Ramasubramanian and Ramakrishna
Sustainable Earth Reviews (2023) 6:17
https://doi.org/10.1186/s42055-023-00069-0

Sustainable Earth Reviews

DEBATE

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What's next for the Sustainable Development Goals? Synergy and trade-offs in affordable and clean energy (SDG 7)

Brindha Ramasubramanian[1] and Seeram Ramakrishna[1*]

Abstract

This Sustainable Development Goal (SDG 7) analysis addresses critical challenges through three questions, backed by literature and evidence. Environmental, social, and governance concerns were discussed. A notable SDG target shortfall was observed from International Renewable Energy Agency, International Energy Agency, and United Nation's publications. Urgent actions include refining greenhouse gas emission equivalent estimations and establishing unified life cycle assessment standards. While prioritizing renewables, minimizing dependence on non-renewables for a lower carbon footprint is vital. Balancing energy production with per capita consumption reduction, especially with a growing population, is key to achieving net-zero emissions. This solution demands a thoughtful evaluation of challenges tied to specific renewable technologies and their socio-economic impact. Balancing economic growth, crisis response, and resource management is crucial for acheiving SDG 7 targets.

Keywords Energy efficiency, Affordability gap, Electrification, Energy access, Global employment

Introduction

Fossil fuels (GT), actuating the progress of human civilization from the industrial age (1800) to current era of economic growth (2023), provides the essentials in the form of electricity for various aspects of modern life, including transportation, thermal comfort, industrial processes, refrigeration, medical care, agriculture (food), electronics, and beyond [1–6]. However, burning of fossil fuels and deforestation, primarily accounts for the escalating greenhouse gas emissions (GHG) (Major: CO_2, CH_4 Minor: N_2O, H_2O, O_3, CFCs) driven by the seven largest emitters (China, India, USA, EU, Indonesia, Russia, Brazil), which has contributed to ~50% of the *climate change* (GT) in 2023, (Floods in Libya, North Africa, 2023 [7]) [8, 9]. To combat these climate challenges and to improve the quality of human's life, the United Nations (UN) has set *SDGs* (GT) encompassing 17 goals, 169 objectives, and 231 indicators [10]. *SDG7* (GT) emphasis on providing affordable and *sustainable energy* (GT) to aid in achieving *netzero* (GT) emissions by 2050 (Paris Agreement, *SDG 13)* (GT) and has interrelations between other SDGs (Fig. 1). Without reliable access to energy, it becomes challenging to eradicate poverty (SDG 1) as it limits opportunities for income generation and hinders access to essential services. Moreover, quality education (SDG 4) is compromised without reliable energy for schools, and good health (SDG 3) is jeopardized without power for healthcare facilities. The objectives of SDG7 involves increasing the adoption of *renewables* (GT), achieving a twofold enhancement in energy efficiency, fostering stronger international cooperation, technological and infrastructural progress, which are accessed by metrics including accessibility to electricity (%), adoption

*Correspondence:
Seeram Ramakrishna
seeram@nus.edu.sg
[1] Center for Nanotechnology & Sustainability, Department of Mechanical Engineering, College of Design and Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117575, Singapore

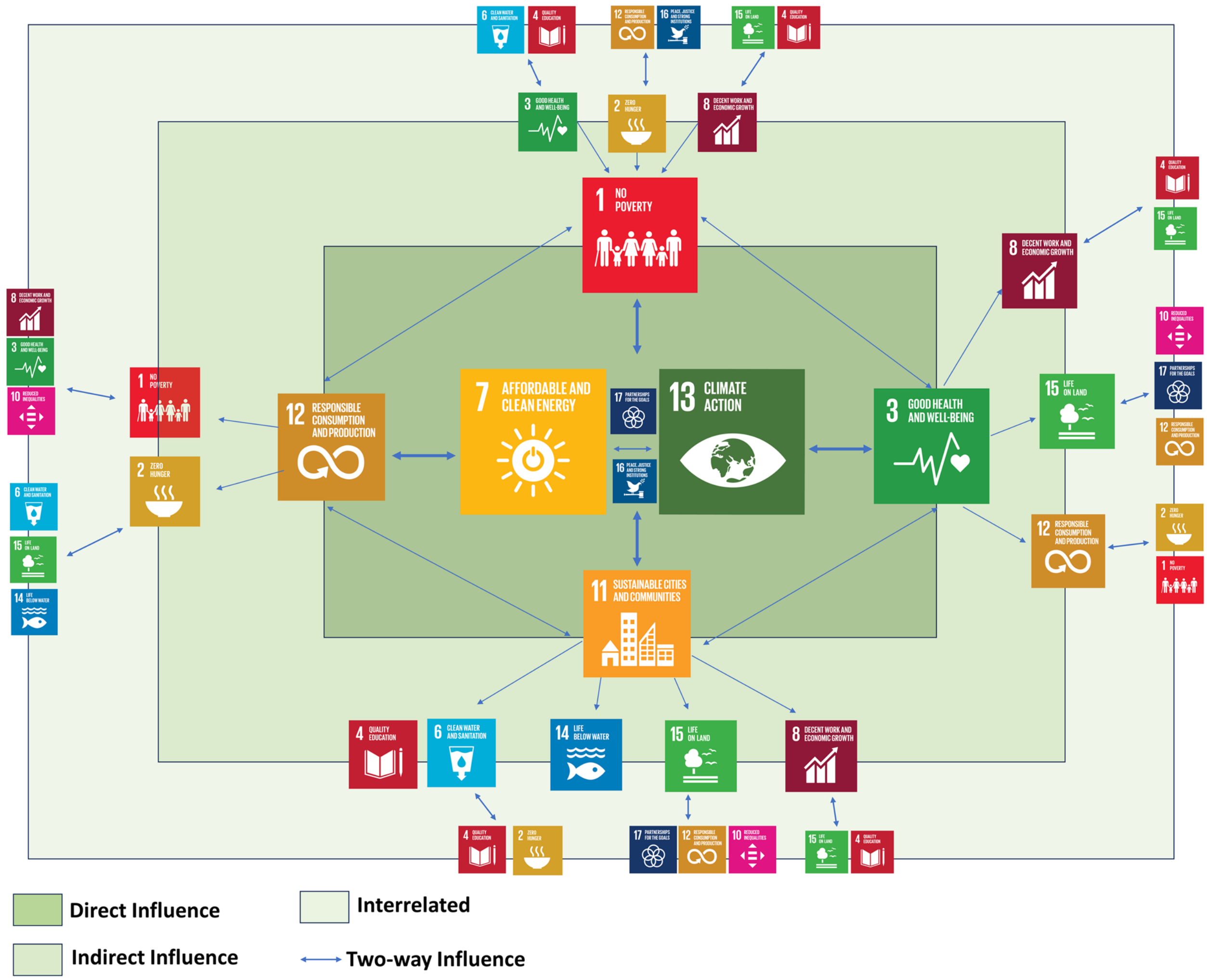


Fig. 1 Interrelations between other SDGs and SDG 7 (SDG 7, centred on affordable and clean energy, directly, curtails reliance on costly and polluting fuels, thereby addressing poverty (SDG 1) while facilitating clean energy for healthcare services (SDG 3) and sustainable urbanization (SDG 11) through reliable infrastructure and power. It also aligns with responsible consumption and production (SDG 12), with lesser consumption of resources and reduced negative effects on ecosystem. Indirectly, SDG 7 supports all kinds of agricultural practices that promotes sustainability (SDG 2), elevates educational quality (SDG 4), empowers women by creating Jobs (SDG 5), facilitates clean water access (SDG 6), drives economic expansion (SDG 8), spurs technological innovation (SDG 9), advances social equality (SDG 10), aids climate change mitigation (SDG 13), safeguards biodiversity (SDG 14, SDG 15), and fosters peace, justice, and collaborative partnerships (SDG 16, SDG 17). This interconnectedness underscores the importance of SDG 7

