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Article

The role of sustainability and sustainable development in climate change mitigation and adaptation

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Abstract: Today, the best way to discern the interlinkages between climate change and sustainability and/or sustainable development is the United Nations (UN) Sustainable Development Goal (SDG) 13—Climate Action framework. The 2030 Agenda for Sustainable Development adopted in 2015 presents a shared blueprint for the peace and prosperity of humanity and the planet both now and in the future. At its core lie the 17 SDGs, which cover the 169 targets by constituting calls for urgent action in global partnership among developed and developing nations. Within this scope, countries acknowledge the imperative need to engage in strategies that simultaneously eradicate poverty and other deprivations, combat climate change, safeguard oceans, forests, and biodiversity, improve health and education, reduce inequality, and promote sustainable and climate-resilient economic growth. This article will briefly evaluate the various geographical, environmental, educational, and social dimensions of sustainable and climate-resilient socioeconomic development, considering the nexus between combating climate change and adaptation to climate change, as well as the adverse effects of climate change.

Keywords: climate change; mitigation emission reduction; sustainable development goals

1. Introduction

It has been over 35 years since the World Commission on Environment and Development (WCED), set up in 1983, published the well-known report entitled “Our Common Future” in 1987, which was also known as the “Brundtland Report” due to the Commission’s chairwoman, Gro Harlem Brundtland. This touchstone report developed the guiding principles of sustainable development as they are generally understood today [1]. The Brundtland Report stated that most global environmental problems were primarily the result of the enormous poverty of the Global South and the non-sustainable and non-equity patterns of consumption and production in the Global North. It developed a common strategy of “united development and the environment”, which is now described by the common term “sustainable development”. Sustainable development is defined in the report as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [2]. In 1989, the report was debated in the UN General Assembly (UNGA), and the UNGA decided to organize a UN Conference on Environment and Development, the first of which was held in June 1992 in the city of Rio de Janeiro, Brazil. Today, sustainability is discussed as a broader concept, including environmental and ecosystem health and protection, social justice, equity, economic and social vitality, etc. For instance, the University of California Los Angeles (UCLA) Sustainability Committee defined sustainability as the “integration

of environmental health, social equity, and economic vitality to create thriving, healthy, diverse, and resilient communities for this generation and generations to come. The practice of sustainability recognizes how these issues are interconnected and requires a systems approach and an acknowledgment of complexity" [3]. In this respect, sustainable practices support ecological, human, and economic health and vitality. Sustainability also recognizes that nature and resources are finite and should be used conservatively and wisely with a view to the long-term priorities and consequences of the ways in which resources are confidently made use of now and in the future for our children and our grandchildren, respectively, and for the living planet of the Earth.

2. Current situation and trends in terms of climate change and climate action

Various human activities are unequivocally understood to have caused global warming by elevating the global surface temperature by 1.1 ℃ above the pre-industrial levels of 1850–1900 from 2011 through 2020, primarily through the emission of greenhouse gases (mainly carbon dioxide—CO_2, methane—CH_4, and nitrous oxide—N_2O) into the atmosphere. Global emissions of greenhouse gases continue to rise due to unequal historical and ongoing contributions stemming from unsustainable energy use, land use changes, deforestation, and disparities in lifestyles, consumption, and production models across regions, nations, and individuals [4–6]. Observed variations and effects indicate widespread and rapid changes in the atmosphere, oceans, polar ice caps, and biosphere. Human-induced (anthropogenic) climate change is already affecting extreme weather and climate events and natural climate variability worldwide, leading to extensive adverse effects, associated losses, and significant harm to nature and humanity including climate and/or environmental migrations. On the other hand, it has been well-known that vulnerable communities and countries, historically contributing the least to the current climate change, are disproportionately affected.

