Renewable Energy: Emerging technologies and innovations to reduce climate change

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Abstract

This science-policy brief explores emerging solar technologies and energy storage innovations to address climate change and advance energy security. It also outlines how renewable energy technologies power up multiple SDG results, examines the trade-offs and recommend actions to accelerate impact and manage trade-offs.

Access to energy is key to human development and wellbeing but the world is not on track to achieve SDG 7 - ensuring access to affordable, reliable, sustainable, and modern energy for all. Solar technologies surpass other sources of renewable energy in terms of their capacity to deliver benefits across different end-use applications and geographical locations and to mitigate the impacts of climate change. Our challenge is to provide affordable, reliable, and sustainable energy to all and to reduce greenhouse gas emissions and reliance on fossil fuel.

The Intergovernmental Panel on Climate Change Sixth Assessment Synthesis Report proclaimed that rapid transition to renewable energy is critical to climate resilient development.[1] At the same time, progress on Sustainable Development Goal (SDG) 7 - affordable clean energy - has been painfully slow. 1 in 10 people in the world are without electricity.[2] 8 million people died from fossil fuel pollution in 2018.[3] This brief provides a broad overview of the potential of renewable energy, especially solar technologies, to reduce climate risks and advance the SDGs. It also examines trade-offs and recommends actions to accelerate impact and manage trade-offs.

Transitioning to Renewable Energy Futures

Renewable energy is cheaper than fossil fuel in most countries. Researchers from Stanford University analysed the technical feasibility of energy transition in a range of different scenarios and geographies and concluded that energy for electricity, transport, and building heating or cooling can be supplied with nearly 100 percent renewable energy at different locations worldwide.[4]

Solar technologies and innovations

Solar technologies dominate innovations in the renewable energy sector. The number of patent applications filed for solar photovoltaic (PV) have accelerated in the past decade (Figure 1, see bellow). The International Energy Agency anticipates solar PV and wind will account for nearly 95 percent of global renewable capacity in 2027.[5]

Most solar cells on the market are based on 'first generation' crystalline silicon solar cell technology. The production of these solar cell is complex, with high energy consumption and pollution. Second generation cells are thin-film technologies that reduce manufacturing and module cost and allows for more straightforward production than first generation solar cells.

Third generation solar cells are emerging technologies with potential to revolutionize the renewable energy sector. They are cheaper to produce than silicon cells. They can be made in a laboratory at scale and generate electricity that can be 'tuned' by controlling the molecules in the manufacturing process. Third generation PV technologies includes perovskite PV, organic PV, and quantum dot PV. Perovskite PVs are predicted to overtake silicon PV in the solar market in the coming decade. Organic PVs are low-cost and environmentally friendly and can be mass produced at scale using roll-to-roll processing. Quantum dot PV can produce energy with solar and UV light. Perovskite tandem cells, where a line layer of perovskite is added to silicon cells, could produce more electricity and at a lower cost than traditional solar cells.[7]

Second and third generation PV technologies have enabled the development of novel solar innovations such as solar film, solar paint, solar glass, solar skin, and solar textile with potential applications for humanitarian situations, post conflict and post-disaster recovery and reconstruction, and development settings.