of clean cooking technologies, utilization of *renewable energy* (GT), improved energy efficiency (J or kWh), investments in clean energy (USD or EUR), and carbon emissions per unit of electricity generated (gCO_2/kWh) [9, 10]. Figure 2a depicts the energy market evolution from 1900 to 2023. Wind and solar energy costs dropped significantly, from 100 USD/MWh in 2014 to 30 USD/MWh in 2022. This signals a strong global push to phase out fossil fuels by 2030. The globe requires > 50% of reduction in GHG emissions by 2030 to limit warming to

(See figure on next page.)

Fig. 2 **a** Schematic timeline of energy transition and global initiatives from 1990 to 2023, here NDC means Nationally Determined Contributions (**b**) Consumption of fossil fuels from 1800 to 2023 and their projected depletion in years (data used under CC license from [16]and [17] Energy Institute Statistical Review of World Energy (2023); Vaclav Smil (2017)) (**c**) Global warming anomaly (data obtained from [16] and [18, 19]) (**d**) % share of renewables equivalent installed in major marketable countries. (All data used and analyzed were obtained from [20] and Ember's European Electricity Review; Energy Institute Statistical Review of World Energy [21], curated and filtered) (**e**) % of electricity contributed from renewables in Association of Southeast Asian Nations (ASEAN), Africa, Asia, Australia, China, Europe, India, UK and Us (Note: Europe includes majorly Germany, Spain, UK and Finland)

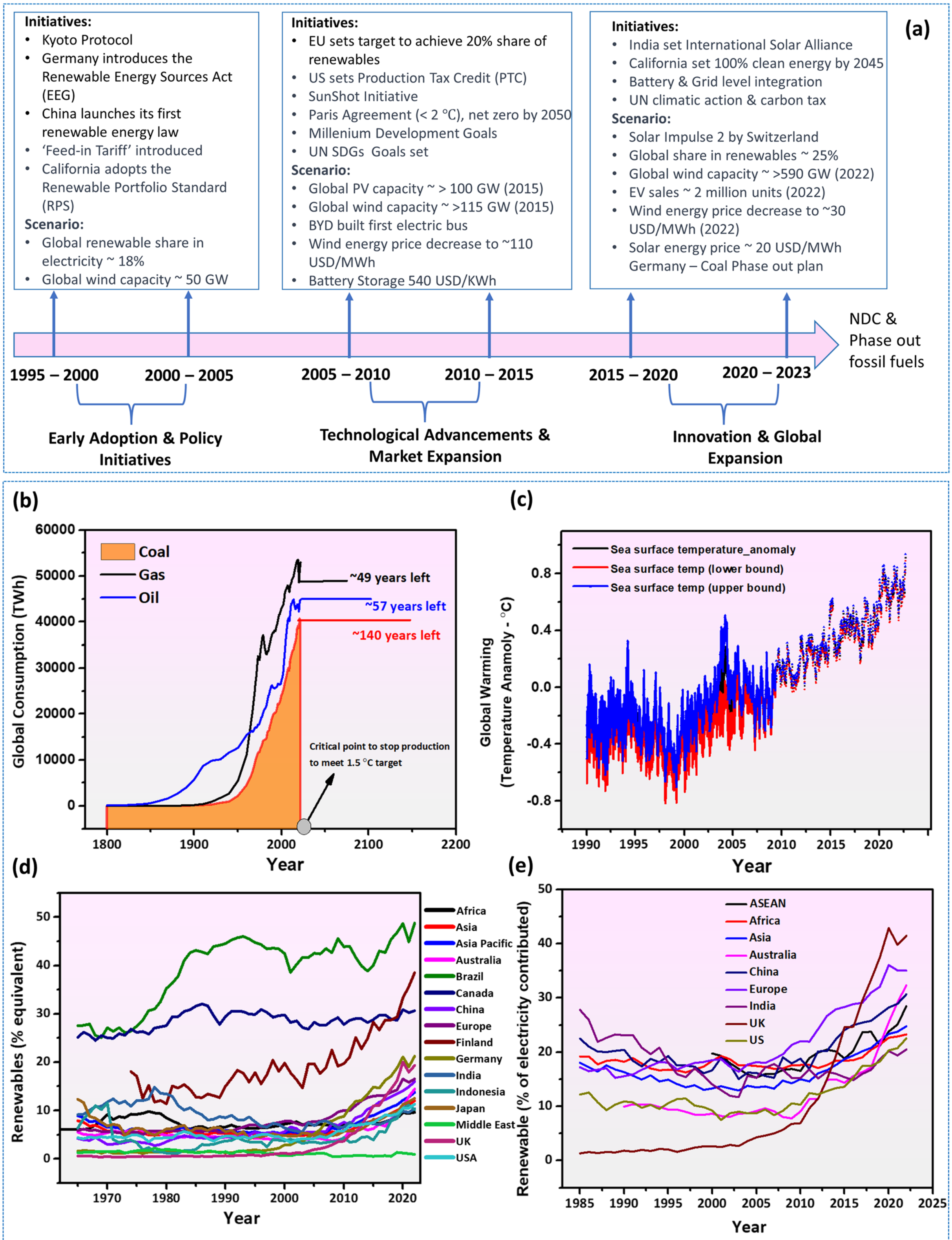


Fig. 2 (See legend on previous page.)

1.5 °C, which is globally supported by shifting to renewables. According to [11] and Fig. 2a SDG7 targets energy poverty and vulnerability, particularly affecting specific social groups, but lacks emphasis on absolute *dematerialization* (GT). Further, the shift to renewables may inadvertently increase production sites in rural areas with lower land values and formalized land rights [11]. Previous reports suggest that the SDG framework broadly focusses on Greenhouse gas (GHG) emissions and decarbonization, accentuating less on technology and socio-economic scenarios [10, 12–15].

In this analysis, we focus on addressing three primary challenges associated with transition to renewables, considering their environmental (E), social (S) and Governance (G) impact in compliance with SDG7: Target 7.1 (Ensure universal access to affordable, reliable, and modern energy services). The 'Just Transition' [22] to renewables involves broader assessment and has complexities related to long-term productions, job security, financial hurdles, which are yet to be clearly addressed.

