UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

A2D
Accelerate to Demonstrate Facility

EXECUTIVE REPORT

MARKET ASSESSMENT ON SMART ENERGY AND INDUSTRIAL DECARBONIZATION INNOVATION IN DEVELOPING COUNTRIES

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Acknowledgement

This market assessment was conducted by KPMG Austria under the overall guidance of Mr. Peter Warren, A2D Facility Manager, and Ms. Yi Zhang, A2D Facility Smart Energy and Industrial Decarbonization Project Coordinator, within the Division of Climate Innovation and Montreal Protocol of the United Nations Industrial Development Organization (UNIDO). This effort was made possible through the support of the United Kingdom's Department for Energy Security and Net Zero (DESNZ).

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The project team extends their gratitude to the survey respondents and interviewed experts (Appendix page 83 in the main report, Experts interviewed) for their precious time and insights.

About UNIDO

UNIDO is a specialized agency of the United Nations with a unique mandate to promote, dynamize and accelerate industrial development. Our mandate is reflected in Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", but UNIDO's activities contribute to all the SDGs.

UNIDO's vision is a world without poverty and hunger, where industry drives low-emission economies, improves living standards, and preserves the livable environment for present and future generations, leaving no one behind.

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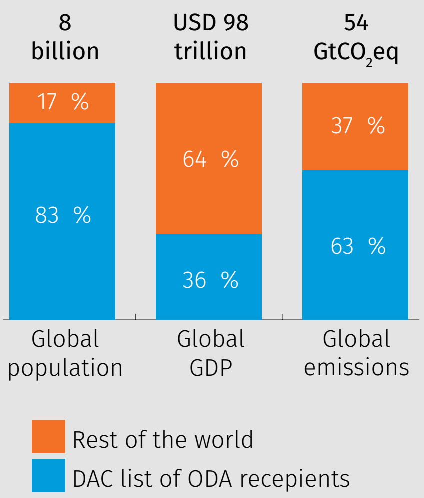
Executive Report

1. Background

The A2D Facility, funded by the UK Government's Department of Energy Security & Net Zero (DESNZ), aims to accelerate the commercialization of innovative clean energy technologies in developing countries. It focuses on four thematic areas: clean hydrogen, critical minerals, smart energy, and industrial decarbonization. These areas are crucial for facilitating clean energy transitions and addressing climate risks in developing countries, which currently account for 83% of the world's population and 63%[1] of global emissions.

TABLE 1: ODA Recipients: Population, Emissions, and GDP Contributions

While the 141 countries on the list of Official Development Assistance (ODA) recipients represent 83% of the global population, they account for 63% of global emissions and 36% of global GDP.



Electricity demand is projected to double in developing countries. Their energy systems present an opportunity for radical transformation.

The A2D Facility closes an important gap in the landscape of climate innovation funds that support developing countries through international climate finance and Official Development Assistance (ODA). It targets the pilot demonstration phase of the climate innovation chain, focusing on projects with a "lighthouse" effect that have the potential for a transformational impact in supported countries.

This document summarizes the results of a comprehensive examination of two of the thematic areas, i.e., smart energy and industrial decarbonization. Smart energy refers to systems using digital technologies, which enable more efficient network delivery of energy. Such technologies and solutions may include, but are not limited to, smart grids, smart devices, energy storage systems, Artificial Intelligence software or solutions, data access and management tools such as blockchain, smart metering, remote monitoring and controls, demand-side response, and the integration of on-grid and off-grid approaches (e.g., swarm grids, mini-grids, etc.).

Industrial decarbonization is the process of strategic reduction or elimination of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions from the industrial sector. This can be achieved by switching to low-carbon energy sources, adopting cleaner production methods, and improving energy efficiency. Decarbonization can be materialized at the level of source, process, and life cycle. In the context of technological solutions, the assessment emphasized on carbon capture, utilization, and storage (CCUS), alternative fuels such as biofuels and hydrogen for industrial applications, process optimization to enhance energy efficiency, and electrification of industrial processes.