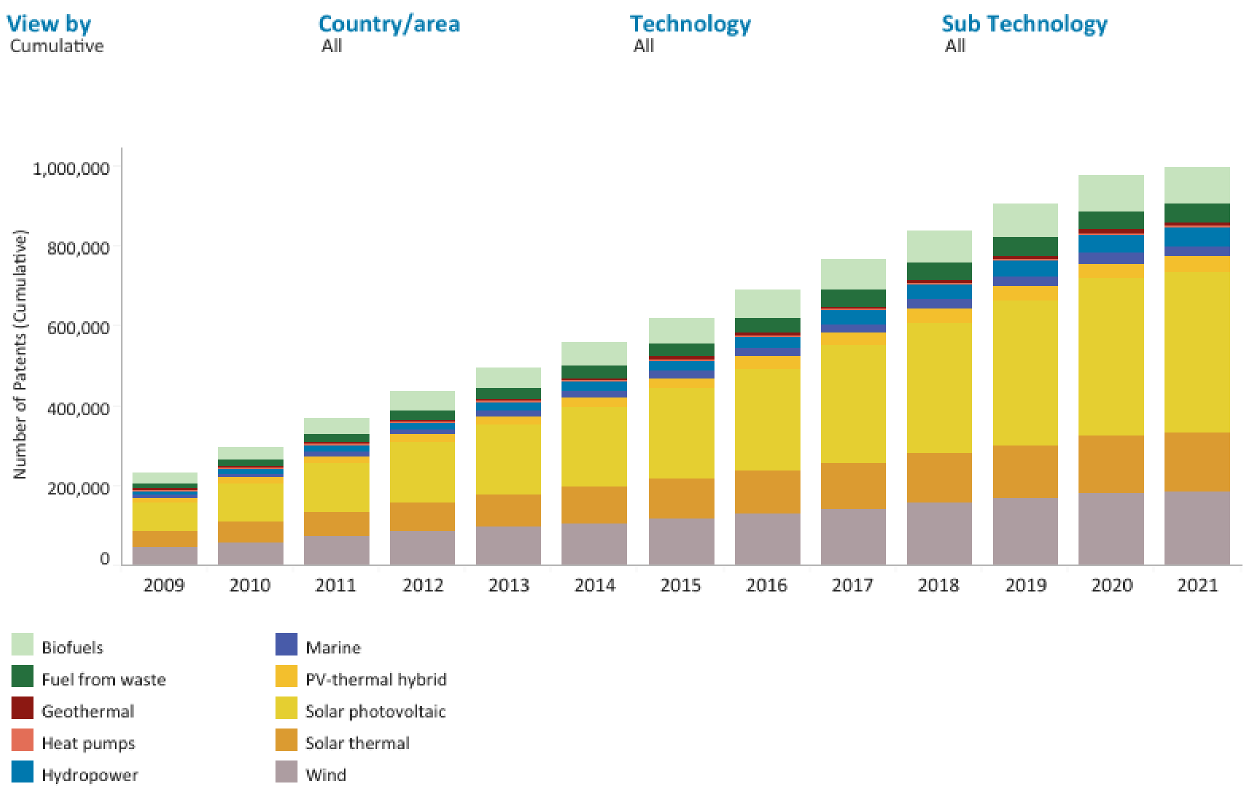
Renewable Energy Storage

Energy storage is critical to the transition of renewable energy. Energy storage solutions must address fluctuation of distributed power sources, enhance the power flow, voltage control and self-recovery capabilities of the distribution network, and have long-duration storage and fast response capabilities.

Batteries are good for short-duration storage. But a lot of batteries are needed to deliver 8-12 hours of electricity. Hence, storage technologies like flow batteries, pumped hydro, and thermal storage, both commercial and under development, are gaining traction for their long duration and large capacity storage ability.

Thermal Energy Storage (TES) technologies present one of the most promising innovations to convert electricity into heat for storage until required – hours, days, even months later – by factories, buildings, or towns. It can help decouple heating and cooling demand from immediate power generation and supply availability, to balance seasonal demand, and to reduce the need for costly grid reinforcements.[8] For example, Miscibility Gaps Alloy, currently at commercial demonstration stage, is a ground-breaking patented zero-carbon and recyclable phase-change TES technology for grid and industrial use.[9]

Figure 1. Renewable Energy Patents November 2022[6]



Multiple benefits

Ensuring access to affordable, reliable, sustainable, and modern energy will unlock multiple benefits for millions of people. If managed responsibly, cooperatively and justly, it can benefit children.[10] Table 1 shows that acting on affordable clean energy enhances synergistic action across the SDGs.

Table 1. Renewable energy technologies power up multiple SDG results

SDGs	Multiple benefits of access to affordable clean energy
1: No poverty	• Strengthen delivery of social services for children, reduce multidimensional poverty, build resilience, and sustain development gains.[11]
3: Good health and wellbeing	• Power life-saving medical equipment 24/7 at healthcare facilities, e.g., vaccine refrigerators, diagnostic equipment, ventilators, and operating rooms.

	• Provide lighting, heating, cooling, and clean water. • Reduce indoor air pollution due to cooking electrification.[12]
4: Quality education	• Increase school attendance, support remote learning and study outside of daylight hours. • Encourage teacher retention.[13]
5: Gender equality	• Increase school attendance and ability to study at home. • Reduce effort for water and fuel collection, provide safety at night, and boost livelihood opportunities.[14]
6: Clean water and sanitation	• Ensure access to sustainable, affordable, and clean water services. Safe clean water reduces children's exposure to deadly waterborne diseases.[15] • Improve food security with solar-powered water pumps.
7: Affordable and clean energy	• Help achieve better health, education, safe water and sanitation, and social policy outcomes in development and humanitarian situations for vulnerable children and young people.[16]
8: Decent work and economic growth	• Increase employment opportunities for young people and women, especially in technical skills training as the renewable energy market grows.[17]
9: Climate action	• Reduce greenhouse gas emissions and air pollution, promote climate-resilient development and disaster recovery.[18]

Trade-offs

The transition to renewable energy is not without deeply concerning human rights and environmental trade-offs. Table 2 outlines some of the trade-offs that need to be managed as the transition to renewable energy accelerates.