Challenge 1 (E): The emissions stemming from equipment production, infrastructure development, transportation, and eventual *decommissioning and end-of-life waste management* (GT) of renewable energy sources necessitate a deeper understanding on how it balances the long-term emissions from fossil fuels. Is the transition to renewable energy truly sustainable?

Challenge 2 (S): Gap exists between fair employment opportunities for workers affected by job displacement from Oil & Gas to renewable energy. Additionally, measures are still needed to bridge the energy efficiency gap between affluent and resource-constrained communities, preventing the potential augmentation of socio-economic disparities.

Challenge 3 (G): While developed nations extend support, the high initial costs of renewable technologies (hydropower and concentrated solar power) hinder the progress in low-income countries. however, acknowledging this trade-off may temporarily benefit low-income households and may develop affordability gaps across income groups. How can governments implement measures to alleviate these upfront expenses ?

Before addressing the challenges, three key questions assisted by literature [8, 11–15, 23–33] and factual evidence from International Renewable Energy Agency (IRENA), International Energy Agency (IEA), Energy Information Administration (EIA), The World Bank Group, British Petroleum (BP), World Resources Institute (WRI), Global Wind Energy Council (GWEC), Solar Energy Industries Association (SEIA) | https://www.iea.org/ | https://www.eia.gov/ | https://www.irena.org/ | https://www.seia.org/ | https://gwec.net/ | https://www.wri.org/ | https://www.bp.com/ | https://www.worldbank.org/en/home are introduced to analyse the listed challenges, accompanied by the constructive suggestions of the authors.

1. Does relying solely on renewables offer an affordable, reliable, and sustainable energy solution?

Transitioning to renewables by 2050 could save up to \$12tn globally but requires a drastic reduction in fossil fuel production and consumption [33]. Figure 2b illustrates the consumption trend of fossil fuels from 1800 to 2023, along with the projected years remaining until their depletion: Coal (140), Oil (57), and Gas (49). With energy demand spiking 2.3% in 2018, and a projected 3.4% Gross Domestic Product (GDP) growth by 2040, thus the priority should be improving the energy efficiency of existing systems. In 2022, oil demand increased by 2.3 mb/d, and projections for 2023 indicated a growth of 1.7 mb/d (IEA 2023) [34]. Roughly 83% of oil reserves, primarily in Canada, should remain untapped (~ > 3% decline in oil consumption is required each year till 2050). Thus, shifting to natural gas is the next priority, given its abundant reserves (7,124 trillion cubic feet, 2018) [35]. Figure 2c underscores the urgency of this transition, with sea temperatures surging from -0.4℃ in 1990 to 0.9℃ in 2023. This alarming trend poses a threat to aquatic habitats [34, 36]. Rising sea temperatures threaten marine ecosystems, causing disruptions in species life cycles, coral bleaching, and biodiversity loss. This underscores the urgency of mitigating human activities linked to climate change to protect marine environments.

The literature reviewed in this study were chosen from Scopus, based on the selection criteria, mentioned in appendix. Based on [37–46], we agree that primary challenges include time and financial constraints. These are exacerbated by the intermittent nature of renewables, requiring auxiliary energy storage and grid upgrades for integration. However, considering long-term viability, we assert the obligation of deep analysis on (i) technological maturity (given the continuous innovation in renewables, standardization remains as a challenge), (ii) economic viability (return on investments, resource availability, market competition & impact, access to capital among other externalities), (iii) subsidy dependence (with implications for market distortion and inequalities), (iv) Levelized Cost of Electricity (LCOE) (should include life cycle assessments and extended producer responsibilities) [47], and (v) regional needs (not an exhaustive list). Thus, a broader assessment is required for this paradigm shift.

2. What is the current level of accessibility to renewable energy, and how swiftly are we progressing towards broader availability? Additionally, what are the projected trends?

Renewable energy comes from naturally replenishing sources, offering lasting potential but limited short-term outputs (EIA 2020). Figure 2c, d shows the 50% of renewables contributions in major marketable countries (Germany, US, Brazil, and China have highest contributions). The per capita installed capacity for renewable energy generation in > 230 developing nations excluding pumped hydrogen increased overall from 104 W in 2013 to 241 W in 2022, with this trend the projections are ~ 630 W in 2050, which means additional ~ 30% increase in production or decrease in consumption is needed to meet the targets [16]. In 2013, the installed solar energy capacity was 141417 MW, which grew to 1061630 MW in 2022. However, concentrated solar power's installed capacity is less (6602 MW) due to its high initial investment. Bioenergy, derived mainly from organic waste, constitutes over ~ 40% of total renewables, followed by wind, hydro, and geothermal energy [48]. Wind energy, harnessed from both onshore and offshore turbines, has seen remarkable growth in the past two decades. Overall, major contributors to renewables include China, India, Brazil, Germany, the UK, and the USA, Australia, Japan, etc., while regions in Asia (Indonesia, Thailand, Philippines, Vietnam, Bhutan, Sri Lanka, Myanmar, etc.), Africa (Congo, Liberia, Angola, etc.), and Europe (Denmark, Norway, Netherlands, Romania, etc.), Middle east could benefit from increased contributions [16, 49].

3. Are the current levels of financial investment in renewables adequate to progress in this transition?

In 2022, global renewable energy investment reached $0.5 trillion, marking a 19% increase from 2021 and a 70% surge from pre-pandemic 2019 levels. In 2020, solar photovoltaic received 43% of total renewables investment, followed by onshore and offshore wind at 35% and 12% respectively [25]. However, this falls short of the annual average needed from 2023 to 2030, underscoring the urgency to boost investments in *off-grid* (G) renewables, especially in solar. Regional disparities persist, with over half of the global population in developing nations (Sub-Saharan Africa, Middle East) receives only 15% of global investments, whereas Europe and US leads by ~ 40% in 2020 [16]. Redirecting $1 trillion annually from fossil fuels to energy-transition-related technologies in developing countries is needed [25].

Sustainability of the renewable energy

The transition to renewables is paradoxically reliant on non-renewable resources, particularly mined metals. In 2020, mining operations for materials essential to renewable energy production was ~ 16% of wilderness areas and the production of a single ton of rare-earth and toxic elements (La, Nd, Sr, Te, Cd of ~ 5 to 10 g/m^2 for PV [50] etc.) generates ~ 2,000 tons of waste. Life cycle assessment (*LCA)* (G) studies are necessary for addressing the environmental concerns of major marketable renewables (solar, wind, hydro, geothermal and others). The methodology of LCA analysis for solar PV and wind is stated elsewhere [51–53] The installed capacities of renewables as per IRENA is shown in Table 1.

Coal emissions increased ~ 1.6% (243 Mt), while oil emissions rose by 2.5% partly due to increased aviation in 2022 compared to 2021. The biggest spike in emissions (1.8% or 261 Mt) occurred in electricity and heat generation, predominantly from coal sources, particularly in emerging ASEAN economies [54–57]. The US saw a 0.8% increase (36 Mt) in emissions, largely due to peak electricity demand during summer heat waves. The analysis in Table 2 and Fig. 3 reveals that biomass and nuclear energy production result in higher CO_2-e emissions compared to solar and wind energy. Hydroelectric energy falls in the mid-range in terms of emissions. Moreover, solar and biomass energy have lower initial installation costs, and the payback period is shorter for solar, wind, and geothermal energy. When considering sustainability, renewables can be ranked from highest to lowest as follows: solar, hydroelectric, wind, biomass, geothermal, and nuclear.

