In collaboration with
Boston Consulting Group

Greening the Renewable Value Chain: China Experience

BRIEFING PAPER

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Contents

Time for a Sustainable Renewables Value Chain

Renewables are considered as both the main driver and catalyst for the global green transition given its role in the energy mix. At COP28, participants achieved an unprecedented breakthrough with a bold action plan in renewables under the terms of which more 130 governments committed to triple their renewable capacity from 2.6 terawatts to 11 terawatts by 2030[1]. Total announced public- and private-sector investments to finance renewables projects now exceed $6 billion. By 2050, according to an International Energy Agency (IEA) forecast based on the net-zero scenario, approximately 80%[2] of capacity additions in the energy sector will run on renewable energy.

China is an important player in the renewable value chain, not only in the upstream equipment manufacturing but also the downstream project operations. Around 80%[3] of solar panel modules, 65%[4] of wind turbines and 80%[5] of lithium batteries are manufactured in China. And according to the IEA, China accounts for almost 60% of new renewable capacity expected to become operational globally by 2028[6].

As capacity for renewable energy generation rapidly expands in the next decades, however, renewable itself may still have a significant incremental carbon impact. In 2050, if the lifecycle carbon intensities of each power source remain at today's levels, about 90% of electricity generation will come from renewables, and renewables' share of carbon emissions in the energy sector will reach about 60%, versus 2% in 2020[7]. (See Figure 1.)

It is therefore crucial for future renewables to come from a greener manufacturing, development and operation process than the existing renewables value chain affords – besides maximizing the proportion of renewable energy in the overall energy mix. To minimize the life-cycle environmental impact of the value chain, low-carbon renewable equipment is needed from material suppliers and manufacturers. Project owners, investors and operators need to apply green products and optimize their operations, and end users and recyclers provide support for end-of-life treatment.

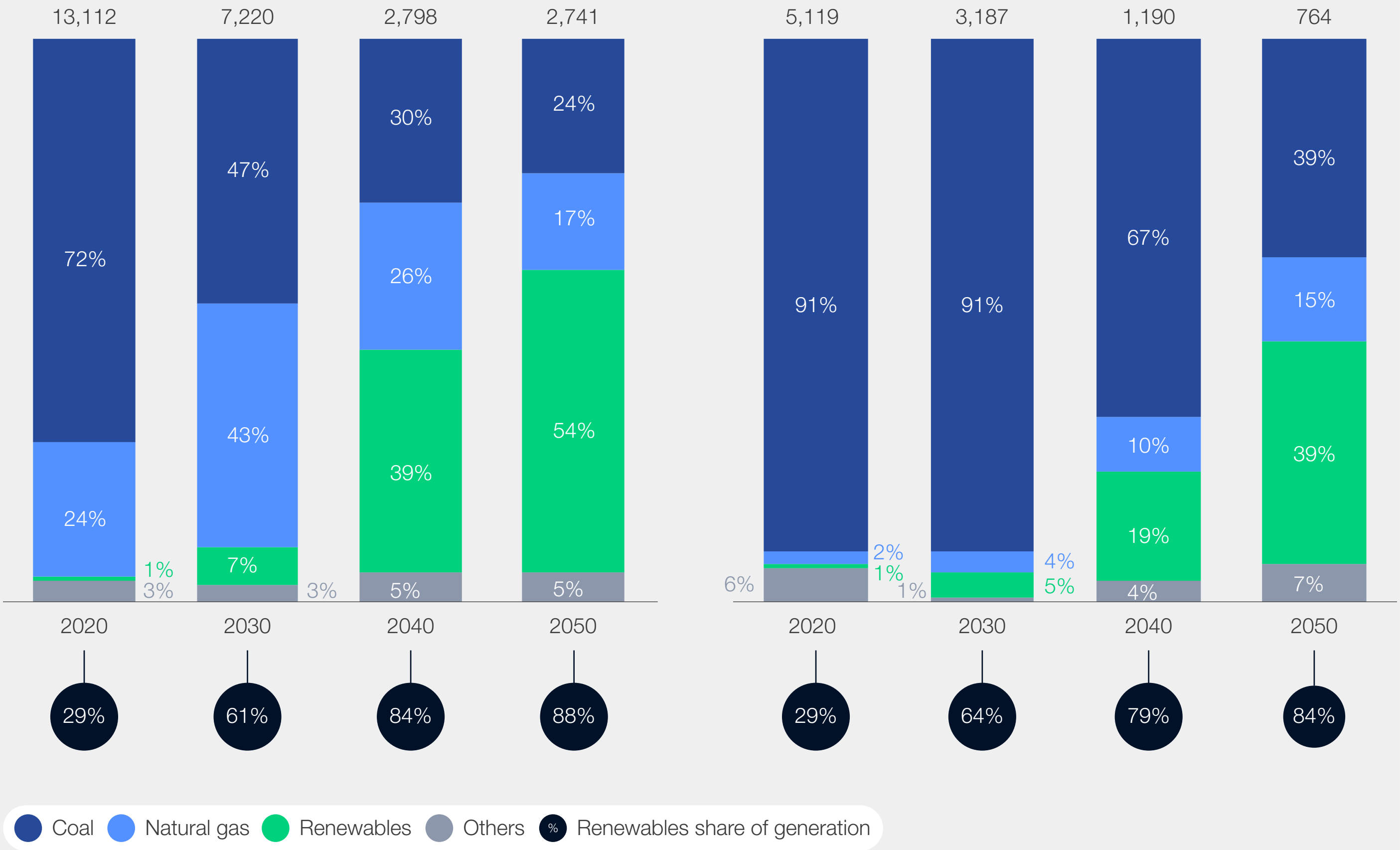
The green transition of China's renewable value chain will provide green products, showcase examples and make a significant impact globally. Some Chinese renewable corporates have already taken action. LONGi, the world-leading solar technology company, and Envision, one of the largest wind turbine companies, have announced their Science Based Targets aligned with the 1.5°C goal[8] and have taken tangible actions to launch supply chain engagement strategies. Constant commitment and adoption along the value chain are needed to accelerate progress.

