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Carbon Farming: A Promising Approach to Climate Mitigation and Adaptation in India

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Authors' contributions

This review was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This article addresses India's role in the reduction of GHG emissions, the impact of renewable energy and the application of solar energy. In response to the climatic challenges, India is meticulously stepping towards offsetting or the onset of carbon farming such as organic cultivation and solar energy interventions. Offset carbon farming area of 5. 387 Mha organic farming could sequester carbon annually of 6.567 mt, simultaneously; it has the advantage of reducing synthetic nitrogen fertilizer application doses ranging from a minimum of 0.27 mt and a maximum of 1.08 mt per hectare. Furthermore, solar energy can indirectly be used as SWH suitable for average family households contributing carbon credits of 771 kg-824 kg in addition to saving an annual electricity

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burden of around 1365 kWh to 1459 kWh and directly utilized for solar PV electricity generation of 1 MW will offset approximately 730 tons of CO_2 emissions, which is equivalent to 33, 183 carbon-absorbing trees (22 kg of CO_2 absorbed/ tree/year). Carbon farming has challenges encompassing economic, technological, policy, and knowledge-based barriers that require innovative solutions and concerted stakeholder efforts.

Keywords: Carbon farming; carbon sequestration; flat plate collector; GHG emission; G-20; organic farming; photovoltaic cell; solar panel.

1. INTRODUCTION

Carbon credit also known as carbon offsets or emission reduction credits, and term used to measure tons of carbon dioxide or its equivalent greenhouse gas is capsized trough climate resilient methods such as soil carbon sequestration, renewable energy, conservation ecology, blue carbon management, ocean alkalization and increase of power efficient machines/tools. Carbon credits are financial instruments used in carbon trading markets to stimulate steps to reduce greenhouse gas emissions. Due to climate change, the Intergovernmental Panel on Climate Change (IPCC) has laid stringent acts and regulatory frameworks for the alleviation of carbon dioxide emissions. In India, the distribution of greenhouse gas (GHGs) emissions from different sectors is electricity & heat-35%, agriculture-23.18%, manufacturing and construction 15%, transportation-8.645%, building-5.08%, industrial process-4.67%, fugitive emissions 2.78%, waste-2.67% and other fuel combustion-2.03 % [1]. Consumption of nitrogen, synthetic fertilizers, in India was 17.6 Mt and its share of global GHGs emissions was 14.7%, through Industry emissions from synthetic nitrogen fertilizer production was 55.2±8.6 Mt CO_2 and soil emissions from application of synthetic nitrogen in agriculture was 110.4±85.2 Mt CO_{2eq} [2].

2. CAUSE FOR GLOBAL WARMING

If the concentration of CO_2 increases, then there will be rise in heat-trapping capacity of GHGs, which may lead to an increase in temperature. India is third largest GHGs emitter after China and the US. There are three major principal gases globally contribute to climate change are 72 % carbon dioxide (CO_2), 16% methane (CH_4), and 6% nitrous oxide (N_2O). The crucial sources of CO_2 is fossil fuel combustion and deforestation, CH_4 was landfills, rice paddles, and livestock (enteric fermentation and manure), whilst N_2O source urea, and animal waste [3].

Among all GHGs, CO2 or CO2equivalent (CO2eq) were used to represent the impact of climate change. Therefore, the magnitude of global warming is measured using the Global Warming Potential (GWP) scale developed by the IPCC. GWP measures the amount of energy or heat absorbed by 1 ton of GHGs emitted over a given life period. Furthermore, the GHGs impact was determined by the length of time it remained in the atmosphere and the ability of the gas to absorb energy or heat. The payoff of 1 ton of methane and nitrous oxide on warming the atmosphere is 28–36 and 265–298 times, respectively, for 1 ton of carbon dioxide [4]. The atmospheric lifetime of methane gas is much shorter than that of CO_2 (about 12 years compared with centuries for CO_2), but N_2O remain in the air for an average of 121 years.

3. SCOPE OF CARBON CREDIT FARMING IN INDIAN SCENARIO

A number of possible routes are available for carbon farming to achieve cash carbon dioxide reduction (CDR) or sequestering carbon in their soils. This carbon credit scheme is available either through offsets or insets of carbon farming schemes.

