Prospective Solar Energy Technologies for Sustainable and Inclusive Development in BRICS Countries

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Abstract

The climate change scenario observed in the last few years calls for immediate attention and planned action. One of the major factors responsible for climate change is fossil fuel-based energy consumption patterns which leads to increased greenhouse gas emissions. Energy availability is important for economic development and improved quality of life, therefore transition to clean renewable energy options is required without compromising on energy availability. According to sustainable development goal number seven, for sustainable and inclusive development it is important to focus on clean and affordable energy for all with consideration for the environment. Here the role of solar energy technologies becomes extremely important, as their carbon footprint is low and can be used for a wide variety of applications. This paper discusses the potential of solar resources for the BRICS countries and the prospective solar thermal and solar PV technologies for each country according to the region-wise resource. BRICS countries represent around 40% of the world's population. The methodology for identifying the prospective solar technologies for the BRICS countries is based on an analysis of the solar resource potential for each country. It is found that all the BRICS countries have good solar potential and can utilize several solar energy technologies to enhance green technology practices. Further, the challenges in the implementation and promotion of solar projects are discussed with suggestions for collaborative research and development in this area. Policy requirements to overcome the limitations of the technologies and their penetration are also pointed out.

Keywords: Solar resource, SDG 7, solar thermal, solar PV, solar technologies, climate change, sustainable development.

Introduction

In today's scenario, energy is one of the basic requirements for growth and development of communities and countries. Sustainable development goal number seven focuses on making available affordable and clean energy for everyone as access to energy is linked to economic growth, enhanced productivity, and improved quality of life (Bhuiyan et.al., 2022; Makieta et al., 2022; Makarova et al., 2020).

The availability of clean energy positively impacts health care services, availability of clean water, education, information, communications, environment, agricultural growth, and industrial productivity. Thus, access to affordable, clean, and reliable energy is essential for the reduction of poverty, the promotion of welfare, improving living conditions, and meeting the goals of climate change mitigation (Sengar et al., 2017).

The BRICS (Brazil, Russia, India, China, and South Africa) countries are the emerging economies of the world which share 30% of the global land and 40% of the global population (Abbas et al., 2022). These countries contribute more than 25% to the global GDP, and as a result of economic growth and industrialisation they are major influencers in energy intensity (Agarwal & Kumar, 2023; Liu et al. 2022).

Over the past few decades, the BRICS countries have witnessed rapid economic growth and population rise which resulted in increased use of fossil fuel leading to increased greenhouse gas emissions. The BRICS countries with more than 40% of the world's population are responsible for about 36% of global energy production and consumption (Xinzhu, 2021; Hasan, 2022). The energy sector plays an important role in CO_2 emissions leading to rising temperatures and the threat of climate change. The UN COP 26 conference suggested that it is important to take action now in order to limit global temperatures to 1.5°C or below by the end of this century. The present scenario of carbon emissions from fuel consumption shows that BRICS countries are in the major emitters list as presented in Table 1. China, India, and Russia are the first, third, and fourth largest greenhouse gas emitters globally, followed by Brazil and South Africa.

Table 1: Carbon emissions from fuel consumption for BRICS countries

Country	$MtCO_2$
China	10,398
India	2,251
Russia	1,795
Brazil	450
South Africa	447

Source: Enerdata, 2023

Energy is essential for sustainable development so instead of cutting down on energy use, it becomes important to make a transition towards clean options of energy and enhanced energy-efficient technologies. BRICS countries play an important role in the global population, economy, and environment, therefore the steps taken by them in mitigating climate change will result in positive global impacts (Paul & Patra, 2022; Khare et al., 2023). To address the increased emissions and climate change issues, the BRICS countries are making a transition from fossil fuel to renewable energy sources and green energy technologies (Abbas et al., 2022; Miranda et al., 2021). Studies show that renewable energy can minimize CO_2 emissions for every BRICS country and electricity consumption increases CO_2 emissions in all BRICS countries, and the coefficients are significant (Voumik & Sultana, 2022).

Amongst the clean energy options, solar energy is a promising choice to provide pathways for social and economic development without triggering climate change. Solar energy technologies are suitable for a wide variety of applications for different sectors such as residential, industrial, commercial, and even transportation (Kabir et al. 2018; Hernandez et al., 2019). BRICS countries receive ample amounts of solar energy and can play an important role in the widespread penetration and use of solar energy technologies (Liya et al., 2021). Further, BRICS countries with their varying strengths in manufacturing, research, and development can contribute towards the development of improved and efficient technologies through mutual cooperation.

