomic outcomes influence whether SOLIDARITY's partners can realize their intended impact:

1. **Full realization costs of unstainable practices:** To promote an environment favorable to sustainable drying and dewatering technologies, it is essential that the costs associated with unsustainable materials and waste generation surpass those of renewable and circular alternatives. Currently, fossil-based virgin materials, landfill, discharge of wastewater and incineration remain cheaper than more sustainable options. As unsustainable practices become increasingly costly due to resource scarcity and government regulations, the demand for sustainable drying and dewatering technologies will grow, driven by their CO_2-reduction, energy-saving, and material-recycling potential.
2. **Increased access to renewable electricity:** Better and easier access to renewable electricity sources is crucial for Dutch companies to successfully implement drying and dewatering technologies. Although these technologies minimize heat consumption, they still require electricity. Currently, access to renewable electricity in the Netherlands is limited, aggravated by increasing congestion in the electricity grid. When electricity can be sourced from renewable sources, the positive impact of SOLIDARITY's drying and dewatering technologies will be further amplified.
3. **Increased investment in sustainable practices:** Encouraging end-users to invest more in sustainable business practices, including current and new production processes, is essential for the adoption of SOLIDARITY's drying and dewatering technologies. While these technologies are presently more expensive than less sustainable alternatives, they offer significant non-financial environmental benefits. Despite a growing interest in sustainable practices, there remains considerable reluctance to invest heavily in them. As investment readiness in sustainable practices increases, the application of drying and dewatering technologies developed by SOLIDARITY is likely to expand.
4. **Rise in skilled workforce pool:** A sufficient pool of young talents and experienced professionals in the Netherlands is necessary for the successful development and commercialization of SOLIDARITY's drying and dewatering technologies. There is significant potential for job creation within the technology sector through the promotion of these sustainable technologies. However, the availability of professionals with the required technological skills is a known challenge in the Dutch labor market. Addressing this gap in skills is crucial for leveraging the job creation potential in this sector.

Thus, the efforts of SOLIDARITY's partners must focus on not only developing and commercializing innovative technologies but also addressing socioeconomic factors that affect technology adoption. By ensuring the widespread adoption of sustainable practices and enhancing investment readiness among industrial players, they can contribute to a more sustainable future while creating economic opportunities in the Netherlands.

3.3 Outputs

The outputs of the SOLIDARITY project partners are the direct insights and developments within their control, aimed at realizing the specific outcomes previously defined. The primary outcome is the widespread adoption of three dewatering and drying technologies within industrial practice. To achieve this, SOLIDARITY partners – in 2030 – have elevated these technologies to TRL (Technology Readiness Level) 6 to 7. TRL 6 demonstrates the technology's functionality in a realistic environment, while TRL 7 showcases a working prototype in an operational setting. This will provide confidence to potential adopters about their reliability and effectiveness in real-world applications.

Ensuring technological feasibility and ease of operation is crucial, but equally important is that SOLIDARTY partners have demonstrated the economic viability of these technologies. It is imperative for businesses to adopt these technologies that the financial benefits outweigh the investments and operational costs over the long term. Moreover, having identified alternative application areas beyond the initial target industries expands the market potential and adoption opportunities for these technologies.

Furthermore, the SOLIDARITY partners have designed the technologies in 2030 to seamlessly fit into current production environments. While greenfield applications offer a clean slate, making them easier to realize, greater impact can be achieved when technologies are integrated into current production environments. Therefore, it is vital that these technologies operate efficiently and robustly within current production systems.

The second set of outcomes pertains to socioeconomic factors that influence the extent to which SOLIDARITY partners can achieve their intended impact. While they have less direct control over these outcomes, they have created four outputs by 2030 to ensure their influence:

1. **Promoted sustainable policy initiatives.** To foster a regulatory environment conducive to sustainable practices across industries, SOLIDARITY partners:
   - engaged in advocacy efforts with policymakers to enact laws and regulations that incentivize sustainable business practices.
   - stimulated the implementation of support mechanisms and incentives to ensure practical, effective, and widely supported regulations.

2. **Advanced sustainable electricity solutions.** To address electricity congestion and promote access to sustainable electricity solutions, SOLIDARITY partners:
   - fostered the implementation of drying and dewatering technologies in industrial processes, reducing electricity consumption.
   - developed strategies with policymakers for increasing access to renewable electricity sources and investment in renewable electricity infrastructure.

3. **Enhanced adoption of drying and dewatering technologies:** To ensure that businesses are willing and able to integrate drying and dewatering technologies into their core operations, SOLIDARITY partners:
   - raised awareness about and interest in the benefits of these technologies in reducing water consumption, heat usage and CO_2-footprint, as well as environmental pollution.
   - established a community of practice that encourages peer learning and support through knowledge-sharing and collaboration among businesses.