When considering the existing progress, gaps, and challenges in adaptation, it becomes evident that adaptation planning and implementation have demonstrated advancement across all sectors and regions with documented benefits and evolving effectiveness. Nevertheless, despite the progress made, there persist gaps in adaptation processes, and these gaps are poised to further increase in current implementation rates. While in certain ecosystems and regions, soft and hard boundaries of adaptation have been reached, disparities in adaptation are experienced across regions and sectors. Global financial flows allocated for adaptation continue to limit the access of developing countries to such options on the grounds of limited adaptation options. When examining current progress, gaps, and challenges in climate change mitigation, it is discernible that policies and laws addressing climate change mitigation have consistently evolved over the past decade. However, the Nationally Determined Contributions (NDCs) submitted under the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement until October 2021 encompass global greenhouse gas emissions (mainly CO_2) in 2030 that could potentially exceed a 1.5 ℃ warming threshold, making it challenging to limit warming below 2 ℃ (the Paris

Agreement's global warming targets). Discrepancies exist between projected emissions from implemented policies and those outlined in the NDCs, while financial flows continue to fall below the required levels to meet climate goals across all sectors and regions [4,5,7,8].

The Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015 as a universal declaration of action to end poverty, protect the Earth, and ensure that by 2030 all people have peace and prosperity [9]. The 17 SDGs are integrated—they recognize that action in one area will affect outcomes in others, and that development must balance social, economic, and environmental sustainability [10]. On the other hand, among others, in terms of having objective indicators of sustainable development, there are criticisms. For instance, Hák et al. [11] pointed out that indicators of varied quality have been proposed to assess sustainable development in various aspects, with respect to the fulfillment of certain criteria. Although there are plenty of theoretical works on quality standards for required indicators, in practice users cannot often be sure how the indicators really measure monitored phenomena [11].

SDG 13 aims to "take urgent action to mitigate climate change and its impacts" and recognizes the UNFCCC as the primary international and intergovernmental forum to discuss the global response to climate change. More specifically, the relevant targets of SDG 13 focus on integrating climate change measures into national policies, enhancing climate education, addressing mitigation or elimination of climate change, adaptation, reducing the impacts of climate change, creating awareness about early warnings, and focusing on institutional capacity building. The goals of SDG 13 also necessitate the implementation of commitments undertaken within the UNFCCC and support mechanisms that can enhance effective planning and management capacities related to climate change, especially in the least developed countries and developing Small Island Developing States [6].

The Future We Want, the outcome document of the Rio+20 Conference, underscores that climate change is an "inescapable and urgent global issue with long-term effects on sustainable development for all countries." Through this document, Member States express concerns regarding the continuous rise in greenhouse gas emissions and the vulnerability or susceptibility of all countries, particularly developing ones, to the adverse impacts of climate change. While present and persisting, these concerns have not been notably considered highly meaningful or serious in subsequent years. Member States have called for the widest collaboration and participation of all countries in an effective and appropriate international initiative against climate change [6,7].

The UN Sustainable Development Goal 13—Climate Action has been significantly considered in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C [4]. This report broadly addresses the impacts of 1.5 °C global warming on the pathways of global greenhouse gas emissions related to natural and human systems. It encompasses the necessary reduction of global greenhouse gas emissions (response) required to address the threat of climate change within the context of sustainable development and efforts to eradicate poverty [6]. The report's more optimistic message lies in the synergy between sustainable development and limiting global warming to 1.5 °C. According to this perspective, many pathways

to achieve the 1.5 °C target would contribute to achieving the SDGs in critical areas such as energy access involving new technologies like decentralized renewable energy systems or improvements in public health [7].