The present paper discusses the solar energy potential of the BRICS countries based on the availability of global horizontal radiation (GHI) and the photovoltaics (PV) output values. Solar resource potential for each of the BRICS countries is presented in section 3 and the feasible solar technologies are discussed in section 4 of the paper. Solar energy technologies can be classified in two major application areas -thermal and electrical. Solar thermal applications fulfil the needs for heating/cooling whereas solar photovoltaics provides electricity (Kabir et al. 2018; Hernandez et al., 2019). In the present study feasibility of both the major areas of solar thermal and solar PV are discussed with their sub-areas such as Agrivoltaics, Floatavoltaics/Aquavoltaics according to each member country's potential. Further, in section 5 of the paper, the challenges in the promotion and penetration of these solar technologies are discussed and suggestions are pointed out for mutual cooperation in this field by BRICS countries to move forward towards sustainable and inclusive development.

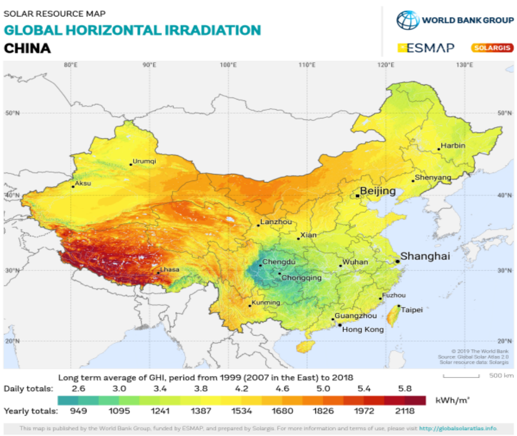
Methodology

The methodology for identifying the prospective solar technologies for the BRICS countries is based on an analysis of the solar resource potential for each country. The global horizontal irradiation and PV power potential for each of the BRICS countries is presented in section 3. Global horizontal irradiation (kWh/m^2) is indicative of the solar radiation availability in different areas. Higher values of global horizontal irradiation are favourable for solar energy technologies, especially solar thermal applications. PV power potential (kWh/kWp) maps show the potential of solar photovoltaic power generation in different areas for each of the BRICS countries. The contribution of solar energy to the total electricity generation of each BRICS country is also discussed. Analysis and comparison of the resource data gives an insight into the prospective solar technologies. The feasible solar thermal and photovoltaic technologies with their sub-areas are presented and reviewed in section 4 of the paper. The challenges in uptake and suggestions for cooperation amongst the BRICS countries in the area of solar technologies are discussed in section 5 of the paper.

Potential of Solar Resource

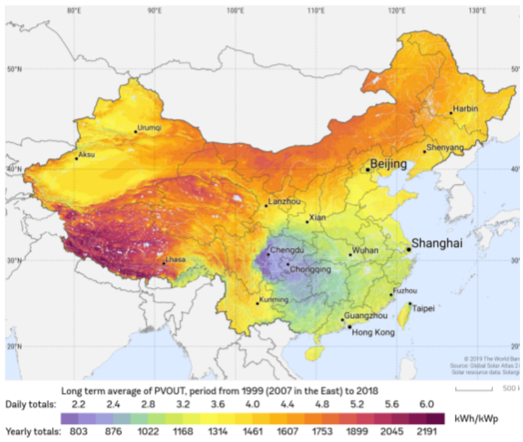
Amongst the BRICS countries China India, Brazil, and South Africa have a good amount of solar radiation potential as can be seen from the solar resource maps presented in figures 1-10. Russia has slightly lower solar potential but still, it holds the promise of supplying useful energy in a clean manner.