4. **Nurtured technical expertise in sustainable technologies:** To cultivate a new generation of technical talent and ensure a sustainable pipeline of professionals skilled in sustainable drying and dewatering technologies, SOLIDARITY partners:

- established learning communities that offer hands-on training, internships, and research opportunities for students.
- created hubs for knowledge exchange and collaboration between academia and industry, addressing real-world faced by businesses.

In conclusion, the SOLIDARITY partners need to make significant strides in advancing sustainable technologies and practices within industrial settings. In addressing socioeconomic factors, they must actively engage with policymakers and stakeholders to advocate for sustainable policies, promote access to renewable electricity solutions, generate interests and awareness among businesses and nurturing technical talent and professionals.

3.4 Activities

The activities encompass specific research tasks and actions necessary for SOLIDARITY partners to achieve their intended outputs. To enhance the development of drying and dewatering technologies, partners must elevate the TRL levels of their technologies through rigorous testing and refinement, including extensive field tests or pilot plants to overcome technical challenges, build confidence, and optimize performance.

Additionally, partners need to conduct thorough economic analyses (Total Cost of Ownership for integral lifecycle) to demonstrate the technological viability by quantifying long-term financial benefits and return on investment. They should also investigate alternative application areas beyond the initial target industries.

Furthermore, they must optimize process integration by conducting compatibility studies and developing interface solutions for seamless integration with existing equipment and processes, including on-site testing in various industries.

Aside from technological development, the SOLIDARITY partners must undertake numerous activities to achieve the targeted four socioeconomic outputs. The eight most important activities are:

a. Collaborate with industry associations to promote the adoption of sustainable practices and advocate for policies that support businesses.
b. Host stakeholder consultations to gather input from various parties, identifying gaps in regulations and proposing practical solutions.
c. Demonstrate the heat and electricity saving benefits of drying and dewatering technologies to end-users and policymakers through pilot projects and case studies.
d. Advocate for incentive programs, like feed-in tariffs and tax credits, to encourage investment in renewable electricity infrastructure.
e. Share successful case studies and best practices at workshops, seminars, and conferences to raise awareness about and interest of end-users in the technologies.
f. Conduct regular technical assistance sessions for end-users in the community of practice to address their specific needs.
g. Develop tailored curriculum and training programs for students in the learning community to meet industry demands.
h. Organize knowledge hub workshops and seminars where academia and industry experts share insights and knowledge.

The outlined activities are vital for SOLIDARITY partners to achieve their outputs. Elevating TRL levels, conducting economic analyses, and optimizing process integration are crucial for technological advancement. Collaboration with industry, stakeholder consultations, and advocacy for supportive policies are key to socioeconomic outcomes. Demonstrating technology benefits, sharing successful case studies, and providing technical assistance foster adoption and awareness. Tailored training programs ensure a sustainable pipeline of skilled professionals, all contributing to SOLIDARITY's impact on circularity, emissions reduction, and economic growth.

3.5 Inputs

The inputs are the resources, materials, or information necessary for SOLIDARITY partners to conduct activities. Five inputs are particularly crucial for carrying out the aforementioned activities effectively and efficiently:

- **People with knowledge and experience:** Having individuals with expertise in relevant fields is essential for SOLIDARITY partners' future technological developments and their intended socioeconomic outputs. The people should bring valuable insights, skills, and experience to understand the industry's intricacies, apply technical know-how, and navigate challenges effectively. Their knowledge and experience are crucial for driving innovation within the project.
- **Pilot location and facilities:** Finding the right pilot location and having access to suitable facilities is crucial for the further development of SOLIDARITY's drying and dewatering technologies. The chosen location should provide an environment conducive to testing and experimentation, including the necessary infrastructure, equipment, and resources to support project activities. In this way, pilots can be conducted efficiently and effectively.
- **Market and technological knowledge:** Understanding the market dynamics and technological landscape is crucial for identifying opportunities and challenges. Having insights into market trends, customer needs, and competitor activities helps SOLIDARITY's partners in developing technologies and socioeconomic activities that are aligned with market demand. Similarly, staying updated with the latest technological advancements enables the partners to leverage cutting-edge solutions and stay ahead of the competition.
- **Collaboration and orchestration based on shared interest:** Collaboration among stakeholders based on shared interests is essential for achieving the outcomes. Through pooling their resources, expertise, and capabilities with others, SOLIDARITY's partners can accomplish more than what they could individually. This requires clear communication, mutual trust, and alignment of objectives. By orchestrating efforts based on shared interests, stakeholders can work cohesively towards achieving desired outcomes.
- **Funding for development:** Adequate funding is crucial for the development and execution of any project. It enables the SOLIDARITY partners to acquire resources, hire personnel, and implement activities. Funding may come from various sources such as government grants, private investors, or philanthropic organizations. Thus, a well-defined funding strategy and effectively managing financial resources are essential for the success of the partners' activities.