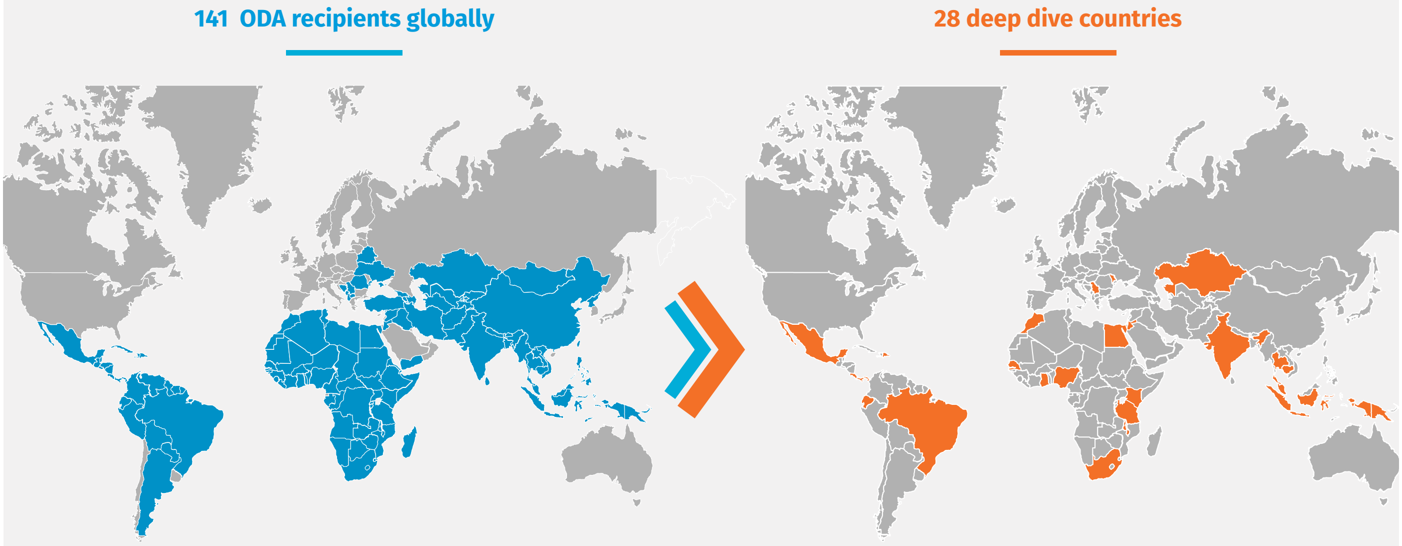
Innovative technologies in these thematic areas provide affordable energy access, accelerate clean energy transitions, and drive economic growth while addressing environmental challenges.

The market assessments (one for each thematic area) served to identify high-potential markets, technologies, and project pipelines, with the objective of accelerating the commercialization of innovative clean energy technologies in developing countries.

2. Country Selection

While the assessments provide a global view covering all 141 ODA recipient countries, a representative set of 28 countries has been selected for deep dive analysis. The criteria for selecting those focus countries were based on several key factors including the presence of progressive policy frameworks and regulatory environments that support technology innovation in smart energy and industrial decarbonization. Additionally, countries with significant economic growth potential, high energy demand, and vulnerability to climate change were prioritized. A balanced selection across Africa, Asia, and Latin America ensured a diverse geographical and economic context. The selected 28 focus countries are:

TABLE 2: Overview focus countries



Africa	Asia	Americas
1. Malawi	13. Cambodia	22. Domin. Republic
2. Rwanda	14. India	23. Costa Rica
3. Tanzania	15. Jordan	24. Mexico
4. Senegal	16. Kazakhstan	25. Panama
5. The Gambia	17. Indonesia	26. Brazil
6. Kenya	18. Malaysia	27. Ecuador
7. Egypt	19. Thailand	
8. Morocco		
9. Ghana	**Europe**	**Oceania**
10. Nigeria	20. Moldova	28. Papua New Guinea
11. Mauritius	21. Serbia	
12. South Africa		

3. Key Findings of the market assessments

Both market assessments cover five core areas of analysis which are critical for the advancement and scaling of respective innovative technologies: stakeholders, markets, projects and initiatives, technology landscape, as well as impacts and SDGs.

While certain findings within these analytic core areas, e.g. for the technology landscape, are distinctive for each thematic area, others clearly stand out as cross-cutting results since they encompass enabling environments, stakeholder interactions, and policy frameworks that are crucial for advancing technology innovation across both areas equally. Subsequently, we have identified distinctive and cross-cutting results with respective icons:

SE ID SE ID

3.1 Stakeholders

SE ID Six critical stakeholder groups have been identified, including innovators, adopters, controllers, funders, advisors, and influencers, all of whom play essential roles in advancing technology innovation in both the two thematic areas of smart energy and industrial decarbonization.

Each stakeholder group contributes in different ways to the innovation process and is comprised of different sub-groups. For example, innovators such as think tanks, academia, research organizations, startups, and tech companies are pivotal in developing new technologies, performing data analysis, and providing technical expertise. Adopters, including end users, SMEs, large users, service companies, and the private sector, are responsible for bringing innovations to market, investing in technology development, and scaling up solutions. Controllers, such as government bodies, regulatory bodies, and certification bodies, set policies and regulatory frameworks, provide initial funding, and facilitate demonstration projects. Funders, including banks, donors, financial bodies, and investment funds, provide capital for R&D and technology deployment and mitigate risks. Advisors, such as NGOs, energy associations, industrial associations, and consultants, engage communities, provide on-the-ground support, and share best practices. Influencers, including media, social media influencers, and associations, raise awareness, facilitate collaboration, and drive engagement through their platforms.