Figure 1: Solar resource map for global horizontal irradiation for China



Source: Solargis

Figure 2: Solar resource map for PV power potential for China



Source: Solargis

Figure 3: Solar resource map for global horizontal irradiation for India

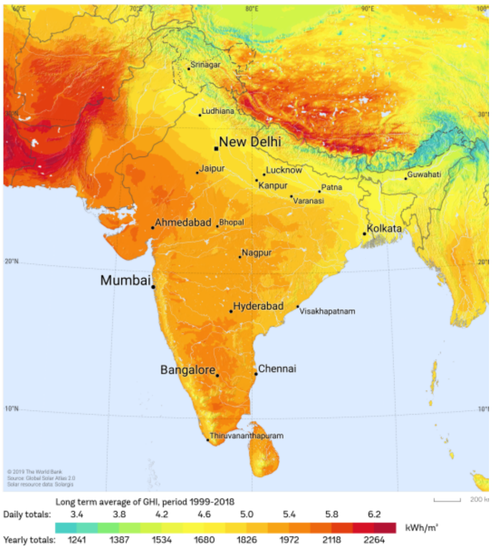


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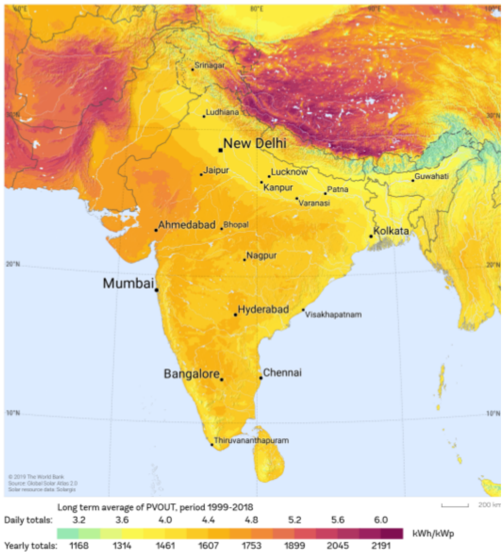
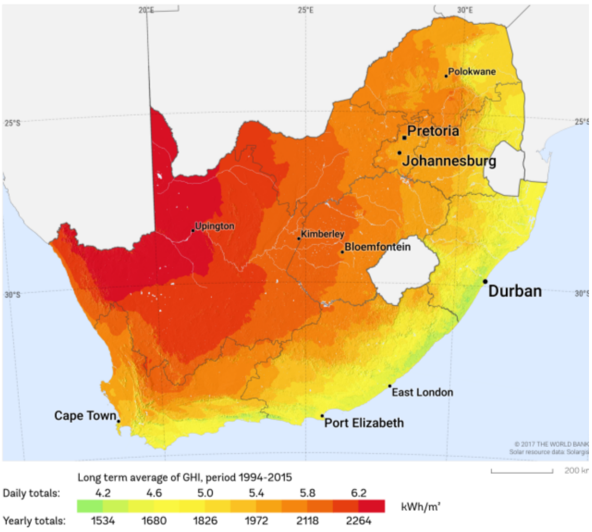
Figure 4: Solar resource map for PV power potential for India