In conclusion, the inputs identified are crucial for the effective implementation of SOLIDARITY's activities. People with knowledge and experience, suitable pilot locations and facilities, market and technological insights, collaboration based on shared interests, and adequate funding are essential for driving technological development and achieving socioeconomic outcomes. These inputs provide the foundation for innovation, testing, market alignment, collaboration, and financial sustainability within the project. By leveraging these inputs effectively, SOLIDARITY's partners can realize their goals of contributing to environmental preservation and advancing a value-driven economy.

4 Conclusions

Recognizing that societal impact is neither automatic nor easy, SOLIDARITY's impact roadmap emphasizes the need for deliberate effort to overcome challenges in the development of sustainable drying and dewatering technologies. Beyond the mere description of the elements, three overarching conclusions can be drawn based on the impact roadmap:

- **Societal transformation:** SOLIDARITY's drying and dewatering technologies aim to achieve a dual societal impact: enhancing industrial resource circularity and reducing greenhouse gas emissions, while also fostering value-driven economic growth in the Netherlands. This implies a holistic approach where decisions regarding these technologies must consider both environmental and economic factors, rather than focusing solely on one aspect. By prioritizing solutions that address both environmental and economic benefits, stakeholders can ensure a balanced approach that maximizes societal impact.
- **Technological and socioeconomic development:** While technological advancements are pivotal for widespread adoption of sustainable drying and dewatering practices in the industry, concurrent efforts to promote sustainable policy initiatives and advance electricity solutions are essential. Moreover, SOLIDARITY's partners must ensure companies are ready to integrate these technologies into their operations, and there is a sufficient pool of technical talent to further develop these solutions. It is essential to recognize that the success of a technology relies not only on its technical merits but also on broader societal acceptance and support.
- **Collaborative efforts:** The roadmap shows that achieving the impact goals of SOLIDARITY requires extensive collaboration with a multitude of stakeholders across various sectors. This includes end-users, membrane suppliers, technology providers, governmental bodies, financiers, and knowledge institutes. Adopting a value network thinking approach enables stakeholders to recognize and leverage the interconnectedness of these entities. By fostering collaboration among diverse stakeholders, it becomes possible to address complex challenges more effectively, promote knowledge exchange, and accelerate the adoption of sustainable technologies. This collaborative approach ensures that the benefits of SOLIDARITY's technologies are realized across the entire value chain, driving meaningful societal impact.

5 Agenda for action

After analyzing the impact roadmap and drawing conclusions, it is imperative to outline the essential actions that SOLIDARITY's partners must undertake now. These five next steps are critical in realizing the impact roadmap:

1. **Identify and secure new sources of financing:** The uncertainty surrounding follow-up funding necessitates proactive measures to secure financial support for further development. Partners should explore grant opportunities and funding programs focusing on sustainable technology and environmental initiatives. Additionally, forging partnerships with government agencies and private companies for co-funding pilot projects and field tests can mitigate financial challenges.
2. **Develop impact monitoring and evaluation tools:** Designing a comprehensive digital framework is crucial for monitoring progress and evaluating impact. This framework should track the progress of each activity, measure desired outputs, outcomes, and impact, and include key performance indicators, milestones, and timelines. Regular progress reviews and evaluations, in collaboration with key stakeholders, will enable partners to balance uncertainties regarding economic and environmental considerations effectively.
3. **Strengthen stakeholder engagement and collaboration:** Conducting a detailed stakeholder analysis based on interest, influence, and involvement is essential for tailored collaboration efforts. Establishing suitable collaboration platforms to facilitate continuous communication and collaboration among partners, stakeholders, and end-users will foster effective coordination and alignment of efforts, overcoming potential challenges.
4. **Continue technology development**: Recognizing uncertainties in technology readiness for full-scale implementation, partners must prioritize ongoing technology development efforts. Elevating the Technology Readiness Levels (TRL) of the technologies, conducting thorough economic analyses, and optimizing process integration are crucial steps. Exploring alternative applications in other industries can broaden adoption possibilities and enhance technology scalability.
5. **Enlarge focus on socioeconomic factors:** While confidence in technology development is high, there is uncertainty regarding the socioeconomic factors essential for achieving the intended impact. Shifting focus towards activities that contribute to creating necessary socioeconomic changes is warranted. This entails balancing efforts between technology development and initiatives aimed at addressing socioeconomic barriers to adoption.

In conclusion, the success of SOLIDARITY’s drying and dewatering technologies depends on proactively tackling uncertainties and challenges through these five strategic actions, realizing the project's intended impact. Through collaborative efforts, SOLIDARITY partners can pave the way for the successful development, implementation, and adoption of innovative drying and dewatering technologies. This endeavor not only contributes to industrial resource circularity and emission reduction but also stimulates the Dutch economy underpinned by sustainable values.

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