In both thematic areas the relationship between innovators and adopters is marked by a collaborative approach Notably, there is significant collaboration between controllers (government), adopters (private sector), and advisors (NGOs) to implement and scale up clean energy end solutions through public-private partnerships (PPPs).

TABLE 3: Stakeholder groups

Stakeholder Groups	Innovators	Adopters	Controllers	Funders	Advisors	Influencers
Role	Develop new technologies, perform data analysis and provide technical expertise	Bring innovations to market, invest in technology development and scale up solutions	Set policies and regulatory frameworks, provide initial funding and facilitate demo projects	Provide capital for R&D and technologies deployment, and mitigate risks	Engage communities, provide on-the-ground support and share best practices	Raise awareness, facilitate collaboration and driving engagement through their platforms
TRL 3-4						
TRL 5-6						
TRL 7-8						

High Limited Low

In general, the relevance of each stakeholder group varies along the technology innovation development process. At Technology Readiness Levels (TRL) 3-4, innovators and advisors are highly engaged in developing and refining the technology, while funders provide the required initial financial support. At TRL 5-6, adopters and controllers become more involved, with increased funding and engagement in implementation . By TRL 7, all stakeholders are significantly engaged: adopters integrate the technology into operations, controllers ensure compliance, and funders provide substantial investments for large-scale demonstrations.

While the main beneficiaries tend to be adopters and controllers in both smart energy and industrial decarbonization, the benefits vary across the two thematic areas, hence serving different sub-categories of beneficiaries.

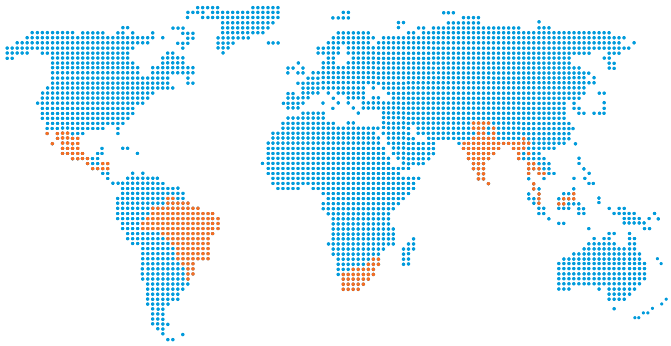
SE **Smart energy** solutions play a particularly critical role for local communities and end users living in regions with poor energy access. Women, especially in rural areas, tend to be most affected by energy scarcity; access to smart energy solutions can reduce their workload and empower them economically.

ID **Industrial decarbonization** is particularly relevant for large companies in emission-intensive sectors. New technologies can lead to significant emissions reductions, thus help meeting regulatory and corporate sustainability goals. Additionally, advanced technologies can improve operational efficiency, leading to cost savings and increased productivity. Beyond that, they also help governments meeting their climate targets.

3.2 Markets

Official Development Assistance (ODA) recipient countries vary significantly across a wide range of dimensions, including income levels, economic performance, political stability, contribution towards Sustainable Development Goals (SDGs), emission reduction ambitions, access to clean energy, and the maturity of policy frameworks. Performance across these dimensions determines the extent to which these countries provide enabling environments for technology innovation.

TABLE 4: High potential markets



High potential markets: Mexico, Brazil, South Africa, India, Thailand

SE ID Both market assessments show a rich policy landscape existing across developing countries related to emission reductions, energy efficiency, and sustainability. High-potential markets include India, Brazil, Thailand, South Africa, and Mexico, as they provide strong enabling environments and policy frameworks which advance the continued reduction in the costs of renewable energy technologies, making them more accessible. There is a commitment to align technological advancements with global sustainability and climate objectives, yet few policies address innovative technology solutions specifically which highlights the need for more targeted policies that support the development and deployment of cutting-edge technologies in both SE and ID. Overall, interventions in these countries, which have set ambitious targets and established strong policy frameworks, are likely to have the most transformational impacts.

Generally, the potential for transformational impact is highest when economic, social, and environmental aspects converge.

SE ID **Both market assessments** show a rich policy landscape existing across developing countries related to emission reductions, energy efficiency, and sustainability. High-potential markets include India, Brazil, Thailand, South Africa, and Mexico, as they provide strong enabling environments and policy frameworks which advance the continued reduction in the costs of renewable energy technologies, making them more accessible. There is a commitment to align technological advancements with global sustainability and climate objectives, yet few policies address innovative technology solutions specifically which highlights the need for more targeted policies that support the development and deployment of cutting-edge technologies in both SE and ID. Overall, interventions in these countries, which have set ambitious targets and established strong policy frameworks, are likely to have the most transformational impacts.