However, the concept of CO_2-e emissions indeed poses several challenges in the context of GHG reduction efforts. Firstly, it fails to distinguish between specific greenhouse gases like CO_2, N_2O, CH_4 as well as other less prevalent but potent gases. This lack of specificity can be problematic because different gases have varying levels of global warming potential (GWP) and different lifetimes in the atmosphere. For instance, while CO_2 is the most prevalent GHG, its long-term impact is more enduring than shorter-lived but highly potent gases like CH_4. Consequently, a reduction in CH_4 emissions might have a more immediate and significant impact on mitigating global warming. Furthermore, CO_2-e labelling may not accurately reflect the true environmental and economic costs associated with each greenhouse gas. Calculating GWP involves a degree of ambiguity, as it depends on complicated models and discrepancies in published literatures [18, 21]. This ambiguity can make it challenging to accurately price

Table 1 Concise listing of installed capacities of specific renewables in MW and nation-wise significant or weak contributors as per IRENA, 2023 [16]

Renewables (Excludes off grid ~ 11866 MW and pumped hydrogen)	Installed Capacity (MW) in 2022	Major contributors to the Installed capacity in 2022 (MW)	Least contributors (MW)
Solar Energy	1061632 (Off grid excluded ~ 4340)	China (393032); India (63193); Germany (66664); Korea Rp (23294); Italy (25083); Netherlands (18849); Spain (20518); Australia (29617); USA (113 015); Brazil (24079); Vietnam (25719); Japan (83055); South Africa (6326) 'o'	Congo Rep (1); Liberia (3); Angola (2); Benin-(3); South Sudan (2); Bhutan (1); Tajikistan (-);St Barth (-);St Martin (-); Greenland (-), Solomon Is (3);Montenegro (2); Indonesia (3) 'o'
Concentrated Solar Power	6602	Africa (1085); China (596); Spain (2304); North America (1497); USA (1480); Chile (108) 'o'	Australia (3); Mexico (17), India (-); Indonesia (-); Thailand (5); Germany (2); Oceania (3); Saudi Arabia & Kuwait (~ 50); rest (-) 'e'
Bio energy	150671	Africa (1866); China (34088); India (10670); Germany (9877); UK (7373); USA (11296); Brazil (17206); 'o & e'	Liberia (-); Madagascar (-);Rwanda (-); Bangladesh (-); Albania (1); Iran (14); Israel (26); UAE (0) 'o'
Renewable waste to Solid biofuels	126418	China (32161); India (10656); USA (9205); Brazil (16702); Finland (2603); 'o'	Bangladesh (-); Maldives (-); Srilanka (45); Greece (60); Middle East (15); 'o'
Municipal waste to fuel	21994	China (16406); Singapore (400); UK (756); USA (1025); 'o'	Indonesia (12); Malaysia (7); Srilanka (5); Brazil (35); 'o'
Bagasse waste to fuel	20783	Africa (1631); Indonesia (219); Guatemala (863); Mexico (816); Australia (500); Brazil (12277); Colombia (387);	China (-); India (-); Germany (-); Srilanka (-); Middle east (-) 'o'
Other bioderived solid biofuels	83442	China (18755); India (10395); Thailand (3647); Denmark (1848); Germany (1558); Sweden (3093); UK (4702); USA (8009); Brazil (4390); Uruguay (2714) 'o'	Africa (69); rest (-)
Liquid Biofuels	2741	Korea (487); Italy (919); Sweden (895); Brazil (19) 'o'	Oceania (3); Austria (-), Belgium (-); China (-); India (-)
Biogas	21512	Egypt (56); China (1928); Thailand (635); Indonesia (149); Japan (97); Germany (7020); Italy (1382); UK (1935); USA (2089)	India (14); UAE (2); Middle east (-); rest (-)
Wind Energy	898856	Egypt (1643); China (365964); India (41930); Turkey (11 396); Italy (11870); UK (28760); Canada (15295); Oceania (1552); Australia (10555); Brazil (24163); USA (382 814); France (21120); Germany (66294) 'o'	Africa (7687); Korea (-); Nepal & Myanmar (-);Middle East (1053)
Hydropower (off-grid)	1799	Africa (264); Asia (1310); S. America (620); Oceania (174)	Oman, Saudi Arabia, China, rest (-)
Marine	523	Asia (260); Europe (241); N. America (21); Canada (21) 'e'	rest (-)
Geothermal	14621	Kenya (941); Indonesia (2360); Philippines (1932); Turkey (1691); Italy (772); USA (2653); 'o & e'	India (-); China (-); Singapore (-); Germany (-); UK (-); UAE (-); Middle east (-); Australia (-)

Table 2 Essential criteria to access the sustainability of renewable technologies, includes cost, payback period, and CO_2-equivalent (CO_2-e) emissions (EROEI – Energy Return on Investment)

Technology	Costs Involved for 1 MW production ($million)	Energy payback time	EROEI and Reproduction Potential	Possible toxic elements present	Emissions (g CO_2-eq/kWh)
Polycrystalline Si PV	1 to 1.5	6 to 48	20 – 40	Pb, $SiCl_4$, Cu	60.1 for 10 MW/year; 50 to 60; 64.2; 41.8; 65.2; 671 [58–64]
Thin film PV	900,000 to 1.8	> 12	NA	Cr, As, Cd, Pb, Te, Cu, Se, In, Ga	40; 12 to 70; 20; 14; 26 [58, 65]
Wind	Onshore: 1.3 to 2.2 Offshore: 2.5 to 4	< 24	18 – 35	Pb, Nd, Dy, Pr, Hg, Asbestos, Be, Cd	34.11; 1.7 to 81; [66–69]
Hydroelectric	2 to 5	< 24	10—80	Hg, Cd, Cr, Ni	50 – 300 [68, 70–72]
Geothermal	Dry Steam: 2 to 5 Flash Steam: 3 to 8 Binary Cycle: 2 to 6	2 to 10	3.6 – 6	H_2S, B, S, As, Sb, Tl, Hg	1.7 to 81 [73, 74]
Biomass	500,000 to 2	6 to 24	3 – 20	Aromatic Hydrocarbons, Dioxins and Furans, Cl and S, Particulate Matter	100 to 400 [67, 70, 71]
Nuclear	Traditional: 6 to 9 Small Modular Reactors (SMRs): 4 to 6	> 24	75 – 150	U, Pu, Cs-137, Sr-90, I-131, C-60, Tc-99 m, Np, Actinides	12; 14; 120; 150 [67, 75, 76]

GHG emissions, potentially leading to misallocations of resources in mitigation efforts.