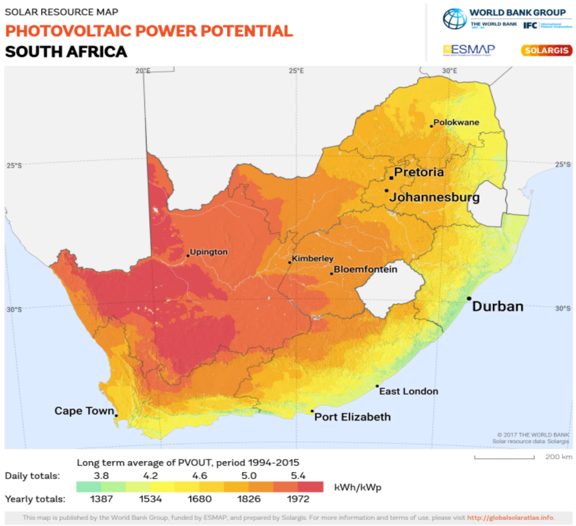
Source: Solargis

Figure 5: Solar resource map for global horizontal irradiation for South Africa



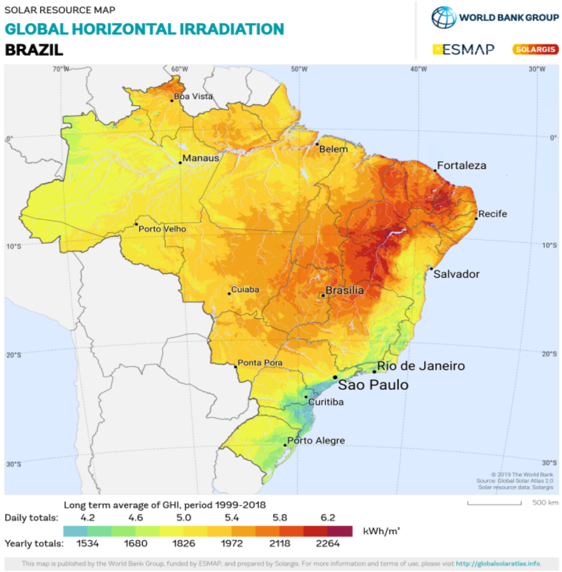
Source: Solargis

Figure 6: Solar resource map for PV power potential for South Africa



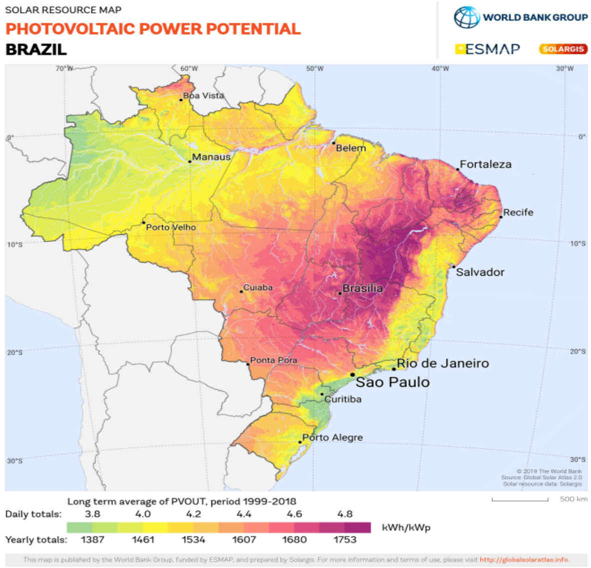
Source: Solargis

Figure 7: Solar resource map for global horizontal irradiation for Brazil



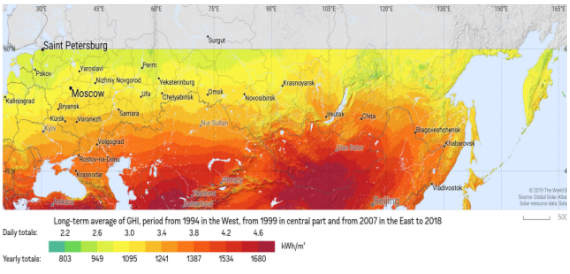
Source: Solargis

Figure 8: Solar resource map for PV power potential for Brazil



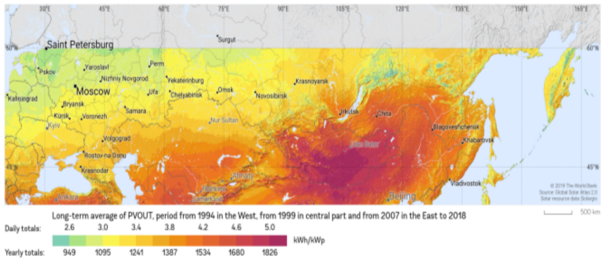
Source: Solargis

Figure 9: Solar resource map for global horizontal irradiation for the Russian Federation



Source: Solargis

Figure 10: Solar resource map for PV power potential for the Russian Federation



Source: Solargis

From Fig. 1 it can be seen that the global horizontal irradiation for China is in the range of 4 to 5 kWh/m², the values are slightly lower for some middle parts (Chengdu and Chongqing) whereas the irradiation is higher than 5 kWh/m² for some western regions in China. The daily total photovolatic power output potential for the entire country of China as can be seen from Fig. 2 is in the range of 4 to 6 kWh/kWp and yearly it lies in the range 1400 to 2000 kWh/kWp. For India the global horizontal irradiation lies between 5 to 6 kWh/m² for major parts of the country except for some areas in North and North-East as shown in Fig. 3. The daily total photovolatic power output potential for India is in the range of 4 to 5 kWh/kWp and on yearly basis, it lies in range 1400 to 1900 kWh/kWp as can be seen from Fig. 4. The values of global horizontal irradiation for South Africa lie in the range 4.2 to 6.2 kWh/m² (Fig.5) and the PV output potential is 4 to 5.4 kWh/kWp on daily basis with values around 1400 to 2000 kWh/kWp for yearly totals (Fig.6).