FIGURE 1: **Renewables’ Share of Carbon Emissions in the Power Sector by 2050**

Renewable sources will be responsible for about 90% of electricity generation and 60% of associated emissions globally by 2050

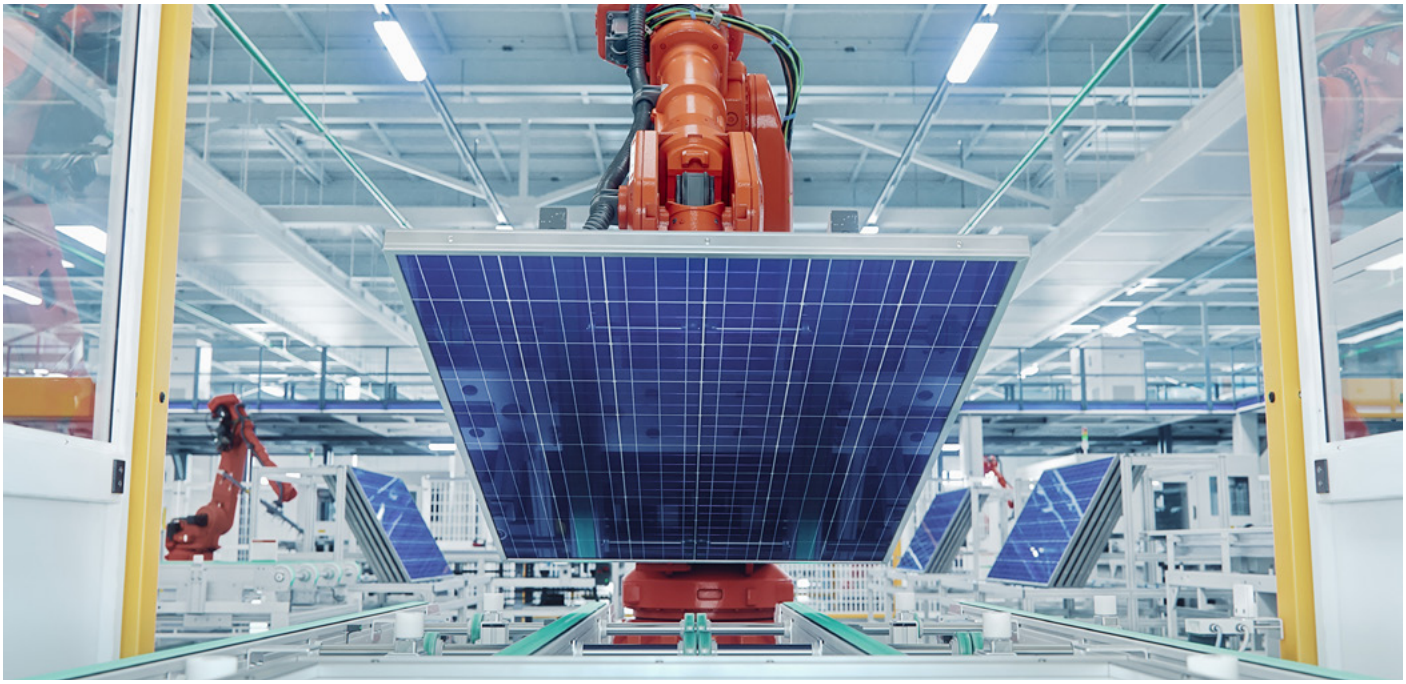
Global carbon emissions from electricity generation by source[1] (megatons of CO_2)