3. Climate change mitigation, adaptation, and interactions with sustainable development

Climate change mitigation can be defined as "a set of human activities, initiatives, actions, measures and policies aimed at reducing greenhouse gas emissions in all human systems and improving and increasing sinks" [6]. It may be possible to define adaptation separately for human systems (socioeconomic sectors, activities, etc.) and natural systems (biomes, ecosystems, habitats, life communities, etc.). With this approach, adaptation in human systems can be defined as "the process of adaptation to the existing or expected climate and its effects to reduce losses and damages or to take advantage of beneficial opportunities," and adaptation in natural systems can be defined as "the process of adaptation to the current climate and its effects" [6,8]. Regular, rational, and planned human initiatives based on the values of nature, people, and ecosystems, considering science, can facilitate adaptation to the future climate and its effects. In fact, adaptation is a factor that should be considered at the very beginning and at every stage of a sustainable development process. By integrating this early into their policies and strategies, governments can accelerate robust economic development while reducing vulnerability to climate change. Adaptation approaches vary by geography, time, funding sources, levels of political support, and dozens of other factors [8]. There is no one-size-fits-all approach to adaptation. In this respect, however, adaptation examples can consist of taking engineering measures, such as raising special walls and levees on highly vulnerable coasts, to protect against, for example, more severe and frequent storms and storm surges that tend to occur higher and more frequently, or to protect water resources, basins, and wetlands, or to protect and restore steppe ecosystems, rainforests or coral reefs, or to provide early warning systems for wildfires and severe droughts.

Climate change mitigation and adaptation together can lead to long-term mutual interactions, synergies, and trade-offs with sustainable development. Accelerated and equitable action in mitigating climate change and adapting to it also provides benefits in avoiding damages caused by climate change and is critically important for achieving sustainable development goals overall [5,7]. Climate-resilient development pathways are progressively constrained with each incremental increase in further global warming. On the other hand, there is an increasingly narrowing window of opportunity to secure a liveable and sustainable future for everyone.

Climate change mitigation and adaptation options can also lead to synergies and mutual interactions with other aspects of sustainable development. Considering climate justice, these synergies and trade-offs depend on the pace and magnitude of changes, including inequalities, within the development context [5]. This is because as climate change intensifies, the potential or impact of certain adaptations and climate change mitigation options diminishes. For instance, transitioning to low-emission systems in the energy sector could yield numerous additional benefits, including

improvements in water, soil, and air quality, and health. Potential synergies exist between sustainable development, such as energy efficiency and renewable energies.

For agriculture, land, and food systems, numerous land management options and demand-side response options (such as dietary choices, reducing post-harvest losses, and reducing food waste and excess) can contribute to eliminating poverty and hunger, particularly in developing countries and impoverished communities, while enhancing health, well-being, access to clean water, sanitation, and sustaining life on Earth [12]. Conversely, certain adaptation options that encourage the intensification of production, such as irrigation methods not based on modern (e.g., drip irrigation, sprinkler systems, etc.) scientific techniques, may have adverse effects on sustainability (e.g., in terms of biological diversity, ecosystem services, depletion of groundwater, and water quality, etc.).

Carbon Dioxide Removal (CDR) represents a significant concept elucidating approaches aimed at removing carbon dioxide (CO_2) from the atmosphere. CDR encompasses a wide array of methodologies, including Direct Air Capture (DAC), coupled with permanent storage, soil carbon sequestration, bioenergy with carbon capture and storage (BECCS), enhanced mineralization, ocean-based CDR, afforestation/reforestation, among others. Importantly, CDR does not imply point-source carbon capture for fossil fuels or industrial sectors. Alongside the simultaneous deployment of greenhouse gas emission reduction measures and other carbon management practices, CDR serves as a comprehensive climate change mitigation tool addressing emissions stemming from some of the most challenging sectors (e.g., agriculture and transportation), ultimately mitigating 'past' CO_2 emissions from the atmosphere [8].