Equitable employment opportunities

Increasing Human development Index (HDI) and higher degree holders imply progress in education and socio-economic status (Fig. 4a) [86]. However, there is a potential downside. Individuals may find themselves accepting jobs with lower pay and positions in energy sector that do not align with their educational qualifications. Additionally, employment in coal industries has drastically reduced (Fig. 4b). The shift to net-zero emissions could create 9 million new energy sector jobs by 2030, despite an estimated loss of 5 million in fossil fuel production. Additionally, clean energy sectors, encompassing efficiency, automotive [87–93], and construction, could generate over 30 million jobs by 2030, offering new opportunities in emissions-reducing technologies (Fig. 4c) [94, 95]. However, the transition has led to job displacement in fossil fuel-reliant communities, particularly in coal. This shift from Oil & Gas to solar and wind energy has resulted in fewer job opportunities compared to the offset in oil and gas as of 2023. Both industries rely on imports, potentially limiting local job growth in countries like US, Singapore, and Australia (Fig. 4d). Transitioning to renewables demands workforce retraining, and encounters resistance from fossil fuel interests, potentially causing social disruptions in communities heavily reliant on fossil fuels [96, 97]. For instance, petroleum related jobs are localized but crucial for many local economies. While the energy sector constitutes a small portion of global employment (1.2%), in places like Saudi Arabia, it significantly contributes to GDP (50%) despite employing a smaller percentage (4.8%) [94, 98].

The top companies in Oil & Gas, renewables, and their number of employees as per 2022 is listed in Fig. 4e. The Oil & Gas, industries, including Saudi Aramco, Chevron, ExxonMobil, British Petroleum (BP) and Royal Dutch Shell currently have more employees than renewable industries (NextEra Energy, Vestas Wind Systems, Siemens Gamesa, and Enel Green Power); however, the recruiting counts of Oil & Gas, have slightly reduced in 2022. Former coal workers often find replacement jobs with lower pay and skill gaps (Fig. 4f). Fossil fuel workers also tend to earn more and have higher health insurance coverage compared to solar and wind workers. Coal-linked pension funds suffer due to economic decline, impacting communities. Areas with power plants and mines experience lower education rates and income instability. Coal closures lead to reduced local tax revenue, resulting in budget cuts, school closures, and job losses [103]. The transition can increase energy insecurity, disproportionately affecting low-income individuals. In 2018, United Steelworkers represented 18% of petroleum workers, while solar and wind workers had lower unionization rates (4% and 6% respectively) [94, 98].

While the shift towards renewable energy is crucial for environmental sustainability, these economic and social consequences highlight the need for comprehensive support measures for affected communities and workers. Existing energy workers possess skills transferable to clean roles, such as in wind, carbon capture, and low-carbon gas. Restoring closed mines can maintain

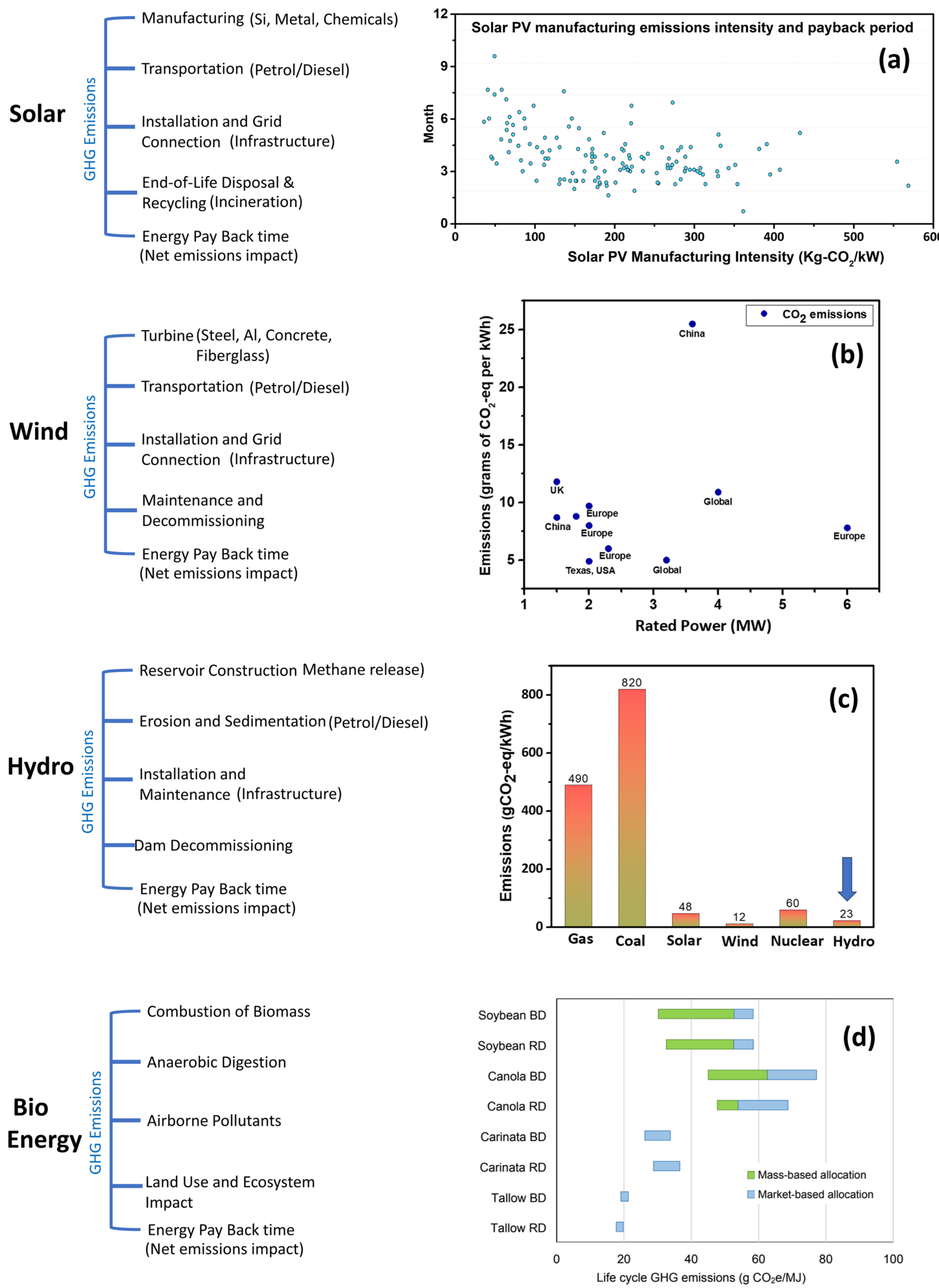


Fig. 3 Major stages of carbon emissions in renewables (**a**) CO_2 emissions from Commercial PV modules (adapted from IEA, 2021) (**b**) Emissions (CO_2-e) from wind energy harvesting (data adapted from [77–83] (**c**) Emissions from hydro compared with other renewables (data adapted from [84]) (**d**) GHG emissions tracking from biomass such as soybean, canola, carinata and tallow (reused with permission from [85])

post-closure jobs [49]. Focusing on qualified workers and inclusive support is vital for clean energy jobs, ensuring safety, equity, and inclusion in affected communities. Government support with inclusive criteria drives economic development and public acceptance. The Global Commission is shaping principles for diverse transitions, guiding IEA's efforts and COP26 input. The overall progress in SDG 7 is shown in Fig. 5a-f. Access to investments in green energy was identified as unstable (7.A.1), indicating a need for increased attention and focus.