Generally, the potential for transformational impact is highest when economic, social, and environmental aspects converge. African countries such as Rwanda, Gambia, Kenya, and South Africa stand out due to high rural population rates and relatively mature policy frameworks. These countries present unique opportunities for impactful interventions due to their demographic and policy characteristics. In Asia, populous countries like India and China depend heavily on hard-to-abate industries, presenting significant opportunities for impactful interventions. Most countries in the Americas are economically better-developed (Upper Middle-Income Country category), yet their policies largely focus on technologies that do not support innovation. Therefore, strategic interventions in these regions should aim to bridge the gap between existing policy frameworks and the need for innovative technology solutions to maximize the transformational impact.

SE ID Critical market constraints hindering the adoption of innovative technologies in both smart energy and industrial decarbonization fall into four main categories: 1) political and legal, 2) economic, 3) technological and environmental, and 4) social. While technology innovation in both thematic areas is essentially affected by the same types of market constraints, the relevance of these constraints may differ across countries, industries,and technologies.

3.3 Projects and initiatives

The market assessments for both thematic areas, revealed a comprehensive landscape of initiatives and projects that align with both national and international sustainability goals. Developed countries such as the EU member states, Canada, and the UAE, along with global industry bodies like the Global Cement and Concrete Association, are leading the way through large-scale regional and global initiatives. However, the success of these externally sponsored initiatives in developing countries hinges on the presence of supportive policies and incentives.

SE ID The project database established through the assessments highlights a broad spectrum of projects across various technologies, including smart grids, Carbon Capture, Utilization, and Storage (CCUS), and alternative fuels production. This diversity demonstrates extensive opportunities for investment in innovative projects across the DAC list of ODA recipients. Many of these projects are pioneering in their respective fields, employing cutting-edge technologies such as the development of aqueous carbon capture technologies, which could serve as benchmarks for future initiatives globally. Strong collaborations between public, private, and international stakeholders, including ministries, Multilateral Development Banks (MDBs), and IGOS such as the United Nations Environment Programme (UNEP), are evident. Additionally, the presence of multiple financial mechanisms, including crowdsourcing and various combinations, reflects an open landscape for new and innovative forms of financial support.

SE In the realm of smart energy, utilities emerge as pivotal players, acting as key adopters and implementers of technologies such as smart grids and virtual power plants. The highly innovative nature of these technologies has introduced significant technological, political, and legal constraints, primarily driven by privacy and security concerns. Despite these challenges, the majority of smart energy projects are buoyed by government grants, as governments aim to foster projects that will catalyze further interest and investment from various stakeholders. Among the smart grid technologies, market-enabling mechanisms like Virtual Power Plants (VPPs) are witnessing the most activity due to their cost-effectiveness and supportive characteristics for renewable and distributed technologies. Furthermore, there is substantial momentum towards upgrading to smart grids, motivated by the growing need for flexibility and the integration of renewable energy sources into the grid.

TABLE 5: The projects database currently comprises 24 smart energy projects across all 28 focus countries SE

Primary Stakeholder	Primary market constraints	Funding mechanism	Technology category
IGOs 4%	Social constraints 0%	Multiple 4%	Digital Technologies 8%
Foreign government 4%	Economic constraints 17%	Subsidies 4%	Automation technologies 8%
Research institutions 8%	Political and legal constraints 29%	Crowdfunding 4%	Smart grid enablers - Infratech 13%
Government owned enterprise 8%	Technological and environmental constraints 54%	Incentives 8%	Smart grid networks 25%
Government 13%		Loans 13%	Smart grid enablers-market mechanisms 46%
Private organization 29%		Equity 25%	
Energy utility 34%		Grants 42%	

Turning to industrial decarbonization, both governments and government-owned institutions are deeply involved, aligning with national ambitions. Private players, driven by the necessity for decarbonization in their respective industries and increasing regulatory scrutiny such as carbon pricing, lead most ongoing projects. However, these projects face substantial economic and technological constraints due to the disruptive and cost-intensive nature of the technologies involved, especially Carbon Capture, Utilization, and Storage (CCUS). Consequently, these projects are principally supported by government or multilateral grants that help bridge the financial gaps associated with these advanced technologies. Within this domain, significant adoption is observed across two primary technology categories: industry-agnostic technologies like CCUS and alternative fuels, as well as industry-specific technologies focused on switching to cleaner fuels or alternative processes.

TABLE 6: The projects database currently comprises 32 industrial decarbonization projects across 28 focus countries ID

Primary Stakeholder	Primary market constraints	Funding mechanism	Technology category
Energy utility 3%	Social constraints 3%	Multiple 3%	Fuel cell technology 3%
Government 9%	Political and legal constraints 19%	Public-Private Partnership 3%	Chemical substitution 6%
Research institution/ university 13%	Economic constraints 28%	Subsidies 6%	Heating and cooling 9%
Government owned enterprise 22%	Technological and environmental constraints 50%	Incentives 16%	Alternative fuel production 13%
Private organization 50%		Equity 28%	Process substitution 25%
		Grants 44%	CCUS 44%

Moreover, lighthouse projects were identified that are recognized not only for their immediate impacts but also for their potential scalability and replicability. These projects demonstrate cutting-edge technology, best practices, or novel approaches in smart energy and industrial decarbonization, showcasing the potential and benefits of new and innovative solutions.