Within this context, reforestation and afforestation/forest restoration, improved forest management, soil carbon sequestration, peatland restoration, and coastal blue carbon management exemplify CDR techniques and application tools that, depending on the context, can enhance biodiversity, ecosystem functions, employment, and local livelihoods. However, the implementation of biomass production for CO_2 capture and storage or bioenergy through biochar or afforestation, especially on a large scale and in areas with insecure land tenure, could potentially result in adverse socio-economic and environmental impacts, including biodiversity loss, food and water insecurity, local livelihoods, and indigenous rights. Modeled pathways that assume more efficient resource utilization or shift global development towards sustainability entail fewer challenges, such as dependence on CDR and less pressure on land and biological diversity, thus presenting more prominent synergies for sustainable development [5].

Strengthening actions to combat climate change and mitigate its effects necessitates both faster transitions and higher upfront investments, while also providing benefits such as preventing damages caused by climate change and reducing the costs of adaptation. The collective impacts of climate change mitigation on the global Gross Domestic Product (GDP) (excluding damages from climate change and adaptation costs) are relatively small compared to projected global GDP growth. Predicted estimates regarding global total net economic losses and adaptation costs generally increase in tandem with the level of global warming [8].

Cost-benefit analysis is limited in its ability to represent all losses stemming from climate change, including non-monetary damages, or capture their heterogeneous

nature and the risk of catastrophic damage [5]. Many studies indicate that even without accounting for these factors or their co-benefits, the global benefits of limiting global warming to 2 ℃ surpass the costs of mitigation. This finding holds strong despite a wide range of assumptions regarding inequalities and social preferences. Therefore, steering global efforts towards limiting global warming to 1.5 ℃ rather than 2 ℃, in line with UN-guided climate actions (such as the UNFCCC Paris Agreement, UN SDGs—Climate Action, etc.), will increase mitigation costs [5,8]. However, it will also bring substantial benefits in terms of reduced impacts, associated risks, and decreased adaptation requirements.

Considering other dimensions of sustainable development, such as the potentially robust economic benefits derived from improving air quality for human and ecosystem health, could enhance the anticipated benefits of climate change mitigation. The economic impacts of strengthened mitigation actions vary across regions and countries, particularly depending on economic structure, regional emission reductions, policy design, and the level of international collaboration. Conversely, ambitious mitigation pathways imply significant and sometimes disruptive changes in the economic landscape, affecting short-term actions, fairness, sustainability, and finance. This holds especially true for developing and least-developed countries and impoverished communities, resembling the potentially more devastating social, economic, societal, and environmental consequences similar to maladaptation actions [8].

4. Some elements of comprehensive climate action for climate resilient development

A comprehensive and equitable approach integrating climate change mitigation, adaptation, and development should be thought of to advance sustainable development in the long term. Comprehensive responses within this scope can leverage synergies for sustainable development and reduce trade-offs [5]. Shifting development pathways toward sustainability and developing climate-resilient sustainable development is possible when governments, civil society, private sectors, and capital groups make community-centric development choices prioritizing risk reduction, fairness, and socio-economic-environmental justice and equity [7,8]. This is achievable when decision-making processes, financing, and actions are aligned across governance levels, sectors, and timeframes, emphasizing local knowledge and inclusive processes that include indigenous knowledge. However, opportunities for action may significantly differ among regions and within them due to historical and ongoing development models, a trend that is likely to persist in the future. Therefore, accelerated financial support for developing countries holds critical importance in enhancing climate change mitigation and adaptation actions.

Moreover, policies that shift from ‘traditional’ continuous production and industry-based growth paths to sustainability can expand the existing array of mitigation and adaptation efforts. Broader sectoral policies integrating approaches that encourage lifestyle or behavioral changes, combined with actions redirecting climate change mitigation towards development pathways such as financial regulations or macroeconomic policies, can overcome various barriers and create a wider range of

mitigation options [8]. Investments in integrated, inclusive planning and decision-making processes related to urban infrastructure can significantly enhance the adaptive capacity of both urban and rural settlements. The significant human habitation in the geomorphologically low coastal zones, coupled with the increasing and compounded climate risks faced by these populations, underscores the crucial role of coastal cities and settlements in advancing climate-resilient development, both within national economies and beyond [13].