Affordability gaps in renewable adoption

Affordability gaps in renewable adoption stem from high initial costs, rapid tech evolution, and economies of high-income favouring larger projects (Fig. 5e, f). This could particularly affect low-income households, who already allocate a significant portion of their income to energy expenses [110]. In 2022, energy investment is set to surge by 8%, but almost half of this increase is due to rising costs rather than expanding capacity or savings. These cost hikes are driven by supply chain strains, labour shortages, and increased prices for materials like steel and cement. However, higher prices alone can't ensure sustainable choices, especially in less affluent nations with inadequate policies [110–112].

Power generation projects in renewables and grids often rely on debt, while smaller ventures or areas with limited credit use equity more. Although advanced economies have easier access to debt, equity remains crucial for emerging sectors. Power generation costs range from 3–7% depending on the region [113, 114]. It's unfair for developing economies to bear the full cost of the transition. Currently, increasing fossil fuel prices disproportionately affect Asia and Africa, with an estimated 90 million struggling to afford energy. This raises concerns about possible energy poverty, affecting nearly 90 million people in Asia and Africa struggling to meet basic energy needs [111, 115].

In the solar sector of Emerging Market and Developing Economies (EMDE), institutional investors grapple with hurdles. A key obstacle is the limited availability of instruments tailored for solar ventures. Additionally, institutional investors in EMDE prioritize liquid assets like equity, bonds, and structured finance, discouraging solar investments. Low credit ratings of solar corporate bonds in EMDE further dissuades participation. To navigate complexities and mitigate risks, investors often rely on intermediaries like debt funds. Unfortunately, a shortage of specialized financial services exacerbates these challenges, hindering the realization of solar energy's potential in these economies [116, 117].

Closing the investment gap in emerging economies is crucial for equitable climate action and sustainable development. Additional financial and technical support, including concessional and private sector capital, are pivotal. Without a substantial increase in clean energy investment, global efforts to combat climate change and achieve sustainability goals will face significant challenges. Geopolitical events are prompting investments in various fuels, including coal in emerging Asian markets [111, 116]. Additionally, rising prices of critical minerals are emphasizing the importance of mining, refining, and processing in the transition to more sustainable energy systems. Institutional investment in renewable projects can be facilitated with essential risk-mitigating tools such as guarantees and insurance. Partial credit guarantees from international development institutions bolster bond ratings, and solar debt funds with public first-loss protection appeal to low-risk investors. The International Solar Alliance (ISA), Global Wind Energy Council (GWEC), Alliance for Rural Electrification (ARE), Global Biofuel Alliance (GBA) (GBA- led by India as the G20 Chair, to accelerates global biofuel adoption) and IEA are actively working on solutions to enhance capital accessibility. Coordinated efforts and innovative strategies are imperative to close the renewable energy investment gap and align with Paris Agreement, SDG objectives [111, 115–117].

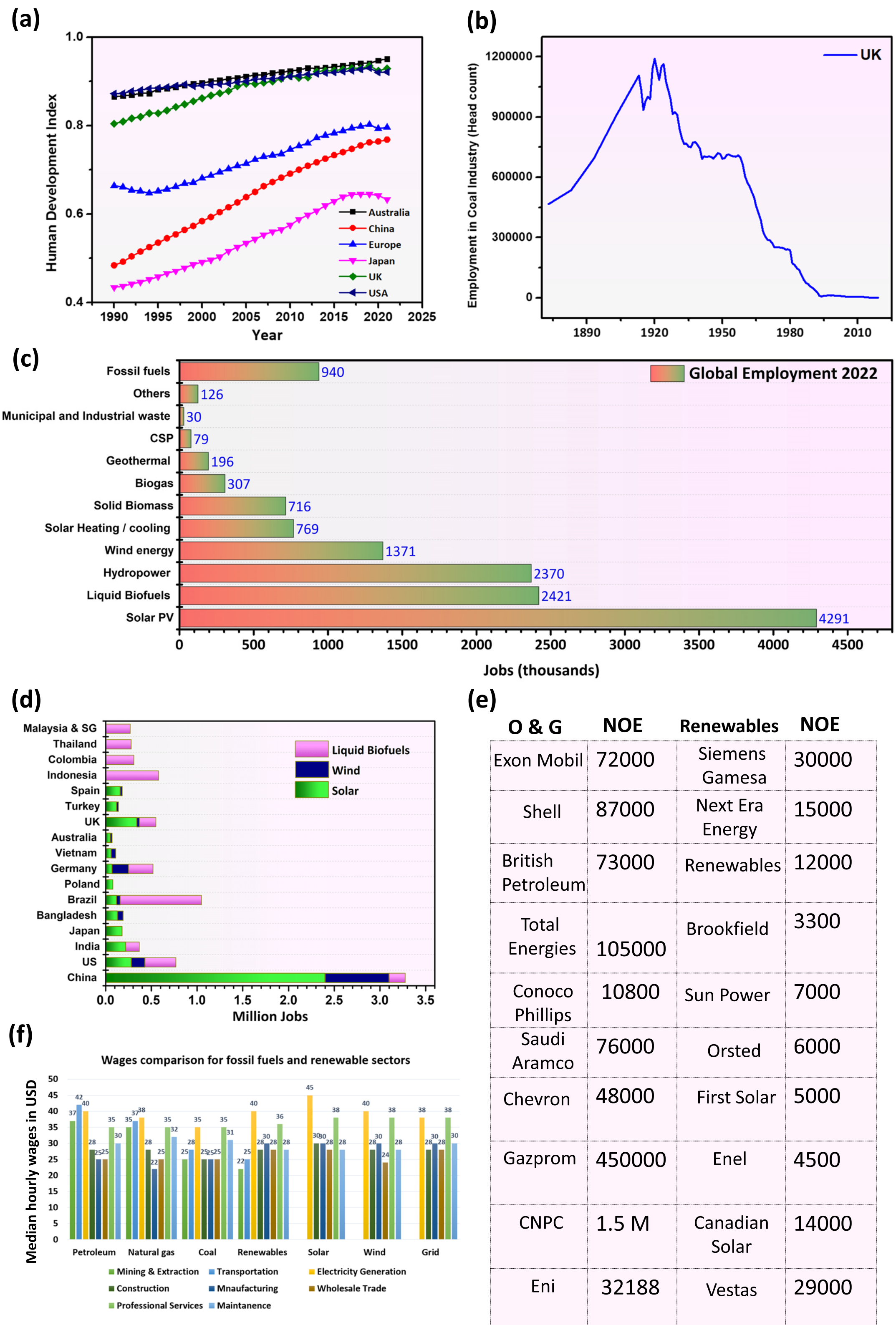
Summary and outlook

Conclusion

This article compiles data and information regarding the current progress in renewable energy development. The speed of this transition is lagging and uncertain, contingent on various factors including policy support, technological advancements, and economic considerations. We have underscored three challenges, the need for more comprehensive and standardized reporting standards for GHG emissions from renewables, the trade-offs in

(See figure on next page.)