China carbon emissions from electricity generation by source[1] (megatons of CO_2)



1. Life-cycle emissions figures are based on a net zero by 2050 scenario; calculations assume that the emissions factors stay the same for each power source. “Renewables” include wind, solar, hydro. “Others” include, for example, nuclear, hydrogen-based fuels.

Source: IEA, BloombergNEF, BCG analysis



Shape Renewables Value Chain for the Future: Characteristics and Key Levers

Future renewables should possess four key characteristics to fully capture their potential green impact (see Figure 2):

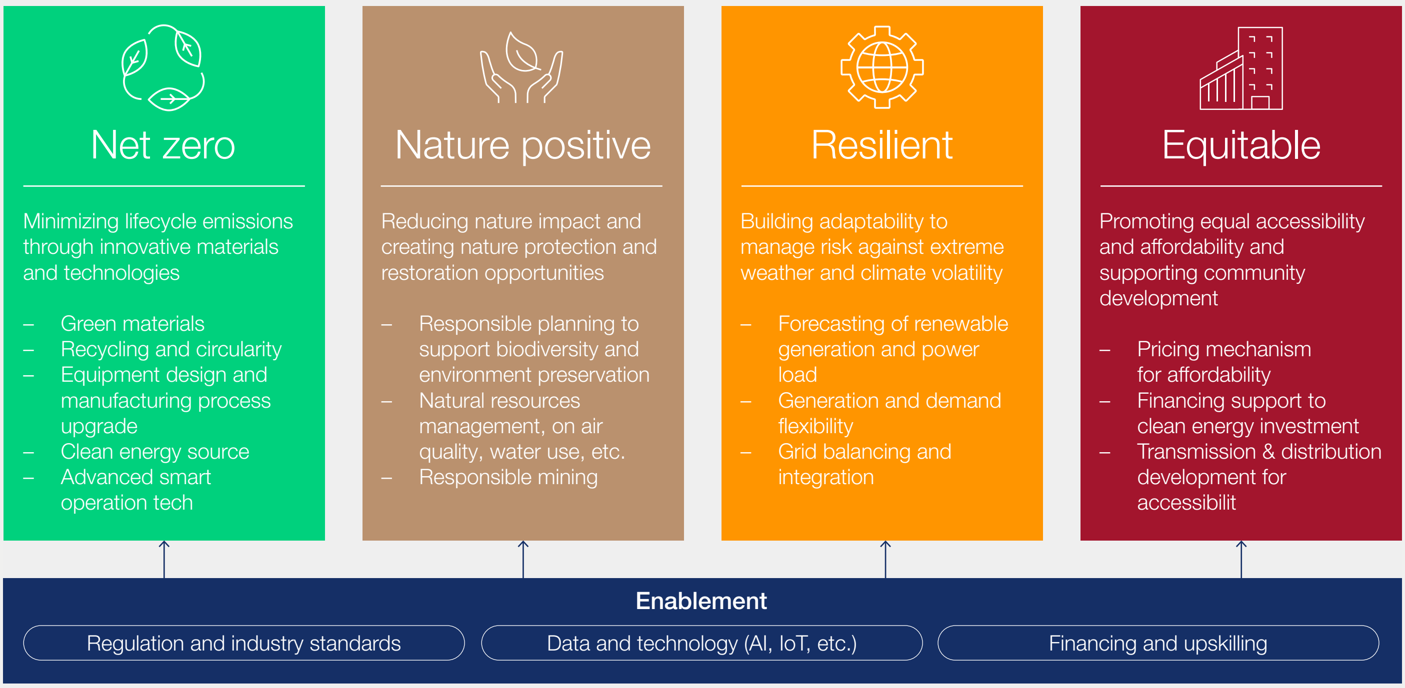
- **Net zero.** Minimize carbon emissions throughout the value chain by adopting innovative materials and technologies such as net-zero targets, green materials, process upgrades and digitization, clean energy sources and advanced smart operation technology