3.1 Offset Carbon Farming

In carbon offsets, carbon credits are generated by reducing carbon emissions or sinking carbon into the atmosphere through agricultural and land management practices. Carbon sequestration involves activities that enhance the capture and storage of carbon in plants and the soil. This can be achieved through reforestation, afforestation, agroforestry, crop rotation, strip till, no till, and cover crops.

Reducing emissions from natural and organic agriculture is another aspect of offset carbon farming that minimizes or completely eliminates the use of synthetic fertilizers and chemicals that reduce potent nitrous oxide gas emissions. Furthermore, the reduction of methane, a potent greenhouse gas from livestock can reduce methane output by 20% with minimal lipid supplementation diet [5] and the rice paddles can be achieved by improving manure management, and alternative wetland rice cultivation methods.

3.2 Inset Carbon Farming

The in-setting carbon mechanism is adopted by multinational companies such as PepsiCo, Coca-Cola, Unilever, Heineken, Walmart, Amazon, IKEA, Google, Apple, Bayer, etc., towards the strategic elimination of GHGs emissions within its own supply chain, manufacturing practices, waste management, and sustainable sourcing of materials to achieve goal. Most companies prefer to target agricultural production chain to sequester carbon through the implementation of regenerative agriculture practices, renewable energy adoption, and energy-efficient tools practice.

4. INDIA ROLE IN ALLEVIATION OF GHGS EMISSIONS

Global warming is one of the greatest treat for future generation existence as some of the biological species are at the verge of extinction. Solving it demands requires framing policies and implementation of frameworks, acts and regulation to mitigate carbon emission on or off sites. Apart from this, it is also important to create awareness through teaching, training and publication to bring socio-cultural practice and behavioral changes. Towards climate resilient endeavor, India pledged a 33-35% reduction in the emissions intensity of its economy by 2030, compared to 2005 through various initiatives. The Government of India has launched National Action Plan on Climate Change (NAPCC) on 2008 was outlined eight national missions for achieve set target and to emerge as carbon neutral by 2070. These are national missions on solar, water, sustainable agriculture, sustainable habitat, sustaining the Himalayan ecosystem, green India, enhanced efficiency energy and strategic knowledge for climate change.

For this purpose, Indian organic farming and renewable energy sectors have made significant contributions to limiting GHGs emission. The organic farming cultivable area of 5.392 million hectare (mha) was 3.848% [6] out of the net sown area 140.1 mha. The organic farming method using manure can sequester 1,218 kg of carbon per ha annually, while the legume-based stockless organic system sequestered 857 kg per ha, and the conventional system sequestered 217 kg per ha [7]. Additionally, organic farming eliminates carbon footprints of nitrogen fertilizer's production, processing and transportation.

In India, the suggested amount of nitrogen fertilizer to apply per hectare for rice is 120-200 kg, and for wheat, it is 50-185 kg. As a result, the minimum and maximum reductions in nitrogen fertilizer due to organic farming are 0.27 metric tonnes and 1.08 metric tonnes, respectively [8].

5. IMPACT OF RENEWABLE ENERGY

Renewable energy sector is booming as it was witnessed recent G-20 summit launch Global Biofuel Alliance for mixing 20% ethanol in fossil fuel petrol. Renewable energy also known as non-conventional, permanent, energy produced from sources like the solar, wind, hydro and biofuels, that are naturally replenished, and do not get extinguished. Solar energy is considered the most promising source of limitless energy among all of them.

5.1 Application of Solar Energy

India, a tropical nation, enjoys 2300-3200 hours of sunshine each year, or around 300 days of acceptable solar radiation. Depending on the location, almost every region receives 4–7 kWh of solar radiation per square meter [9]. The energy industry, which is used to produce heat and power, is mankind's largest contributor to the climate catastrophe. Therefore, it is inevitable source of free and ample energy can be harvested broadly classified into two categories:
(1) direct electricity generation using solar photovoltaic panels; (2) indirect conversion using solar thermal collectors [10].

5.1.1 Solar thermal collector–solar flat plate water heater

There are two distinct types of solar flat plate water heaters (SWH): active and passive. The primary distinction between the two is pumping of water through the SWH. The active type of SWH utilizes external electrical energy to pump water, while the passive type does not. The passive type SWH consists of following parts;

5.1.1.1 Flat Plate Collector (FPC)

The FPC rectangular box is an essential component of the solar heating system. It is equipped with liquid heating conductive tubes, and the interior is completely covered in black paint to absorb the heat generated by solar irradiance. The box is sealed with a top cover made of transparent glass, and insulated along the sides and bottom to prevent heat loss. It is constructed from either aluminium sheet or wood, , and is mounted on four stand-angular iron supports inclined south facing in Figure 1.