The observed adverse effects of climate change, related losses and damages, anticipated risks, vulnerability trends, and adaptation limits indicate that the urgency for transformation toward sustainability and climate-resilient sustainable development is more pressing than previously assessed [7,12,14]. Furthermore, climate-resilient development integrates both adaptation and greenhouse gas reductions to advance sustainable development for all. Paths toward climate-resilient development have been gradually constrained by past developments, emissions, and particularly by each increment of warming above 1.5 ℃ due to climate change. Several studies, notably the latest reports from the Intergovernmental Panel on Climate Change (IPCC) offering the most significant global climate change assessments [15–17], suggest that in some regions and sub-regions, climate-resilient development may not be achievable if global warming surpasses 2 ℃. Protection of water resources, agricultural lands, biodiversity, and ecosystems among other aspects is essential for climate-resilient development. However, the capacity of biodiversity and ecosystem services to adapt to escalating levels of global warming is limited, increasingly complicating the achievement of climate-resilient development beyond the 1.5 ℃ global warming threshold [4,13,14].

Globally, every geographical and climatic region of the Earth is currently facing more frequent and severe compound and/or consecutive climate risks in the short term. Changes in these risks stem from alterations in the degree of danger or disaster, the exposed population, and the level of vulnerability of humans, living beings, biodiversity, and ecosystems [8]. Climate-related disasters can trigger chains of risks that spread across regions, affecting multiple sectors, and following intricate natural and societal connections (**Figure 1**). This initiates significant obstacles to the successful advancement and widespread implementation of adaptation and climate-resilient sustainable development. For instance, a severe compound heatwave and drought striking an agricultural region exemplify how interconnected risks lead to consecutive geographical, ecological, economic, and societal consequences, particularly impacting vulnerable groups like small-scale farmers, children, and pregnant women even in distant areas (for example, in **Figure 1**). Additionally, the figure might include various impacts of a prolonged and severe compound heatwave and hydrological-ecological drought on forest fires.

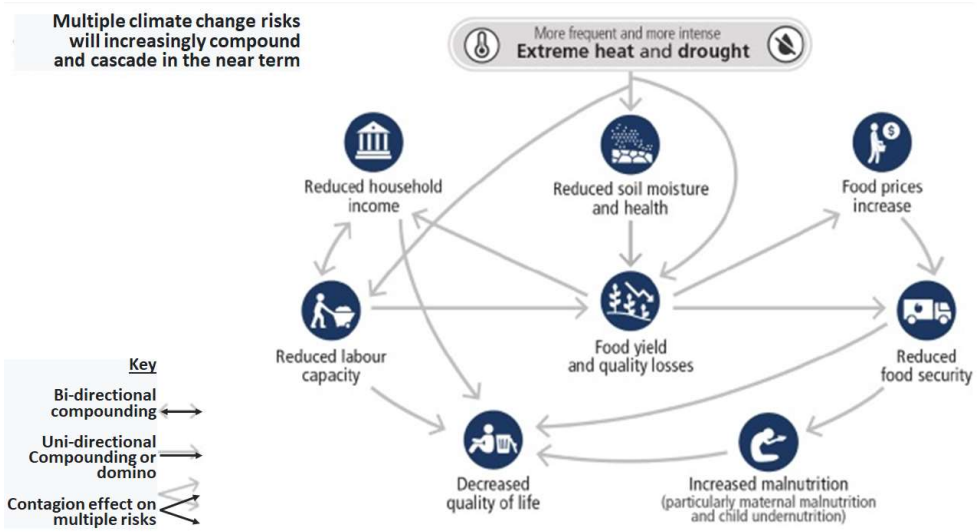

Figure 1. The compounding effects and various interactions of multiple climate change risks for smallholder farmers (re-arranged with some modifications from IPCC 2023). The figure displays the compounded impacts and interactions resulting from extreme high-temperature events and drought occurrences, such as record-high temperatures, prolonged and severe heatwaves, and agricultural-hydrological droughts. These factors lead to yield losses and quality reduction in agriculture.