Table 2. Renewable energy and potential adverse impacts

Renewable energy	Potential adverse impacts
Solar energy	• Large utility-scale solar facilities (solar thermal plants) raise concerns about land degradation and habitat loss.
Wind energy	• Offshore wind farm developments can impact the structuring of coastal marine ecosystems on basin scales and the local ocean dynamics.[19]
Hydropower	• Potential loss of biodiversity and agricultural land.
Geothermal energy	• May emit carbon dioxide, silica, methane, ammonia, and sulphur dioxide, and depending upon the depth and location of the reservoir, some may contain lethal substances such as boron, mercury, and arsenic.
Bioenergy	• Energy created by burning biomass creates greenhouse gas emissions, but at lower levels than burning fossil fuels.
Ocean energy	• Equipment used to capture this ocean energy can disrupt and destroy marine life and the ocean's ecosystems.

Other trade-offs include:

- **Modern slavery.** The global renewable energy supply chains are susceptible to modern slavery and forced labour.[20] The risk is particularly high in the polysilicon solar market where production and procurement practices lack transparency and accountability.[21]
- **Impact of critical mineral extraction.** The Business and Human Rights Resource Centre monitors companies that mine commodities vital to the clean energy transition.[22] From 2010 to 2021, it identified 495 allegations of human rights abuse and attacks against Human Rights Defenders and Indigenous peoples.[23]
- **Forced displacement.** Large scale renewable energy projects and mining critical minerals can result in forced displacement. People's livelihood is disrupted and they face serious long-term risks of becoming more vulnerable economically and dislocated socially.
- **Solar panel waste.** The International Renewable Energy Agency estimates that annual solar waste could total 78 million tonnes by 2050.[24] Statistical modelling published in the Harvard Business Review claims the PV waste is likely to be 50 times more than IRENA's estimation.[25] Due to the high cost of solar waste recycling, most panels will go to landfill. This poses significant risks of toxic heavy metal leachate on land and river systems.[26]

Recommendations

Multiple instruments are needed to deal with the challenge of balancing the benefits and trade-offs of renewable energy solutions. Below are four areas of intervention for consideration.

1. Policy options to accelerate the transition to renewable energy.

- **Enabling policy levers**. Prioritize renewable energy as a strategic industry; streamline permits and approval processes; build technical capacity and workforce skills especially considering young generations and support commercialization of novel solar technologies as they reach maturity.
- **Demand-side policy levers**. Create incentives for domestic renewable energy products; establish government procurement guarantees, decarbonize heating and cooling, and develop economic modelling for coal plant repurposing for renewable energy.
- **Supply-side policy levers**. Concessional finance; price guarantees; capital grants; investment and production tax credit.
- **Cross-sector policy integration.** Align policy objectives of transport, construction, and farming sectors with renewable energy policy instruments; support the development of standards and codes of practice, and experiment with policy interventions to boost small business productivity, adopt renewable energy technologies and contribute to net zero.

2. Address technical barriers

- **Knowledge commons.** Establish open-source repositories to share knowledge on renewable energy R&D, sustainability studies and other environmental and climate change related metrics.
- **Collective innovation.** Support national and international R&D cross-sector collaborations to build up national expertise and competence and to build on synergies with other areas of innovation.

3. Mitigate environmental and social trade-offs

- **Mainstream sustainability.** Promote life-cycle assessment (LCA) of renewable energy technologies and innovations. LCA evaluates the environmental impact a product over the whole life cycle, namely: design, material preparation, production, post processing, use, and end of life treatment.[27]
- **Strengthen business and human rights in the renewable energy sector.** Develop initiatives such as supply chain, human rights and modern slavery due diligence trainings that support the implementation of the UN Guiding Principles on Business and Human Rights, which call on governments and companies to identify, prevent, mitigate, and remedy actual and potential human rights abuses.