For Brazil the global horizontal irradiation lies between 5 to 6.2 kWh/m² for major parts of the country as shown in Fig. 7. The daily total photovolatic power output potential for Brazil is in the range 4 to 4.8 kWh/kWp and on a yearly basis it lies in range 1400 to 1800 kWh/kWp as can be seen from Fig. 8. The values of global horizontal irradiation for Russian Federation lie in the range 2.8 to 4.6 kWh/m² (Fig.9) and the PV output potential is 3 to 5 kWh/kWp on daily basis with values around

1000 to 1800 kWh/kWp for yearly totals (Fig.10). The values of solar irradiation vary over a larger range for Russian Federation as compared to the other BRICS countries but still it can be seen that the PV output potential is quite close to other countries for major parts of the Russian Federation. International Energy Agency (IEA) data for electricity production shows that the contribution of solar energy is in the range of 0.2% to 4.6% for BRICS countries (IEA, 2024).

The total electricity production in China in 2021 was 8598977 GWh with 3.8% contribution from solar energy as per IEA. For India in 2021, the total electricity production was 1635165 GWh with 4.6% contribution from solar energy. The IEA data for Brazil shows total electricity production of 677173 GWh with a 4.4% contribution from solar energy in 2022. The total electricity production in Russia was 1159416 GWh with 0.2% contribution from solar energy whereas the total electricity production in South Africa was 244383 GWh with 2% contribution from solar energy in 2021 as per IEA. Therefore, from the above data it can be seen that the contribution of solar power is still quite less in the total electricity generation in BRICS countries. From a look at the solar resource maps (Fig. 1 -10), it is evident that solar potential is available which is still underutilised. Thus, based on the solar resource potential analysis and IEA data it can be said that all the BRICS countries hold the promise of utilization of solar energy technologies for sustainable development.

Feasibility of Solar Energy Technologies

BRICS countries have resolved to increase the share of renewable sources of energy and working towards the adoption of green technology practices in various areas. Fig. 11 summarizes the findings of an interesting study on green technology practices by BRICS countries in the form of intersections to deliver a clear picture of options for mutual cooperation (Miranda et. al., 2021).

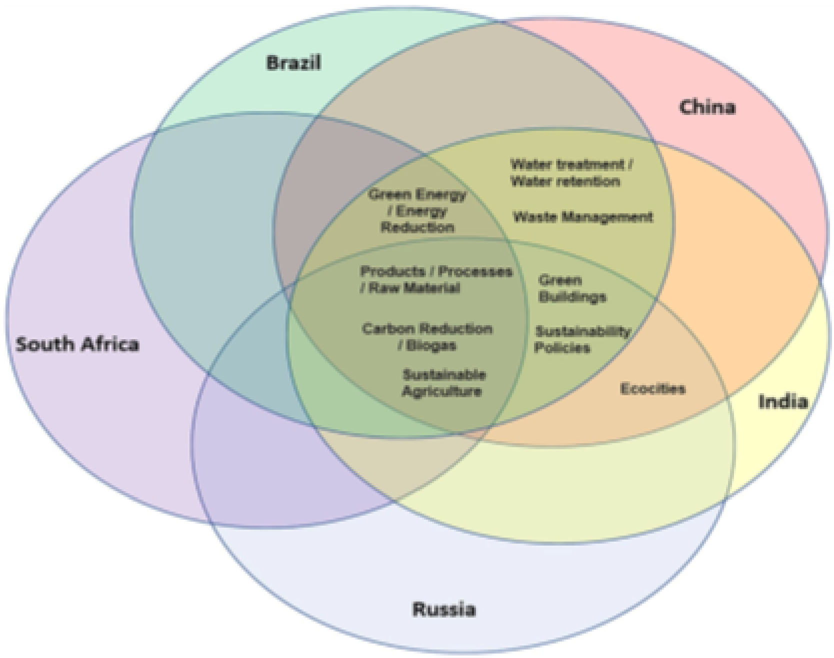


Figure 11: Intersection of Green Technology practices from BRICS countries

Source: Miranda et. al., 2021

From Fig. 11 it can be seen that BRICS countries are focusing on the adoption of green technology practices in the major areas of green energy, products/processes/raw material, carbon reduction, sustainable agriculture, water treatment, waste management, green buildings, eco-cities, and sustainable policies. From Figure 11 it is clear that China and India are trying to adopt all the green technology practices mentioned in the figure whereas Russia, Brazil, and South Africa are focusing on some of the practices. From the point of view of the available solar energy technologies, it is possible that a number of these green technology practices can be met through solar energy.