SE In the field of smart energy, projects like the Evolve Virtual Power Plant in South Africa and smart grid networks in India and Indonesia are particularly noteworthy. The Tata Power DDL AI Enabled Smart energy Management System in India exemplifies how Artificial Intelligence (AI) and machine learning can optimize energy distribution and consumption. This project's scalable model can be replicated across other regions, promoting energy efficiency on a broader scale.

Strong collaborative efforts across key stakeholders, including government bodies, private investors, and multilateral agencies, have been a critical success factor. For instance, the Mae Hong Son Smart Grid Pilot Project in Thailand serves as a knowledge hub for smart grid technologies in rural settings, enhancing local capacities and offering insights into sustainable energy management that can be shared globally.

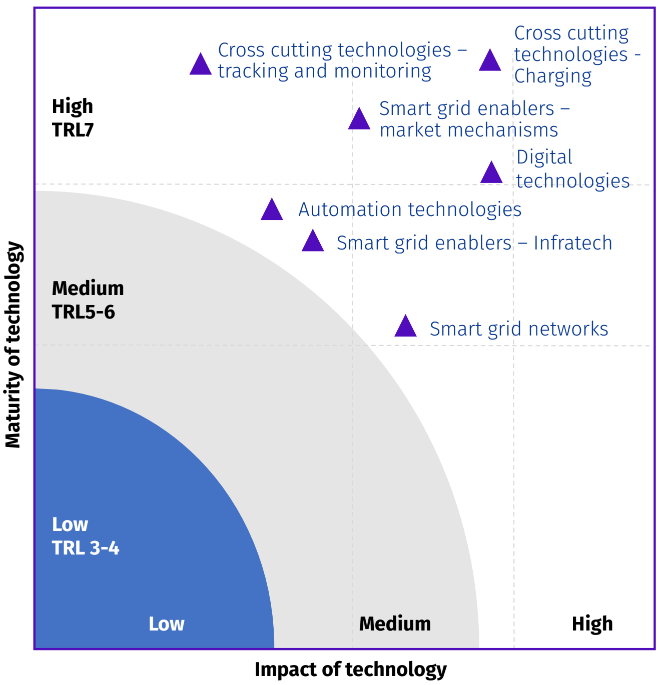
ID In the area of industrial decarbonization, notable projects include the Indian Oil Corporation Koyali Refinery Project and the NoNSToP Project located in Egypt. The Koyali Refinery Project in India focuses on capturing carbon dioxide emissions from hydrogen generation units, aiming to significantly reduce the refinery's carbon footprint and serve as a model for similar initiatives globally, illustrating the benefits of integrating carbon capture technologies in industrial processes. The Nonstop Project is dedicated to developing a cost-effective solar concentrating photovoltaic system, which aims to increase energy output and make solar energy more accessible and affordable. The project's innovative approach could significantly impact the adoption of renewable energy, especially in regions with high solar irradiance.

3.4 Technology landscape

Both market assessments reveal a dynamic landscape of technological innovations that are pivotal for advancing sustainability goals.

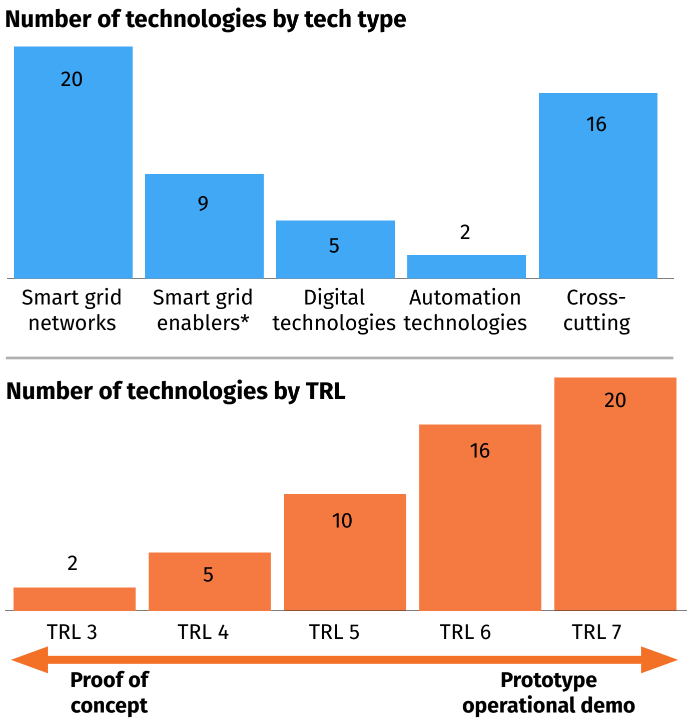
SE In the realm of **smart energy,** innovation is primarily focused on enhancing the robustness, efficiency, and flexibility of the electricity grid. This is crucial for the seamless integration of variable renewable energy sources and energy storage solutions. Key technologies in this area include smart grid enabling technologies and market mechanisms such as demand response and virtual power plants. The advent of digital technologies such as Artificial Intelligence, Machine Learning, Blockchain, and the Internet of Things is revolutionizing energy infrastructure, making it smarter and more connected. These technologies are increasingly integrated into energy systems and industries to enhance productivity and improve energy efficiency. Significant uptake is being witnessed in large middle-income countries such as India and Indonesia, which are transitioning to improved and connected electricity grids to cater to growing and variable demand. In contrast, least developed countries (LDCs) are primarily focused on more mature grid and storage technologies.