Fig. 4 **a** Evolution of human development index (HDI), which is proportional to employment (data adapted from Our world in data [86, 99] [99]) (**b**) Total employment in coal industries in UK from 1890 to 2022 (data adapted from Our world in data [86, 99]) (**c**) Global employment in terms of number of Jobs as per 2022 (World Bank, IEA, Our World in Data [100]) (**d**) Job shift towards renewables marked by individual countries 2022 (World Bank, IEA, Our World in Data [99]) (**e**) Top companies in O &G, renewables and NOE – Number of Employees (World Economic Forum, Thomson Reuters, Wikipedia) (**f**) Comparison of wages in fossil fuels and renewables sector (data adapted from [101] and [102])



O & G	NOE	Renewables	NOE
Exon Mobil	72000	Siemens Gamesa	30000
Shell	87000	Next Era Energy	15000
British Petroleum	73000	Renewables	12000
Total Energies	105000	Brookfield	3300
Conoco Phillips	10800	Sun Power	7000
Saudi Aramco	76000	Orsted	6000
Chevron	48000	First Solar	5000
Gazprom	450000	Enel	4500
CNPC	1.5 M	Canadian Solar	14000
Eni	32188	Vestas	29000

Fig. 4 (See legend on previous page.)

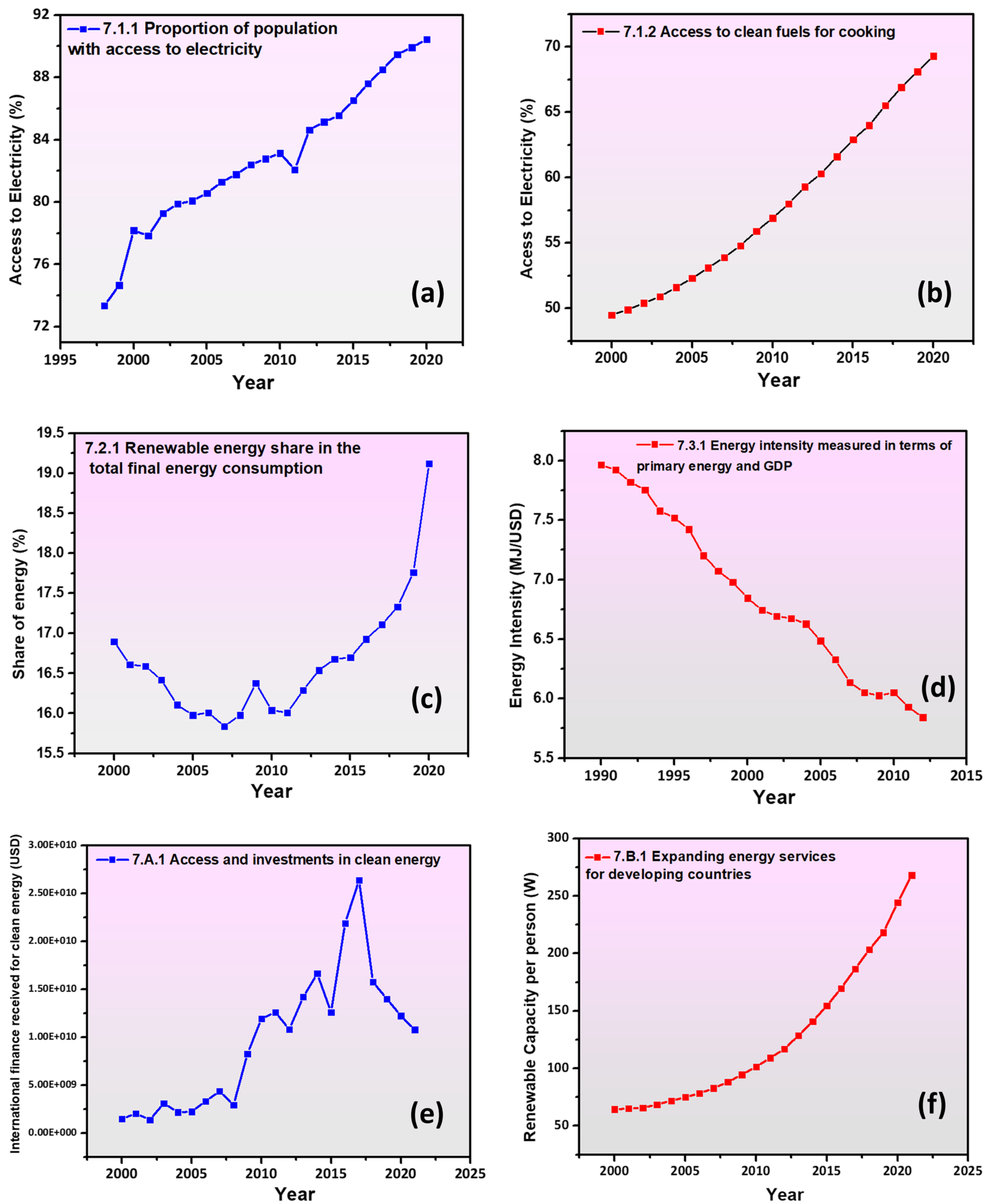


Fig. 5 Mapping the progress in SDG 7 individual goals (**a**) 7.1.1 Proportion of population with accessibility to electricity (**b**) 7.1.2 Access to green fuels for cooking (**c**) 7.2.1 Renewable energy share in total energy consumption (**d**) 7.3.1 Energy Intensity measured in GDP and primary energy consumption (**e**) 7.A.1 Investments in clean energy (**f**) 7.B.1 Energy services for developing countries. (Data adapted from Our World in Data, World Economic Forum [104–109])

job opportunities, and affordability gaps for low-income communities in adopting renewable technologies. The following analysis were made,

- The United States witnessed a 0.8% CO_2 emission increase (36 Mt), primarily due to increased electricity demand during summer heat waves. Solar and biomass energy showed promise with lower installation costs and shorter payback periods. When assessing the sustainability of renewables, solar, hydroelectric, wind, biomass, geothermal, and nuclear energy were ranked from highest to lowest sustainable. Immediate challenges to address are the issues associated with the credibility of CO_2-equivalent emissions. The method lacks specificity in distinguishing between different gases, such as CO_2 and CH_4, each with unique global warming potentials and atmospheric lifetimes. Focusing on methane emissions reduction may offer more immediate global warming mitigation.
- The shift toward achieving net-zero emissions by 2030 has the capacity to generate 9 million new jobs in the energy sector, counterbalancing the anticipated loss of 5 million jobs in fossil fuel production. In the realm of clean energy, encompassing efficiency, automotive, and construction, there is a potential for over 30 million jobs, underscoring the opportunities in emissions-reducing technologies. However, such a transition necessitates workforce retraining and may encounter resistance from fossil fuel interests, posing the risk of social disruptions in affected communities. It is imperative for government support, characterized by inclusive criteria, to play a vital role in facilitating economic development and securing public acceptance.
- Closing the investment gap in emerging economies is crucial for equitable climate action and sustainable development. Increased financial and technical support, involving concessional and private sector capital, is essential. Without a substantial rise in clean energy investment, global efforts to combat climate change and achieve sustainability goals will face significant challenges.