5.1.1.2 Heating Pipes

It consists of 0.5-1 inch closed conductive copper, steel, or vacuum glass pipes. These pipes are assembled inside a flat-plate collector, where heating and passage of liquid take place inside pipes based on the thermosyphon and capillary flow principle. Furthermore, for the thermosyphoning process to work correctly, the base of the hot water storage tank must be situated at least 1–2 feet (300–500 mm) above the top of the flat-plate collectors. Moreover, these collectors are composed of many evacuated glass tubes connected in parallel. The most common types are glass-glass tubes and glass-metal tubes, which are made of tubes fused to one another at one end. While single evacuated tubes with an aluminium curved plate attached to a copper pipe in the inner part are very efficient but may present some vacuum loss issues because their seal is glass to metal, the selective coating on the inner glass tube in glass tubes absorbs the majority of the available solar radiation.

5.1.1.3 Hot Water Storage Tank

The solar water heating system component has special design to store the heated water based on the size of the FPC and Sunshine exposure time.

$$\text{Solar heat, kj/sec} = \rho x v x \Delta u/\Delta t \quad (1)$$

Where,

ρ=Water Density (Kg/m^3)
v= Water Volume (m^3)
$\Delta u = 4.18\ (T_2 - T_1)$ (KJ/Kg)
Δt=Sunshine time (Sec.)

5.1.2 Sizing a solar flat plate water heater

The size of a solar thermal system is contingent upon a variety of factors, including the amount of hot water required, the desired temperature, and the amount of energy consumed.

Let consider, an area of 1000 cm^2 (1 sq. ft.) can heat approximately 10 liters per day, reaching temperatures of up to 70^{O}C. A flat plate solar water heating system with a total area of 2.01 m^2 and a 200 L storage tank is best suitable for an average four-person household. This SWH system could benefit from annual carbon credits of 771 kg to 824 kg in addition to saving annual energy burden around 1365 kWh to 1459 kWh with a solar incidence of 39.4% to 34.2% [11].

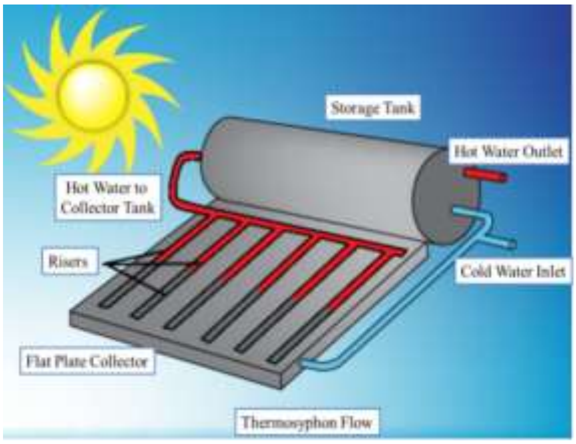

Fig. 1. Solar flat plate water heater

5.1.3 Direct electricity generation: Solar photovoltaic panels (PV cell)

When solar radiation photons strike the surface of the PV cells, the photovoltaic effect directly converts sunlight into electricity without mechanical intervention. These PV cell is the basic building block of a PV system, individual cells can vary from 0.5 inches to about 6.0 inches across and one cell only produces 1 or 5 Watts. There are three main sizes of solar panels or modules to know: 60-cell, 72-cell, and 96-cell have a power output between 250watts and 450 watts. The solar array is a set of solar modules arranged to meet power demands, as shown in Figure 2. The solar panel consists of the following parts [12].

5.1.3.1 Solar Photovoltaic (PV) Module

PV cells were created using doped silicon n-p-type semiconductor materials [13]. These solar cells are sandwiched between front transparent antiglare glass and back plastic, polyvinyl fluoride film, and a rigid panel, as shown in Fig. 3(A). The n-type semiconductor is produced by doping phosphorus, a pentavalent group V element, and this thin wafer is embedded with a metallic conductor and enclosed with a module encapsulater. The p-type semiconductor is made by doping boron, a trivalent group III element, which is embedded with a metallic conductor and enclosed with a module encapsulater. Photovoltaic effects occur when sunlight passes through the thin top layer, an n-type semiconductor, over the depletion zone through the thick p-type semiconductor (Fig. 3-B).