4. Strengthen SDG synergies

- **Leverage regional forums to foster and strengthen SDG synergies.** Convene forums as part of a major regional dialogue. For example, a major Climate and Clean Energy Transition Forum was held at the ASEAN-Australia 2024 meeting to deepen cooperation on climate change and clean energy transition and help unlock up to 66 million jobs for the region by 2050. [28]

References

1. International Panel on Climate Change (2023). AR6 Synthesis Report: Climate Change 2023. Ipcc.ch; IPCC. https://www.ipcc.ch/report/sixth-assessment-report-cycle.
2. United Nations. (2022). The Sustainable Development Goals Report 2022. New York: United Nations Department of Economic and Social Affairs, 2022. p.40.
3. Vohra, K., Vodonos, A., Schwartz, J., Marais, E. A., Sulprizio, M. P., & Mickley, L. J. (2021). Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem. Environmental Research, vol. 195, 110754. doi: 10.1016/j.envres.2021.110754.
4. Stanford University. (18 July 2023). Abstracts of 89 Peer-Reviewed Published Journal Articles From 37 Independent Research Groups with Over 210 Different Authors Supporting the Result That Energy for Electricity, Transportation, Building Heating/Cooling, and/or Industry can be Supplied Reliably with 100% or Near-100% Renewable Energy at Different Locations Worldwide. https://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/100PercentPaperAbstracts.pdf
5. International Energy Agency. (2021). Renewables 2022, Analysis and forecast to 2027.
6. International Renewable Energy Agency. (2021). Renewable energy patents. https://inspire.irena.org/Pages/home.aspx
7. Foehringer Merchant, E. (8 Jan 2024). Super-efficient solar cells: 10 Breakthrough Technologies 2024, MIT Technology Review.
8. International Renewable Energy Agency. (2020). Innovation Outlook: Thermal Energy Storage, IRENA.
9. Kisi, E., Sugo, H., Cuskelly, D., Fiedler, T., Rawson, A., Post, A., Bradley, J., Copus, M., Reed, S. (2018). Miscibility Gap Alloys: A New Thermal Energy Storage Solution. In Sayigh, A. (Ed.) Transition Towards 100% Renewable Energy. Innovative Renewable Energy, Springer. doi: 10.1007/978-3-319-69844-1_48.
10. UNICEF Innocenti – Global Office of Research and Foresight, Global Outlook 2024: Prospects for children – Cooperation in a fragmented world, UNICEF Innocenti, Florence, January 2024.
11. United Nations. (n.d.). SDG1: No poverty. https://sdgs.un.org/goals/goal1.
12. United Nations. (n.d.). SDG3: Good health and well-being. https://sdgs.un.org/goals/goal3.
13. United Nations. (n.d.). SDG4: Quality education. https://sdgs.un.org/goals/goal4.
14. United Nations. (n.d.). SDG5: Gender equality. https://sdgs.un.org/goals/goal5.
15. United Nations. (n.d.). SDG13: Climate action. https://sdgs.un.org/goals/goal13.
16. United Nations. (n.d.). SDG7: Affordable and clean energy. https://sdgs.un.org/goals/goal7.
17. United Nations. (n.d.). SDG8: Decent work and economic growth. https://sdgs.un.org/goals/goal8.
18. United Nations. (n.d.). SDG13: Climate action. https://sdgs.un.org/goals/goal13.
19. Daewel, U., Akhtar, N., Christiansen, N., Schrum, C. (2022). Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea'. Communications Earth & Environment, 3,292. doi:10.1038/s43247-022-00625-0.
20. Walk Free. (2023). The Global Slavery Index 2023, Minderoo Foundation. https://www.walkfree.org/global-slavery-index/
21. Murphy, L. and Elimä, N., In Broad Daylight: Uyghur Forced Labour and Global Solar Supply Chains, Sheffield Hallam University, Helena Kennedy Centre for International Justice, Sheffield, UK, 2021. Around 95 percent of all solar modules are made with polysilicon.
22. Business and Human Rights Resource Centre. (May 2022). Transition Mineral Tracker: 2021 Global analysis of human rights in the energy transition. Business and Human Rights Resource Centre. https://www.business-humanrights.org/en/from-us/briefings/tmt-2021
23. Ibid.
24. International Energy Agency-Photovoltaic Power Systems (2016) End-of-Life Management: Solar Photovoltaic Panels. IRENA. ISBN: 978-92-95111-99-8. https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels
25. Atasu, A., Duran, S., & Van Wassenhove, L. N. (18 Jun 2021). The Dark Side of Solar Power, Harvard Business Review. https://hbr.org/2021/06/the-dark-side-of-solar-power
26. Ibid.
27. International Organization for Standardization. (2020). ISO 14040:2006/Amd 1:2020 Environmental management - Life cycle assessment - Principles and framework. ISO. https://www.iso.org/obp/ui/en/#iso:std:iso:14040:ed-2:v1:amd:1:v1:en
28. ASEAN Centre for Energy and GIZ. (2022). The 7th ASEAN Energy Outlook 2020-2050, ASEAN Centre for Energy. https://asean.org/book/the-7th-asean-energy-outlook-2020-2050/.