- **Nature-positive.** Reduce adverse impacts on nature, protect biodiversity and pursue restoration opportunities, such as improved water quality, through enlightened project planning, natural resources management and responsible mining

- **Resilient.** Ensure projects' capacity to manage risk against extreme weather and climate volatility by applying advanced forecasting of power generation and load, enhancing power system flexibility and integration

- **Equitable.** Design for future renewables should promote equal access to and affordability of clean energy for everyone concerned and ensure community involvement and readiness for work opportunities. The white paper, Building Trust through an Equitable and Inclusive Energy Transition[9], by the Centre for Energy and Materials of the World Economic Forum has introduced a thorough framework and actionable measures for promoting equity, justice and inclusivity of renewables.

FIGURE 2: **Characteristics to Pursue for the Sustainability of the Renewables Value Chain**



Source: BCG

Three key enablers are necessary to implement green approaches and achieve substantial sustainable impact:

Regulation and industry standards. Activities that come under this heading fall into the following categories – standards, certification and policies for sustainability of renewables products; and regulations governing power market design to ensure the integration, flexibility and accessibility of renewables.

Data and technology. Digitalization such as artificial intelligence (AI) can be widely used in manufacturing and project operation optimization. High-quality data tracking, analysis and exchange are essential to support it. Advanced material technology such as carbon fibre and new electrode materials are heavily needed to reduce embodied emissions.