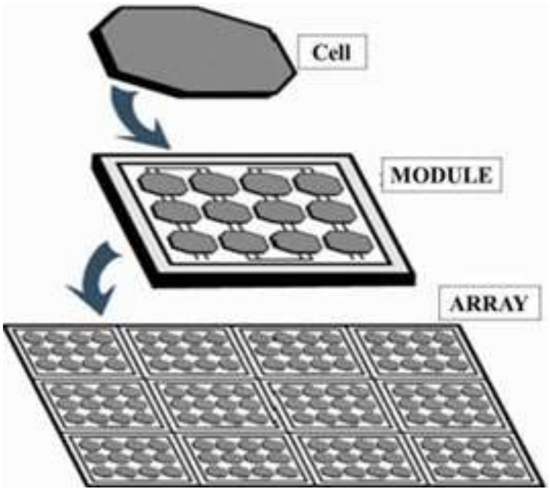

Fig. 2. PV cell system

5.1.3.2 Support Frames

The mounting system that secures the solar array to the ground or rooftop is referred to as a support frame. These frames made up of steel or aluminium is either fixed stationary type or movable type to modify the orientation of the panels, optimizing their exposure by tilting them towards the sun's rays in Figure 4.

5.1.3.3 Electric Cables

These are the cables that carry energy from the system to the users.

5.1.3.4 Inverter

The electronic equipment is responsible for converting the energy generated by the modules (known as direct current, or DC), into the kind of energy used by consumers at home or at the workplace, known as alternating current, or AC.

5.1.4 Applications of direct solar PV cells

Sun light directly used to generate DC current through PV modules are installed in various means of applications demand are broadly classified as;

5.1.4.1 Roof Top Solar (RTS) Programme

The Indian government has set a remarkable and ambitious target of installing 40 gigawatts (GW) of rooftop solar (RTS) capacity by 2022, but as of June 2021, the actual achievement stands at 7.7 GW its adoption is still relatively lower (17%) [14]. Under this scheme, a Central Financial Assistance (CFA) of 40% for RTS systems of up to 3 kW capacity and 20% for capacities beyond 3 kW and up to 10 kW is provided for RTS in Figure 5.

5.1.4.2 Solar Parks

The solar park program was designed to assist solar project developers in establishing solar parks using a plug-and-play model as shown in figure 6. The target for this program was initially set at 100 GW and was launched in 2014 to encourage the development of large solar power projects. Under this scheme, solar projects with a capacity of over 500 MW are considered as solar parks, also referred to as ultra-mega solar parks (UMSP). However, an approximate 467,000 square meters of wasteland available in India that could be utilized to install these large solar parks with a total capacity of 28.8 GW [15].

According to the annual report 2022 of the MNRE, the approved capacities of aggregated solar parks in Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, and Rajasthan are 2,000, 4,000, 2,750, 1,500, and 3,351 MW, respectively.

5.1.4.3 Greening of Islands

This program's heart hub was to install 52 MW of distributed solar PV electricity that was connected to the grid in order to completely changeover the Andaman & Nicobar and Lakshadweep islands to green energy.

5.1.4.4 Solar Cities

The resolution of solar cities is part of the broader movement towards sustainable and renewable energy sources, aiming to reduce CO_2 and tackle climate change. In Indian context, at least one city of each state, which is more tourist destination or state capital, is being developed as a solar city. All electricity needs of the city will be fully met from renewable energy sources, primarily from solar energy.