TABLE 7: SE technology maturity map



Approximately 50 relevant smart energy technologies within the Technology Readiness Level (TRL) range 3 to 7 were identified and assessed. Most of these technologies are currently in the post-conception phase, with nearly 50% at the prototype or pilot testing stages.

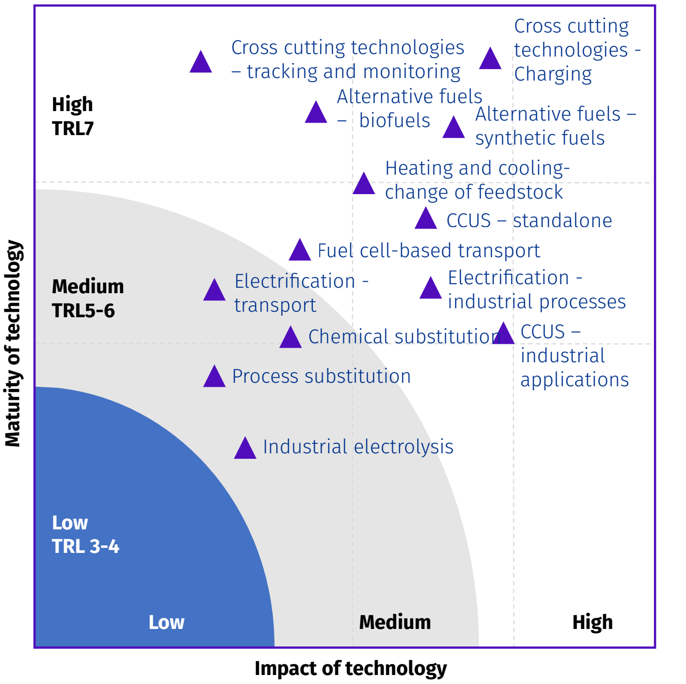
TABLE 8: Technology types and distribution among TRLs - SE



Technologies in the TRL range from 6 to 7 can offer benefits due to their advanced degree of maturity. Since they have demonstrated their feasibility and effectiveness in pilot projects, already existing results bolster confidence in their potential, thus limiting technical and financial risks. Such derisking may be of particular relevance in developing country contexts where various risks are likely to be higher than in more developed regions, thus exceeding the risk-appetite of investors and stakeholders and discouraging their engagement. Additionally, governments and regulatory bodies are typically more inclined to support the deployment of well-validated technologies, which can help create supportive policy frameworks and incentives such as subsidies and tax benefits. More mature technologies may also allow for quicker deployment compared to earlier-stage innovations, leading to faster realization of benefits.

ID In the field of **industrial decarbonization**, innovation is centered on replacing incumbent, emission-intensive technologies with low-carbon alternatives. Key target areas include the substitution of industrial fuels, materials, and processes with more efficient and cleaner technologies. In hard-to-abate sectors such as metals and mining, chemicals, and petrochemicals, there is significant traction in developing and prototyping various types of Carbon Capture, Utilization, and Storage technologies, with a focus on improving efficacy and making these technologies more viable. LDCs primarily rely on relatively mature and cost-efficient technologies. However, as income levels increase, countries tend to invest in more innovative and scalable decarbonization technologies such as CCUS, alternative fuel production, and the use of hydrogen in industrial processes.