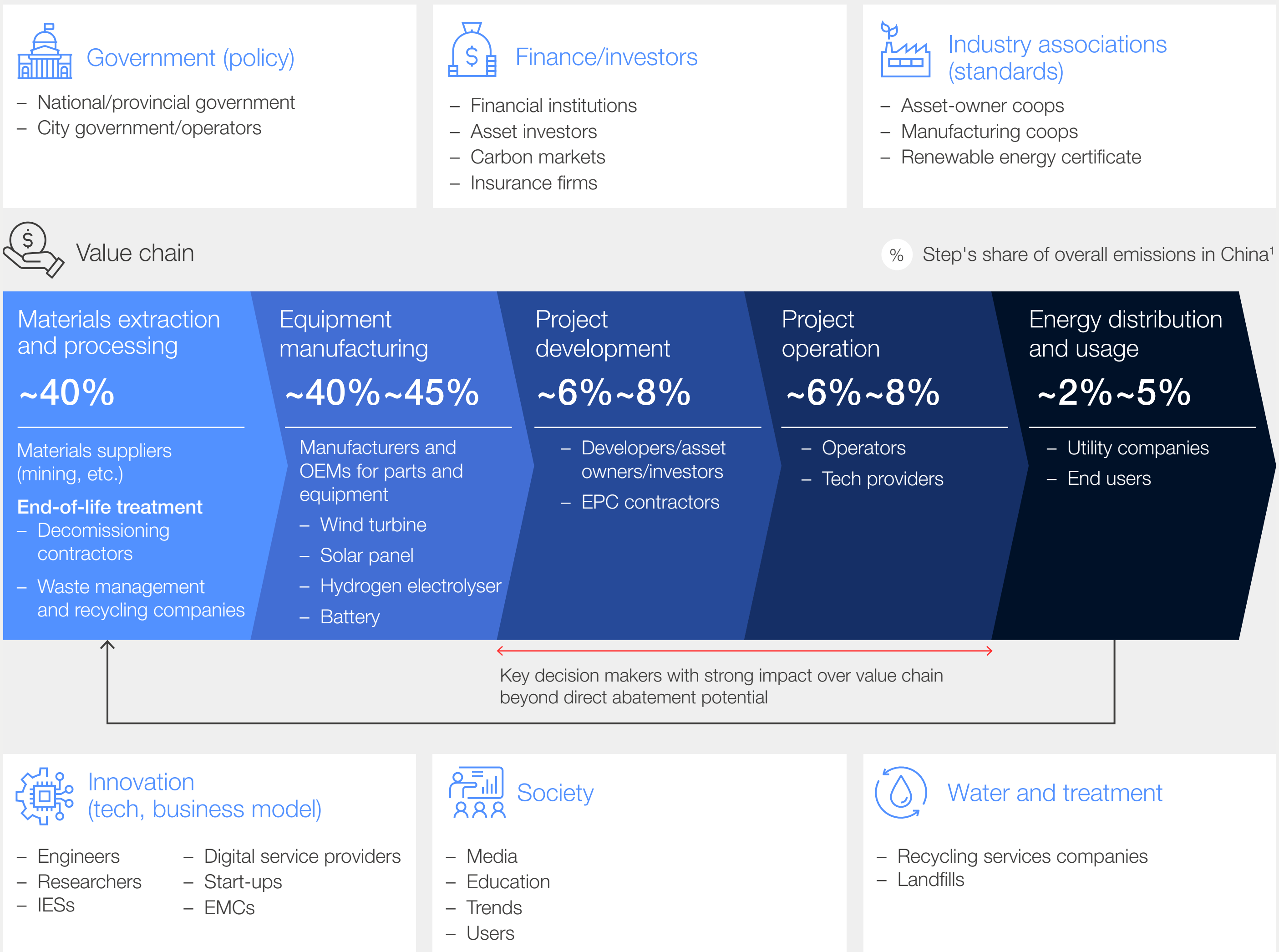
Financing and upskilling. Support the implementation by investment in technology R&D, scaling up, and infrastructure development and capacity building of professionals in the value chain.

Mobilizing value chain players on key levers

There are five main stages in the renewable value chain: material extraction and processing; equipment manufacturing; project development; product operation; and energy distribution and usage. About 80% of the value chain's carbon footprint comes from the first two stages.

The renewable value chain involves various players at each stage – materials suppliers, equipment manufacturers and OEMs, project developers/owners, EPC contractors, operators, technology providers, end users and recyclers. (See Figure 3.) Further, multiple enablers, including policy-makers, financial institutions, carbon markets and start-ups, must provide support.

FIGURE 3: **Renewables Value Chain and Players**



Note: EMC = energy management contract; EPC = engineering, procurement, and construction; IES = integrated energy service.

1. Adopted values from solar PV industry as an example to demonstrate step's % share of overall emission, based on China Electricity Industry standard on "Life Cycle Carbon Emissions quantification and assessment criteria for Photovoltaic Power Systems"

Source: China Electricity Council; BCG

To achieve the future renewables, a series of levers have been identified along the value chain (See Figure 4). Among them, seven levers need to be prioritized based on their abatement potential, nature positivity, resilience, equitable impact and technological and economic feasibility. (See Figure 5.)