Prospects

1. If renewables are harnessed with a concerted effort to minimize GHG emissions, the prospects are promising. A substantial reduction in carbon footprint would be achieved, significantly contributing to global climate goals.
2. While the renewable energy sector holds great potential for innovation and job creation, it requires efforts to retrain and upskill the workforce from traditional energy industries. Adapting to this shift will be crucial in maximizing the economic benefits and ensuring a sustainable transition for all stakeholders involved.
3. Implementing targeted subsidies and financial incentives to reduce the upfront costs of renewable technologies for consumers and businesses could also support the global climatic initiatives.

Authors viewpoint

The transition from petroleum to electrification and the fight against climate change present a multifaceted challenge that demands a debatable approach. There is no one-size-fits-all solution; instead, a careful evaluation of interconnected processes in energy extraction is required until renewable technologies can independently lead the way. While fossil fuels are currently necessary for decarbonization, powering EVs, and supporting renewable energy production, it is crucial to ensure their use aligns with UN sustainability goals. Despite notable progress, achieving the SDG7 goals demands ongoing efforts, including the establishment of comprehensive and unified GHG reduction standards, optimized resource allocation, micro-assessment of GHG emissions, mandatory sustainable reporting, and the introduction of Green Scores. Developing economies face an inequitable burden in the transition, experiencing the impact of rising fossil fuel prices, particularly in Asia and Africa where 90 million people struggle with energy poverty. This situation adversely affects education and income stability. There is an urgent call for investments in off-grid renewables, especially solar. Ongoing regional disparities show that Europe and the US lead in investments, making up 40%, while developing nations receive only 15%. Innovation, market-driven strategies, data transparency, fact verifiability, global collaboration, and increased public awareness about climate change are critical components of this clean energy transition.

Appendix

Methodology

This article was drafted by reviewing 67 primary research articles from the Scopus database from 2014 to 2023 based on PRISMA approach [118] and [119]. These articles were curated through targeted searches using specific keywords combinations, "SDG7 AND Efficiency," "SDG7 AND Challenges," "SDG7 AND Africa," "SDG7 AND China," "SDG7 AND India," "SDG7 AND Europe," "SDG7 AND Indonesia," "SDG7 AND Trade-offs," 7 AND

Renewable Energy", "SDG7 AND Sustainable Development", "SDG7 AND Energy Access", "SDG7 AND Clean Energy", "SDG7 AND Rural Electrification", "SDG7 AND Energy Transition", "SDG7 AND Policy Implementation", "SDG7 AND Technology Innovation", "SDG7 AND Energy Security", "SDG7 AND Carbon Emissions", "SDG7 AND Green Economy","SDG7 AND Climate Resilience", "SDG7 AND Power Generation", "SDG7 AND Energy Poverty", "SDG7 AND Sustainable Practices", "SDG7 AND Access to Electricity", "SDG7 AND Energy Affordability", "SDG7 AND Decentralized Energy", "SDG7 AND Urban Energy", "SDG7 AND Energy Efficiency Measures" and "SDG7 AND Case Study." The initial pool of identified articles across all searches ranged from 150 to 170.

The final selection was refined based on relevance, and alignment with the theme, culminating in a set of 67 research articles. The article also has used data from sources including the IEA, IRENA, World Economic Forum, EIA, and Our World in Data. The data for this study was gathered from various sources, curated, and subsequently visualized using Microsoft Excel and Origin 3.2. Additionally, the study delves into the authors' perspectives on potential future developments in this context. For the convenience of researchers and stakeholders interested in further scrutinizing or replicating our work, all the datasets employed in this study have been available for access in the 'Datasets.zip' archive, provided the original source solely owns the rights for the datasets and must be cited. Furthermore, to uphold transparency and acknowledge the contributions of the original data sources, we have documented the copyrights and sources in the accompanying 'copyrights and sources.docx' file.

Abbreviations

CO_2	Carbon dioxide gas
CH_4	Methane gas
O_3	Ozone gas
N_2O	Nitrous oxide
H_2O	Water
ASEAN	Association of Southeast Asian Nations
BP	British Petroleum
CO_2-e	CO_2 equivalent
CFCs	Chlorofluorocarbon
EIA	U.S. Energy Information Administration
EMDE	Emerging Market and Developing Economies
EROEI	Energy Return on Investment
GDP	Gross Domestic Product
GWEC	Global Wind Energy Council
GWP	Global Warming Potential
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
SEIA	Solar Energy Industries Association
SDG	Sustainable Development Goals
WRI	World Resources Institute

Glossary

Climate change	Long-term alterations in temperature, weather patterns, and sea levels due to human activities, primarily the release of greenhouse gases
Decommissioning	Reducing material usage and waste generation by employing efficient technologies and sustainable practices
Dematerialization	Reducing material usage and waste generation by employing efficient technologies and sustainable practices
Fossil fuels	Non-renewable natural resources like coal, oil, and natural gas used for generation of energy (electrical)
LCA	Method to evaluate environmental impacts of a product or process over its entire life cycle, from production to disposal
Netzero	Achieving a balance between the greenhouse gases emitted and those removed from the atmosphere
Off-grid	Energy systems or communities independent of the main electrical grid, often relying on localized renewable sources
Paris Agreement	Global treaty adopted in 2015, aiming to limit global warming and promote climate resilience
Renewable energy	Power generated from sources that naturally replenish, minimizing environmental impact
Renewables	Energy derived from naturally replenished resources like sunlight, wind, and water
SDG 13	Focuses on climate action, urging immediate steps to combat climate change and its impacts
SDG7	Targets universal access to affordable, reliable, sustainable energy by 2030
SDGs	United Nations' set of 17 global goals to address social, economic, and environmental challenges by 2030
Sustainable energy	Power sources with minimal environmental impact, ensuring long-term availability and reducing harmful emissions

Acknowledgements
Authors thank National University of Singapore for supporting with in-house facilities and access to literatures. Authors acknowledge NUS Hybrid-Integrated Flexible (Stretchable) Electronic Systems (HiFES) Program Seed Fund (Grant No. R265000628133), NUS Resilience and Growth fund for Development of Li-ion rechargeable batteries (A-0000065-54-00).

Authors' contributions
BR and SR did formal analysis, collected, and curated the data, BR wrote the original draft, SR reviewed, edited, supervised, and validated the original draft.

Funding
No funding was received or used for this work.

Availability of data and materials
The data used in this study were discussed in the manuscript. Datasets can be provided upon reasonable request to the authors.

Declarations

Ethics approval and consent to participate
This study does not require ethical approval from Institutions or Organizations. The data utilization adheres to all relevant national and international ethical guidelines, ensuring the rights, safety, involved in the study.

Consent for publication
Authors involved in this study have provided Informed consent for publishing the work in Sustainable Earth Reviews.

Competing interests
There are no conflicts to disclose among the authors.

Received: 19 October 2023 Accepted: 20 November 2023
Published online: 07 December 2023

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