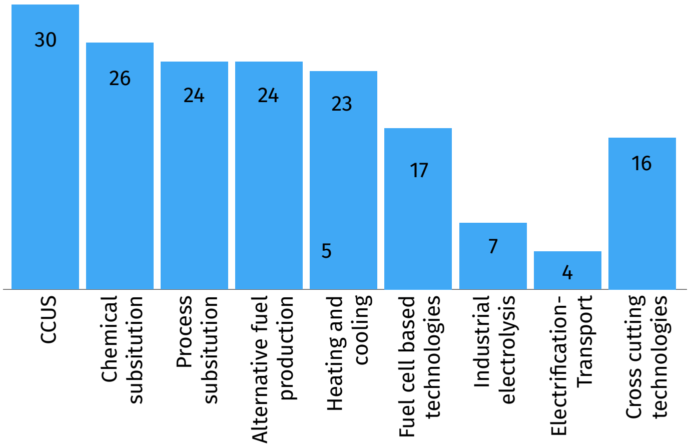
TABLE 9: ID technology maturity map



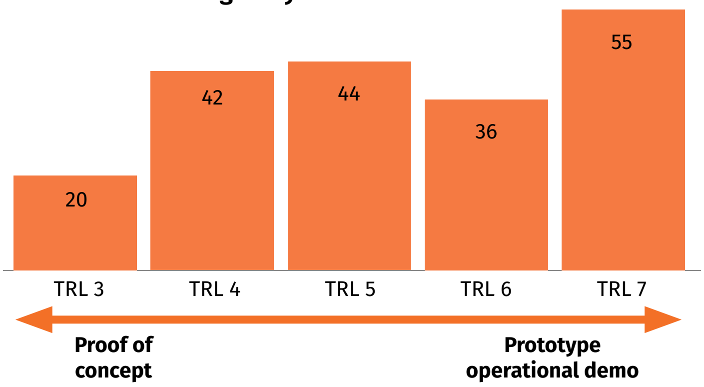
In the area of industrial decarbonization approximately 200 technologies across TRLs 3-7 were identified and assessed. Most of these technologies are in the post-conception phase, with nearly 50% at the prototype or pilot testing stages. The technologies can be broadly categorized into six major groups, with Carbon Capture, Utilization, and Storage (CCUS) being the most researched one globally.

TABLE 10: Technology types and distribution among TRLs - ID

Number of technologies by tech type



Number of technologies by TRL



SE ID Certain technologies create a cross-cutting impact by improving overall process and energy efficiency, as well as aiding in decarbonization. These include advanced charging technologies such as ultra-fast charging and inductive charging, monitoring technologies, and technologies related to battery recycling. These technologies have a significant digitalization component and contribute to the decarbonization of specific industries by enhancing material and energy efficiency. The integration of these cross-cutting technologies is essential for achieving broader sustainability goals and ensuring that both smart energy and industrial decarbonization efforts are effective and scalable.

3.5 Impacts and SDGs

The promotion of the Sustainable Development Goals (SDGs) occurs on at least two levels: country level and technology level. Accordingly, the underlying theories of change will differ. The degree to which each country provides an enabling environment for clean energy and decarbonization technology innovation and technology adoption, in turn, impacts the promotion of the SDGs[1]. at the country level, creating a dynamic interplay between national policies and technological advancements. The 28 focus countries currently drive innovation in SE and ID with a comparable set of major initiatives, with some regional initiatives spanning across several countries.

Table 11: Snapshot of national initiatives in the Americas

Country	Number of initiatives
Brazil	**7**
Mexico	**2**
Costa Rica	**1**
Panama	**1**
Dominican Republic	**1**
Ecuador	**1**

Technology focus

Smart Energy	Industrial Decarbonization
Smart grids	Sustainable fuels
Energy storage systems	Circular economy
Integrating renewable energy (RE) sources	

SE In the Americas, a notable smart energy initiative is "REnovables in Latin America and the Caribbean" (RELAC). This initiative includes 16 member countries and is driven by stakeholders such as the National Renewable Energy Laboratory (NREL), the Global Climate Action Partnership (GCAP), and the Inter-American Development Bank (IDB). RELAC focuses on developing country-specific energy storage action plans, providing capacity building, strategic planning support, and technical assistance. Additionally, it aims to create a stakeholder network for knowledge exchange and regional dissemination of content. The project is funded by IDB and NREL, showcasing the central role of international collaboration in advancing energy storage solutions.

Table 12: Snapshot of national initiatives in Africa and Europe

Country	Number of initiatives
Moldova	**4**
Serbia	**1**
South Africa	**6**
Ghana	**6**
Nigeria	**6**
Kenya	**4**
Rwanda	**3**
Mauritius	**1**
Egypt	**1**

Technology focus

Smart Energy	Industrial Decarbonization
Smart grids	Sustainable fuels
Energy storage systems	Circular economy
Energy efficiency	Energy efficiency

SE The assessment identified several key regional initiatives in the realm of smart energy across Africa. Notable actions including "Smart Energy Solutions for Africa" which is active in many of the selected deep dive countries such as Ghana, Kenya, Malawi, Morocco, Nigeria, Rwanda, South Africa, and Tanzania. Another significant initiative is the"Energizing Development," focusing on Kenya, Nigeria, Ghana, Rwanda, Malawi, Senegal, and Tanzania. These projects receive funding from a mix of public and private sources, supported by international development agencies.