Climate change poses a threat to both human well-being and the health of the planet. Therefore, any delays in coordinated and forward-looking global action concerning climate mitigation and adaptation carry characteristics that might lead to missing a rapidly closing window of opportunity to secure a liveable and sustainable future for everyone [8]. Removing or mitigating barriers to implementing and executing widespread climate mitigation and adaptation options will be necessary. Numerous limits on the feasibility or realization of these options, including economic, technological, institutional, social, environmental, and geographical barriers, could be overcome by addressing a range of obstacles [5]. The feasibility and effectiveness of these options increase through public, comprehensive, multisector solutions that differentiate responses to climate risk, interrupt between systems, and address social inequalities [8]. Strengthened short-term actions in cost-effective pathways modelling global warming to 2 ℃ or lower can better reduce the overall risk to the feasibility of system transitions compared to modelled pathways involving delayed or uncoordinated actions.

Various socio-economic and ecological development pathways and their associated outcomes indicate a rapidly narrowing window of opportunity to secure a liveable and sustainable future for everyone and all living beings. For instance, climate-resilient development represents the process of implementing greenhouse gas reduction and adaptation measures against the adverse impacts of climate change to support sustainable development [8]. Divergent pathways demonstrate how interactive choices and actions made by various government, private sector, and civil society actors can advance climate-resilient development, shift pathways towards sustainability, and facilitate lower emissions (high emission reductions) while adapting to climate change [5,13]. These various insights encompass diverse

knowledge and values, cultural perspectives, indigenous and local knowledge, and scientific information.

Droughts, storms, extreme rainfall, floods, or non-climatic events like epidemic diseases (e.g., COVID-19 pandemic, Ebola virus disease, etc.) can create more severe disruptions in pathways with lower climate resilience compared to those with higher climate resilience. In a 1.5 °C global warming scenario, there are limits to adaptation and adaptive capacity for some human and natural systems, and with each incremental increase (e.g., 0.1 °C) in warming, losses and damages will escalate [4,5,7,18]. The development pathways followed by countries throughout all stages of economic development influence the level or magnitude of greenhouse gas emissions, shaping the varying challenges and opportunities for mitigation across countries and regions. Action pathways and opportunities are shaped by past actions (or inactions and missed opportunities, etc.) as well as facilitative and constraining conditions, and they intersect within the context of climate risks, adaptation limits, and developmental gaps [5]. The longer emission reductions are postponed, the fewer effective opportunities will remain available for adaptation.

5. The role of science and education in achieving the sustainable development goals

In this section, a brief review of the current science and education policies and actions on climate change mitigation and adaptation has been performed. In the context it was discussed so far, answering the questions of how the national and global scientific community should support the implementation of the SDGs and strengthen its capacity, focusing, inter alia, on how educational institutions from primary and secondary education to universities and science academies can play their role in this system to improve the input of the SDGs into the national and global policy environment, etc. are all vital.

There are many scientific articles written about climate change education and the role of science and education in climate change mitigation and adaptation and disaster risk reduction, etc., many of which were prepared as a review or an assessment study [19–26]. It is recognized that the Climate Change Education for Sustainable Development is a comprehensive and multidisciplinary approach. “It asserts that it should not only include relevant knowledge on climate change, environmental and social issues, disaster risk reduction, and sustainable consumption and lifestyles, but also a focus on the institutional environment in which that content is learned to ensure that schools and education systems themselves are climate-proofed and resilient as well as sustainable and green” [20].