FIGURE 4: **Levers for a Sustainable Renewables Value Chain**

Value chain step	Pillar	Decarbonization levers	Developers and owners	Operators	Engineers	Suppliers	Manufacturers and OEMs	Utilities	Contractors (EPC/service)
			Major value chain players						
Materials extraction and processing	Net zero	Materials and equipment recycling (batteries, wind turbines, photovoltaics, etc.)	✓	✓		✓	✓		✓
	Net zero	Equipment electrification and digitalization			✓	✓			
	Nature positive	Rehabilitation of mining sites				✓			
Equipment manufacturing	Net zero	Renewable product design optimization (e.g., lightweight design, design for recycle)	✓		✓	✓	✓		✓
	Net zero	Equipment manufacturing process optimization (digital, clean energy use, etc.)			✓	✓	✓		
Project development	Cross pillar	Eco-friendly project planning (optimization of location, scale, materials, etc.)	✓		✓	✓	✓	✓	
	Cross pillar	Existing powerplant upgrade (coal to biomass, photovoltaic retrofits, etc.)	✓	✓	✓			✓	✓
	Net zero	Construction/installation optimization (digital, clean energy use, etc.)	✓		✓			✓	✓
Project operation	Cross pillar	Smart operation management of renewable energy plants		✓			✓	✓	✓
	Cross pillar	Increased energy storage utilization rate and asset optimization	✓	✓	✓		✓	✓	✓
Energy distribution and use	Cross pillar	Expanded UHV power grid coverage					✓	✓	✓
	Cross pillar	Promotion of micro-grid/virtual power plants	✓	✓				✓	✓
	Cross pillar	Promotion of demand response	✓	✓				✓	✓
	Equitable	Promotion of low-income community solutions (community solar programs, etc.)	✓	✓				✓	✓

Cross pillar · Net zero · Nature positive · Resillient · Equitable

Note: EPC = engineering, procurement, and construction; UHV = ultra-high voltage.
Source: BCG

Upgrading existing power plants. The goal of upgrading existing power plants is to enable them to fully utilize existing infrastructure, minimize the need for new construction and reduce the environmental impact per unit of energy produced. This effort involves measures such as shifting existing fossil fuels plants to biomass co-generation, as well as retrofitting existing renewable energy farms with higher-efficiency solar panels or wind blades.

Material and equipment recycling. Recycling materials and equipment such as batteries, turbine blades and solar panels will facilitate the recovery of materials including steel, lithium, cobalt and nickel that must otherwise be obtained through hard-to-abate processes. Effective recycling processes can reduce carbon emissions by more than half in comparison to raw material extraction and processing.

Increased energy storage utilization rate and asset optimization. By improving the utilization rate of energy storage systems through the use of digital technology and by optimizing the energy storage capacity ratio for renewable projects, renewable energy can be more effectively integrated into the power grid to reduce curtailment and improve balancing.

Smart operations management of renewable plants. Use of advanced technologies such as the internet of things, AI and data analytics can equip renewable plants with real-time monitoring and smart control systems.

Equipment manufacturing process optimization. Such optimization efforts may involve deploying efficient equipment and digital tools to streamline manufacturing processes and maximize use of clean energy.

Renewable product design optimization. Approaches include lightweight design and design for recycling to reducing embodied emissions in the renewable energy value chain. For example, solar panel company Trina Solar reduces the thickness of silicon wafers to achieve 20% carbon intensity abatement. Envision promotes reducing embodied carbon of wind turbines in design by leveraging lightweight material, intelligent tools, etc.

Eco-friendly project planning. Careful consideration of factors such as project location, scale and materials choices can help ensure efficient energy production relative to demand, minimizing transmission losses and avoiding overproduction and unnecessary emissions. It can also support corporates realizing impact related to the broader Sustainable Development Goals. LONGi, for example, leverages co-location of solar and agriculture to promote economic growth of rural citizens while ensuring clean energy use. Elion, a Chinese environmental protection group, integrates solar power planning and desertification combat in its business model.

BOX 1: **Examples of key levers in the value chain**

Longyuan Power: Eco-Friendly Project Planning

- Avoid the ecological red line and environmentally sensitive areas during project site selection
- Assess and minimize wind power projects' impact on bird migration routes; and protect bird species by adjusting start-up speeds during the summer, nest building, etc.