Presently there are many solar energy technologies and this field is rapidly growing. With sustainable and inclusive development in mind, the main solar energy technologies can be classified as shown in Fig. 12 for different application areas.

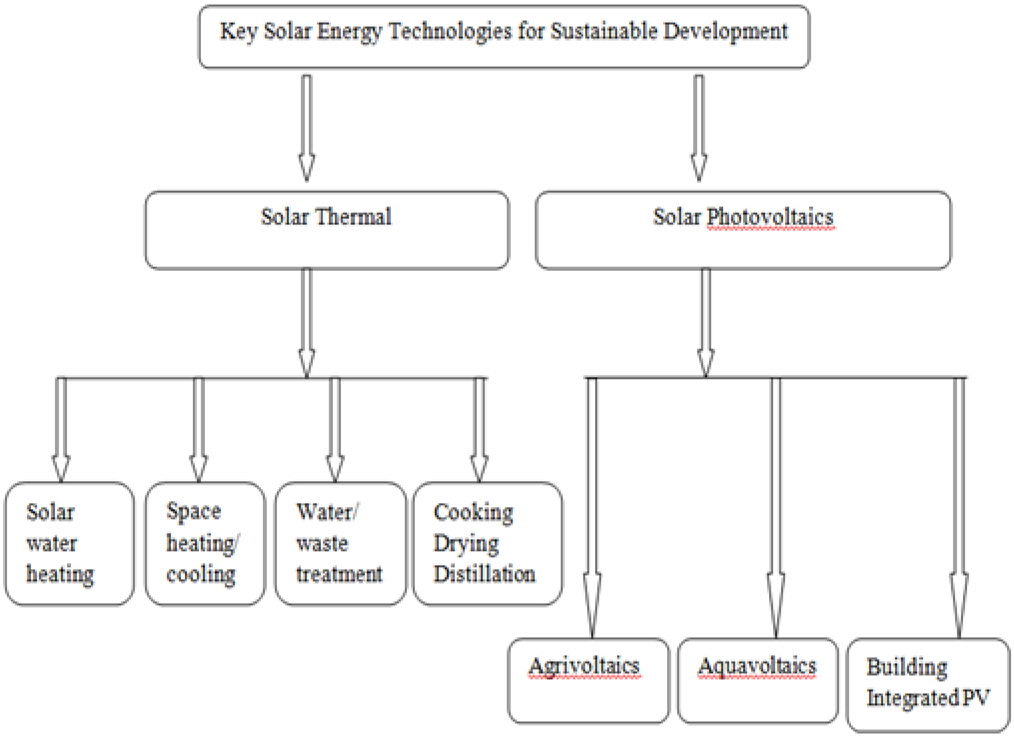


Figure 12: Key solar energy technologies for sustainable development

Source: Compiled by Author

Solar energy technologies can be broadly classified as solar thermal and solar photovoltaics and then these can be sub-classified in divisions according to application areas and technology type. Solar thermal technologies focus on the utilization of solar energy directly for heating or cooling applications. Globally, a major application of fossil fuels is for heating purposes, which can be easily partially met through solar thermal technologies thus reducing carbon emissions. From Figure 12 it can be seen that major application areas of solar thermal technology can be for solar water heating, space heating/cooling, water/waste treatment, cooking, drying, and distillation. There are other applications of solar thermal technology such as power generation but it has not been included here in the figure because due to challenges of its high cost and operation and maintenance requirements, it is not feasible presently (Maka & Alabid, 2022). These solar thermal technologies can be developed further through mutual cooperation by BRICS countries and used in industrial, residential, and commercial sectors for a wide variety of applications. China, India, Brazil, and South Africa can benefit by solar thermal technologies for the adoption of green practices, whereas Russia with a focus on green buildings and ecocities can take solar passive architecture and solar space heating to its advantage.