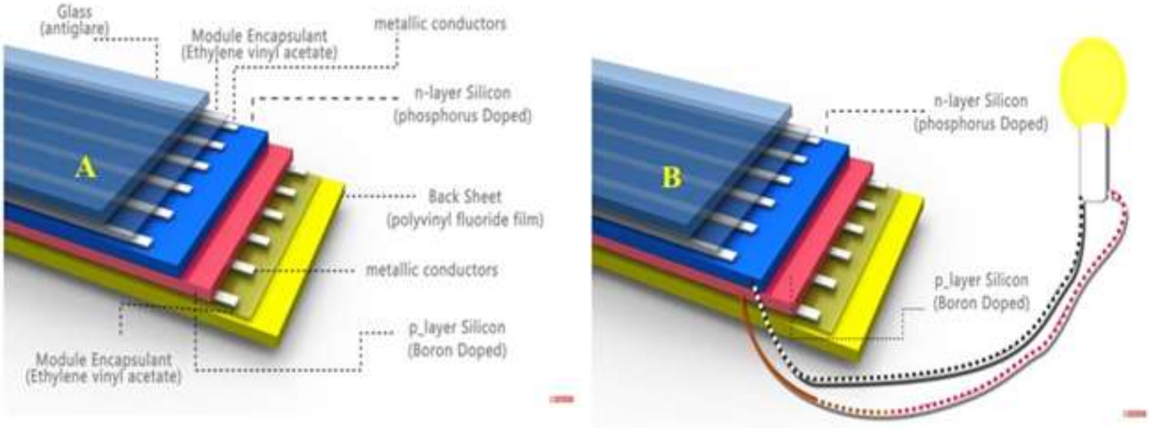

Fig. 3. Configuration and working of solar photovoltaic (PV) cell
(Courtesy: https://www.chrvojeengineering.com)

5.1.5 Sizing of a solar PV panel

India is a tropical country, lying entirely in the Northern Hemisphere, and the mainland extends between latitudes 8°4 N and 37°6'N. Being in tropical zone, the country has assessed a solar potential of 748 GW shown in Figure 7.

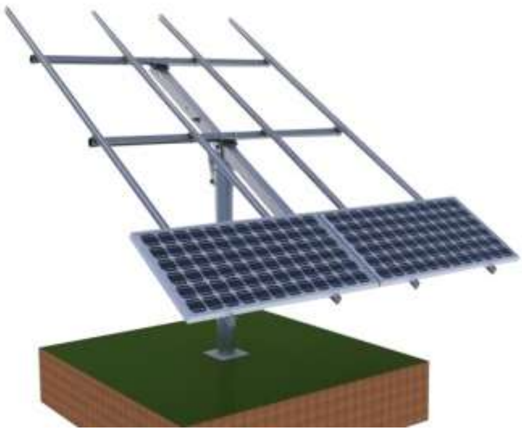

Fig. 4. Solar panel racking system

Fig. 5. Solar roof top PV panel system

A standard solar panel for residential use will contain 60 solar cells with a length of 65 inch and width of 39 inch, while a commercial panel will have 72 solar cells, a length of 78 inch, and a width of 72 inch. The payback time and carbon emission for different types of PV cells are presented in Table 1 below.

Fig. 6. Solar power parks

In the year 2015, India target was to raise 100 GW of solar capacity (including 40 GW from rooftop solar) by 2022 once realized, this would help the country reduce 170.483 million tons of CO2 emissions over the full life cycle of these projects [16]. Further, the solar power installed capacity has reached around 61.97 GW which includes solar projects of 52 GW from ground-mounted, 7.82 GW from rooftop, and 2.09 GW from off-grid (street, home light, and solar pumps) [17].

5.1.7 Solar Electric (PV) System Calculations – Off grid system only

5.1.7.1 Estimating Solar Electric (PV) System Size

Modern photovoltaic (PV) solar panels typically provide 8–10 watts per square foot of the solar panel area (as a general "rule of thumb"). For instance, using an estimated PV cell output of 9 watts per square foot, it is possible to produce approximately 1.8 kilowatts of electricity from a roof measuring 200 square feet in size.

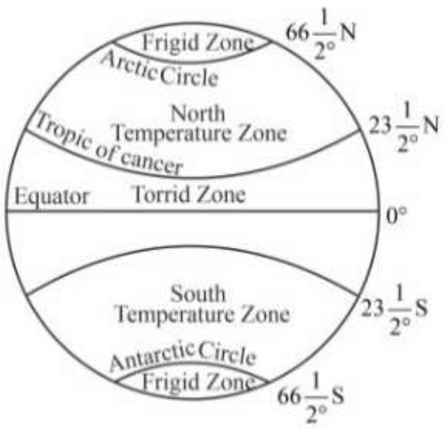

Fig. 7. Latitudes and heat zones

5.1.7.2 Converting Power (watts or kW) to Energy (kWh)

A power source that produces 1,000 watts of electricity per hour is said to produce one kilowatt-hour (1 kWh). A solar energy system typically produces energy for five hours every day. Therefore, if the solar energy system has a capacity of 1.8 kW and operates for 5 h per day for 365 days a year, it will generate 3,285 kWh in a year (1.8 kW x 5 hours x 365 days).