Education, which is linked to “SDG 4: Quality education”, and science is key to achieving all SDGs in Agenda 2030. The remaining 7 years to 2030 will be critical to revitalizing national and global efforts to transform education so that states and communities have the skills and knowledge to live together in harmony with our approximately 4.6-billion-year-old Living Planet of the Earth. However, aside from the effects of major global crises to date, it is observed that efforts to achieve the SDGs have slowed down not only in Turkey but also in many other countries, which have never been at the level they should be. In this context, one of the biggest obstacles to

progress has been the lack of scientific literacy, especially the understanding of sustainability, among the generations that will assume leadership. Therefore, there is an urgent need to find new ways of education that will serve our common needs and future. On the other hand, there are many strengths to take forward and many things that need to change. For example, a new social contract for education both in my country and other countries could provide both a vision and a solid and ambitious process for transforming education.

Science and education have always had to adapt to and respond to a changing world. Today, more than ever, education must help transform the world. In this context, first, it should be ensured that education is a lifelong human right. Unsustainable, undemocratic, and non-participatory economic and social development models endanger the future of humanity and the Earth. In this context, education is a part of the problem and the solution, and the education systems do support environmentally sustainable, democratic, and socially fair progress and development models [6,8]. Moreover, education is the best tool to optimize the relationship between democracy, diversity, social progress, prosperity, justice, and equity. However, currently, worldwide education is not suitable for these purposes. That is why a bold transformation in education is urgent and a priority.

For example, the SDG Academy, which supports UNESCO's 2030 Education for Sustainable Development (ESD) roadmap, was tasked with creating and curating the best educational content available on sustainable development and presenting it as a global public value [27]. Although the initial focus was on higher education institutions, the focus is now on ensuring the continuity of sustainable development education from pre-school to lifelong learning and implementation efforts. The core mission of the SDG Academy is to promote educational pathways that will help students acquire the tools, skills, and knowledge that will promote sustainable development at all stages of their lives.

Ideally, individuals at all stages of life should understand how they live together in harmony with other people, societies, and the Earth. In this context, all of us, in Turkey and in all countries of the world, must learn how to establish positive bonds with humans and nature in our daily activities and pursuits. This will not only secure a much-improved life support system for today's generations but also a sustainable future for future generations and societies.

Finally, it is useful to remind people that ESD is the key to achieving sustainable development through the following six SDG transformations [28]:

1) Education, gender, and inequality.
2) Health, welfare, and demography.
3) Decarbonization of energy and sustainable industry.
4) Sustainable food, soil, water, and oceans.
5) Sustainable cities and communities.
6) Digital revolution for sustainable development.

6. Concluding remarks

Each incremental increase in global warming will escalate losses and damages, making avoidance increasingly challenging, and the most vulnerable, impoverished

individuals, communities, and low-income working or unemployed labor classes in every country will experience intensified adverse effects. Global assessments indicate that overall adaptation cannot prevent all losses and damages effectively, even before reaching firm boundaries. As it has been learned from past discussions under the UNFCCC process and current negotiations within the Paris Agreement, losses and damages will highly likely be distributed unequally among social classes, regions, and sectors. Especially in highly vulnerable developing and least developed countries, which have high vulnerability, these losses and damages are unlikely to be comprehensively and fairly addressed by existing financial, governance, and institutional arrangements. "High levels of poverty, water, food, and energy insecurity, vulnerable urban areas, degraded ecosystems, rural environments, or biomes with limited resources face numerous non-climatic challenges exacerbated by climate change, hindering climate-resilient sustainable development" [13].

On the other hand, there should be a clear education agenda at the global, regional, and national levels in climate change adaptation and mitigation strategies, which require learning new knowledge and skills and changing behaviors to manage and overcome the risks of adverse climate change impacts by reducing the vulnerabilities of the human and natural systems. Consequently, not only investing in quality education for mitigating and adapting to climate change but also strengthening emergency preparedness through capacity-building in disaster risk reduction and climate change adaptation in the education sector are essential tools in achieving SDG transformations.

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