Jinko Solar: Material and Equipment Recycling

- 12 MW pilot PV recycling line since 2019
- Developed a combination of physical and chemical recycling process, reaching a 92% recycling rate of the total recycling process and 95% for precious metal such as silver and copper
- Temperature control system allows heat recirculation and reduces energy consumption of the recycling process

TCL Zhonghuan: Equipment Manufacturing Process Optimization

- Industry 4.0 intelligent factory with AI learning model to enhance flexibility and efficiency of solar panel manufacturing process, resulting in 23% reduction in production energy intensity
- Waste minimization, resource recycling reach 100% zero-waste factories by 2025
- Maximize clean energy use to reduce embodied carbon of solar panels

Source: Corporate reports; BCG

FIGURE 5: **Key Levers, Players and Enabling Actions for Achieving the Sustainability of the Renewables Value Chain**

Sustainable Renewables Value Chain

Key levers and players

Key levers	Pillar	Developers and owners	Operators	Engineers	Suppliers	Manufacturers and OEMs	Utilities	Contractors (EPC/service)
Upgrading existing power plants	Net zero	✓	✓	✓			✓	✓
Materials and equipment recycling	Net zero	✓	✓		✓	✓		✓
Increased energy storage utilization rate and asset optimization	Cross pillar	✓	✓	✓		✓	✓	✓
Smart operation management of renewable plants	Cross pillar		✓			✓	✓	✓
Equipment manufacturing process optimization	Net zero			✓	✓	✓		
Renewable product design optimization	Net zero	✓		✓	✓	✓		✓
Eco-friendly project planning	Cross pillar	✓		✓	✓	✓	✓	

Enabling actions

A1 Cultivate **guidelines and standards** of sustainable practices of renewables

A2 Showcase **flagship business models** and support policy-making

A3 Engage value chain stakeholders and innovators to **push for technology breakthroughs**

A4 Build a demand-side community to support **green product procurement**

● Cross pillar ● Net zero ● Nature positive ● Resillient ● Equitable

Note: EPC = engineering, procurement, and construction; UHV = ultra-high voltage.
Source: BCG

Collectively, these seven prioritized levers have the potential to achieve about 70% abatement over the entire renewable value chain and generate a global market worth $2 trillion by 2030 (see Figure 6), unlocking numerous green opportunities for stakeholders. These opportunities include new market growth, differentiated value propositions, advanced service and technology and increased operational efficiency increase.

FIGURE 6: **The Abatement Potential and Global Market Opportunity of Seven Levers**

Note: Design optimization and eco-friendly project planning can trigger large abatement over the value chain, although has limited direct carbon impact.
Source: BCG

Four Enabling Actions to Mobilize the Renewable Value Chain

To accelerate the green transition, players along the renewables value chain need to be mobilized through four major actions to push past some major barriers to success.

Key barriers to overcome

To attain sustainable development of the renewables value chain, several significant barriers need to be overcome:

- **Lack of standards to guide development of the sustainability of renewables.** Although pilot projects involving sustainable renewables are present in some regions, there are no widely accepted measurement guidelines for sustainable practices of renewable energy products and no well recognized standards for recycling tech and security of batteries, wind turbines and solar panels. This lack of standards hampers alignment and scaling of green solutions.

- **Unclear business model and weak incentives.** Current business models for demand response, renewable recycling and other activities are not yet mature in some regions. Stakeholders have to proceed without clear guidelines on profit sharing, risk allocation, data transparency and the like, which weakens their incentive to collaborate. Also, there are no mandated requirements to push them towards more ambitious efforts.

- **Technology and cost limitations on scaling up.** Although various technologies exist for green steel, cement and other materials, some of them – especially those for high-quality output – are immature and expensive.

- **Lack of committed demand for low-carbon renewable energy equipment.** Demand from stakeholders such as investors, operators and end users for net-zero solar and wind products is not strong, which leaves supply-side companies with less incentive to invest and produce.

Four enabling actions

To overcome these barriers and support a green transition in the renewable energy value chain, four key enabling actions need to be taken by stakeholders. (See Figure 7.)