Solar photovoltaics is growing in its diverse forms such as agrivoltaics, aquavoltaics, and Building Integrated PV (BIPV) to cope with sustainability (Hernandez et al., 2019). Agrivoltaics is a technology that focuses on producing electrical power with agricultural yield so that land area is optimally used and communities are provided with an option of better income and yield. Aquavoltaics is the use of water bodies with solar PV panels for producing power along with aquaculture. These two above-mentioned technologies try to address several issues related to large-size solar power plants and present promising solutions for sustainable and inclusive development of communities, societies, and countries. Buildings are major consumers of electricity, therefore the field of BIPV is developing rapidly to address the issues of carbon footprint by buildings. BIPV offers an opportunity for moving towards energy-efficient and net zero energy buildings which is a main focus area for Russia, India, and China (Miranda et al., 2021). The above-mentioned key solar energy technologies can provide several options for fulfilling energy-related requirements without compromising the environment. Further, these technologies present opportunities for jobs, income, enhanced productivity, and meeting social needs contributing to an increased pace of socio-economic development.

Challenges and Suggestions for Cooperation

Solar energy has the advantage of being widely available, clean with low running cost but there are some challenges also. The main challenges associated with solar energy technologies are that solar energy is diffuse and intermittent in nature and is difficult to store. Due to its intermittent nature, solar energy is not available all the time for fulfilling the requirements therefore backup systems or storage systems are required. With the widespread growth of solar energy, there will be challenges to the existing grid system as it is not prepared to handle the varying power from the solar systems. As discussed in section 2 the contribution of solar energy in total electricity production in BRICS countries is still quite less in the range of 0.2% (Russia), 2% (South Africa) to around 4% (China, India, and Brazil). To increase the contribution of solar energy it is important to work on the challenges related to widespread awareness, policies, incentives, and regulations.

These above-mentioned challenges present opportunities for mutual cooperation of the BRICS countries in research and development in this area. BRICS countries with strengths in research & development, manufacturing, policymaking, and promotion, can effectively cooperate to develop efficient solar technologies for different worldwide regions. The following are the recommendations for cooperation:

- Mutual cooperation in designing solar thermal technologies can save a substantial amount of fossil fuel with a major reduction in carbon emissions for various industries where hot water or steam is required.
- Researches and studies on solar passive architecture combined with BIPV can solve problems of building energy consumption to a large extent.
- Comprehensive study and growth of agrivoltaics and aquavoltaics systems can provide employment opportunities with power generation.
- Water/waste treatment and management through the use of solar energy is an upcoming area that can be further developed through mutual cooperation by BRICS countries.
- Further, for community needs such as cooking, drying, and distillation better systems can be designed and promoted by the BRICS energy experts.
- Solar energy storage and grid renewal with improved transmission and distribution networks are major areas that require strong mutual cooperation and in-depth study and research.
- BRICS can offer a global platform for sharing advanced energy knowledge, designing energy-based educational programs, information on best practices, exchange of data and plans for energy-based sustainable development (Paul & Patra, 2022).

- Mutual cooperation in the form of future research is required to study the viability and feasibility of a consolidated BRICS Just Energy Transition policy. BRICS member countries should be motivated to make a transition to zero carbon through the policy with the option for shared renewable energy resources and components (Ramluckun et al., 2024).

The initiation of BRICS Energy Research Cooperation Platform in 2017 is a welcome step in the direction of cooperation in the energy area which has a major influence on socio-economic development and climate change (Mujumdar & Shadrin, 2021).

Conclusions

The paper presented a study of the solar resource potential and the feasibility of key emerging solar energy technologies for the BRICS countries to address the climate change issue with reduced emissions without compromising on socio-economic development. It is found that all the BRICS countries have good solar potential and can utilize several solar energy technologies to enhance green technology practices. Various solar thermal technologies, agrivoltaic, aquavoltaic, and BIPV technologies can provide promising solutions for reducing carbon emissions, and also at the same time provide opportunities for economic growth, jobs, social security, and improved living conditions. For effective development of these technologies as per the region's requirements, the BRICS countries must cooperate mutually in study, research, design, and manufacturing. It will be a win-win situation for everyone to cooperate in the energy area to promote sustainable and inclusive development of all.

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