ID In the area of **industrial decarbonization**, the assessment highlights the "Project Development Program" and the "African Circular Economy Alliance (ACEA)." ACEA operates across 13 African countries, promoting material efficiency and circular economy practices. The alliance backs policy development and advocacy, and the scaling of circular economy projects, with financial support from a multi-donor trust fund. The activities include policy development, stakeholder engagement, and support for innovative micro-, small-, and medium-sized enterprises (MSMEs), including financial support, market access, and network building.

[1] Specifically SDG 1 (No Poverty), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action)

Table 13: Snapshot of national initiatives in Asia and Oceania

Country	Number of initiatives
India	**9**
Cambodia	**6**
Indonesia	**4**
Papua New Guinea	**3**
Kazakhstan	**2**
Thailand	**2**
Jordan	**1**

Technology focus	
Smart Energy	**Industrial Decarbonization**
Smart grids	CCUS
Big data	Sustainable fuels
Energy storage systems	Circular economy
Energy efficiency	Energy efficiency

SE In Asia and Oceania there is a focus is on improving energy efficiency, smart grids, and battery energy storage systems (BESS). Efforts aim at enhancing the technical infrastructure and operational efficiency. For instance, the "Asia-Pacific Economic Cooperation (APEC) Smart Grid Initiative" promotes smart grid technologies across the region on order to address energy challenges such as security, resilience, efficiency, and sustainability.

SE Smart energy technologies hold substantial potential for promoting SDG 1 (No Poverty). Smart grids and decentralized energy systems exemplify how theories of change can be articulated to support technology innovation in smart energy within developing country contexts, addressing the most relevant SDGs. By enhancing energy access and reliability, these technologies can drive economic growth, improve living standards, and reduce poverty. The integration of digital technologies such as AI, ML, and the IoT into energy systems further amplifies these impacts by optimizing energy distribution and consumption, thereby fostering sustainable development.

ID **Industrial decarbonization** technologies are particularly impactful in promoting SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action). Innovations in this area focus on replacing emission-intensive technologies with low-carbon alternatives, thereby driving industrial efficiency and reducing greenhouse gas emissions. CCUS technologies provide a compelling example of how theories of change can be formulated to support technology innovation in industrial decarbonization within developing country contexts. By capturing and repurposing carbon emissions, these technologies contribute to climate action while fostering industrial innovation and infrastructure development. As countries progress economically, the adoption of advanced decarbonization technologies such as CCUS, alternative fuel production, and hydrogen utilization in industrial processes becomes increasingly viable, further promoting sustainable industrial growth.

4. Conclusion and way forward

The heterogeneity across the identified critical stakeholder groups, their different roles, and varying degree of engagement along the technology innovation development process shows that there is a multifaceted and complex ecosystem which drives and shapes technology innovation in both thematic areas. Understanding the landscape of key player and facilitating the interactions between the relevant stakeholders is key to advancing and accelerating clean technologies, especially those requiring a mix of specialized expertise and significant financial investments.
This includes:

- Facilitating knowledge transfer for local stakeholders, including government officials, industry leaders, and community members, could support the establishment of critical expertise for implementing and maintaining new technologies, thereby enhancing the sustainability and scalability of projects.
- Collaborating with private sector companies, industry associations, and NGOs can further enhance the scalability, replicability, and overall deployment of innovative solutions.
- Public-private partnerships can provide access to additional resources, expertise, and funding. For example, technology companies can offer specialized training on their products, while industry associations can help identify skill gaps and training needs.

Furthermore, ensuring that interventions are inclusive and equitable is critical, particularly in rural areas where women and minorities are disproportionately affected by energy scarcity. Empowering women through access to smart energy solutions can lead to significant socio-economic benefits. Ensuring access to energy and training in the maintenance and operation of these systems can empower women economically and socially and enable them to become active participants in the energy transition.

While all developing countries can benefit greatly from advances in clean technology solutions, some countries stand out in the potential they have given their economic development, population size and maturity of relevant policy frameworks. Amongst those countries are India, Brazil, Mexico, South Africa and Thailand.

The assessment revealed that a wide range of technologies across the TRL range 3 to 7 exist to date, with some notable lighthouse projects providing guidance on how innovative technology solutions in SE and ID can be successfully scaled and be applied as a new solution in different contexts. While technologies at the earlier development stage may prove to be crucial for future efforts to combat climate change, technologies with a higher development grade have already demonstrated their feasibility and effectiveness. This implies a significant reduction of the technical and financial risks associated with their implementation, making them more attractive to investors and stakeholders with a lower risk-appetite. Governments and regulatory bodies, for example, tend to be more likely to support the deployment of technologies that have been validated in real-world conditions. The higher maturity of technologies allows for quicker deployment compared to earlier-stage technologies, leading to more immediate impacts on energy efficiency, emissions reduction, and economic development, thus making the contribution towards combating climate change and achieving the SDGs more easily tangible.

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