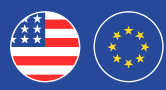
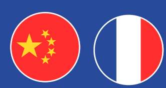
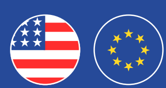
Cultivate guidelines and standards of sustainable practices of renewables. Comprehensive standards for sustainable practices of renewable products, security and technology from manufacturing to deployment need to be established. Guidelines should include detailed coverage of materials, carbon accounting, recycling, etc. to build the groundwork and pin the direction for the market. Although effort has been made to establish guidelines and regulations on this front, there is a pressing need for more consistently aligned approaches in regions and jurisdictions. Industry associations, thought leadership and large corporates can collaborate to build consensus on such topics as promoting data transparency and ensuring traceability of renewable production and recycling.

Showcase flagship business models and support policy-making. Collaboration among leading players and value chain partners is essential to develop flagship projects for sustainable renewables value chain practices. Such projects give players an opportunity to demonstrate the economic viability, technical feasibility and environmental benefits of sustainable renewables projects, thereby inspiring other players in the value chain to adopt similar approaches and accelerating the transition to a sustainable energy future. To successfully implement these projects, suitably calibrated policy supports, such as incentives and mandates, also need to be developed.

Engage value chain stakeholders and innovators to push for technology breakthroughs. Value chain players and innovator companies should consider new types of partnerships to develop pathways to create and scale the new technology needed for the transition. This could range from a focus on R&D to providing investment and capacity-building support. Traditional value chain stakeholders can also leverage digitization innovations such as AI and incorporate them into manufacturing, operations, management and other processes to enhance efficiency and optimize practices.

Build demand-side community on green product procurement. Key buyers and leading companies can form alliances to provide a demand signal for sustainable products. It would boost confidence for suppliers and manufacturers to invest in and continuously provide sustainable renewables products, which cumulatively can have profound positive effects on the whole supply chain. Policy incentives and new types of financing could also play a role to enable procurement transformation.

FIGURE 7: **Key Barriers and Enabling Actions for Sustainability of the Renewables Value Chain**

Barrier	Enabling actions to tackle each barrier	Key parties involved	Global best practices
Lack of standards to guide development of green renewables	**Cultivate guidelines and standards of sustainable practices of renewables** – Government and industry groups to publish standards on green renewable certification, recycling and reuse security/technology to pin the direction for the market and coordinate practices	– Government – Industry associations – Thought leadership – Large corporations	
Unclear business model and weak incentives	**Showcase flagship business models and support policy-making** – Leading players to develop flagship projects with value chain partners to test business models and showcase best practices – City/regional governments to provide incentives/mandate to support flagship implementation	– Large corporations (developers, OEMs, recyclers, electric vehicle companies) – Government – Industry associations	
Technology and cost limitations on scaling up	**Engage value chain stakeholders and innovators to push for technology breakthroughs** – Value chain players and start-up partnerships to test innovative solutions and accelerate breakthroughs – Funding and capacity building support to start-ups to activate broader tech innovation	– Large corporations – Start-ups – Venture capital and private equity funds	
Lack of committed demand for low-carbon renewable energy equipment	**Build demand-side community on green product procurement** – Key buyers and leading companies to form alliances and create committed demand – Suppliers and manufacturers to fulfil committed demand by providing low-carbon wind/solar products	– Multilateral entities – Thought leadership – Large corporations (developers, operators) – Local government	

Source: BCG

The Beginning of a Community Effort

The renewables value chain needs to manufacture, operate and handle clean energy in a sustainable manner. To achieve this promise, various stakeholders along the value chain need to plan together, reach alignment and take collaborative action.

The World Economic Forum is focused on catalysing business action under climate change through a multistakeholder approach. In addition to the Forum's global efforts on the Rapid and Responsible Clean Power, under the Clean Power, Grids and Electrification programme – which aims to ensure the massive clean power infrastructure required for the energy transition is designed and deployed rapidly and responsibly – this dedicated China effort on Net-Zero Opportunities of Value-Chain Action will continue to host local dialogues on value chain decarbonization and facilitate collaboration across sectors on key accelerators to enable this transition.

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