5.1.7.3 PV System Capacity Required (kW of PV)

Annual electricity usage, kilowatt-hours = Monthly Usage x 12 monthly electricity

6. BENEFITS AND CHALLENGES OF CARBON CREDIT FARMING INTEGRATED WITH SOLAR ENERGY

6.1 Benefits

Carbon Sequestration: Trees and vegetation planted on farmland sequester carbon, helping to offset carbon emissions from other sources. This carbon sequestration can be quantified and traded as carbon credits in carbon markets.

Clean Energy: Solar panels provide a sustainable source of electricity or heat, reducing the reliance on fossil fuels and cutting greenhouse gas emissions associated with conventional energy sources.

Financial Incentives: By participating in carbon credit programs, farmers can earn revenue through the sale of carbon credits, offering an additional income stream.

Sustainable Agriculture: Solar energy can enhance the sustainability of farming operations, making them more energy-efficient and reducing operational costs.

6.2 Challenges and Considerations

6.2.1 Upfront costs

Installing solar energy infrastructure can require a significant initial investment, although it often pays off in the long run through reduced energy bills and potential carbon credit revenue.

6.2.2 Land use planning

Careful consideration is needed to ensure that solar installations do not conflict with agricultural land use and can coexist with farming activities.

6.2.3 Regulatory compliance

Compliance with local regulations and permitting for solar installations is essential.

6.2.4 Monitoring and reporting

Robust monitoring and reporting systems are necessary to accurately quantify and verify carbon sequestration for carbon credit certification.

In summary, carbon credit farming with solar energy is a holistic approach that aligns environmental and economic goals. It contributes to climate change mitigation, renewable energy generation, and sustainable agriculture. While there are challenges to overcome, the integration of carbon credit farming and solar energy represents a promising solution for a more sustainable and resilient agricultural sector.

Table 1. Energy payback period and GHG's emissions various among different type of PV panel are detailed [18]

Sl No.	PV panel	Pay-back period	GHG emissions
1	Mono-crystalline silicon (mono-Si)	1.7 to 2.7 years	29–45 gCO_{2eq}/kWh
2	Multi-crystalline silicon (multi-Si)	1.5–2.6 years	23–44 gCO_{2eq}/kWh
3	a. Amorphous silicon (a-Si) b. CdTe thin film c. CIS thin film	0.75–3.5 years	10.5–50 gCO_{2eq}/kWh

While implementing a carbon credit scheme, that also poses several challenges; the challenges are given below:

1. Regulatory and Environment Policy: The effectiveness and stability of renewable energy, regenerative farming practices, afforestation, and reforestation credit schemes are often influenced by the regulatory and policy environment. Frequent policy changes or a lack of supportive policies can create uncertainty for market participants.
2. Verification and Tracking: Accurately verifying the production and delivery of carbon credits via renewable energy, regenerative farming practices, afforestation, reforestation, and other sources can be complex. Thus, tracking these sources' carbon footprint is time consuming and costly and often requires specialized expertise and technology
3. Market Oversupply: Companies investing in renewable energy, regenerative farming methods, afforestation, reforestation, and energy-efficient technology are having trouble because of lower pricing and less incentives brought on by market overstock.
4. Complexity and Transparency: Lack of capacity building and awareness among small and medium sized enterprises (SMEs) to participate in carbon credit markets can be a barrier and complex. Ensuring transparency and ease of participation can help overcome this challenge.
5. Market Fragmentation: Different regions and countries often have their own credit systems and standards, leading to market fragmentation.

7. CONCLUSION

To build safer climate to the next generation, invariably, one has to think of harnessing free and regenerative sources of renewable energy production routes. These greenery paths not only results way forward safer climate, balanced ecosystem and evades fossil fuel dependency. To combat climate change, fundamentally, there can be top down approach and/or bottom up approaches such as domestically framing policy and implementing framework, forming rules and regulation, and capacity building, awareness programs, changes in behavioural perception and socio-cultural options, respectively. India had pledges to reduce CO_2 or CO_{2eq} GHGs by meeting energy requirement 50% from renewable energy by 2030 and has target to achieve net zero carbon by 2070.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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