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Article

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Prospects and Barriers for Renewable Microgeneration in India

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ABSTRACT

Today, India is one of the largest emitters of greenhouse gases with fast growing energy demand. The fact that India has no nationwide energy system due to natural causes such as impassable forests, mountainous areas, and considerable distances, makes the development of microgeneration based on renewable energy is a promising direction for this country from technical, economical, and environmental points of view. The present paper aims at analyzing barriers for developing the microgeneration based on the most advanced renewable energy technologies (photovoltaics and small wind) in India. Our results demonstrate that for many territories in India, microgeneration is not just a supplementary way to provide electricity to the local population, but also the only way. Therefore, higher technical requirements are imposed, particularly the need for parallel development of microgrid management and energy storage technologies. This creates additional technical, infrastructural, and financial barriers to development and reduces the role of an individual consumer (prosumer). Due to the low importance of individual consumers, companies selling and servicing micro-generating equipment are more focused on the B2B sells format, manifested in the strategy of their representation on the Internet.

Keywords: Renewable Energy, Microgeneration, Microgrids, Energy Policies, Solar Power, Wind Power
JEL Classifications: Q20, Q43, Q48

1. INTRODUCTION

Today, India is one of the largest emitters of greenhouse gases with 3.3 Gt CO_2 according to 2019 data, which is 6.71% of the global emission rate (IEA, 2019; Crippa et al., 2020). The volume of CO_2 emissions from fuel combustion in India amounted to 2.4 Mt of CO_2 in 2019 (Worldbank, 2022). Over the past 9 years, the demand for electricity in the country has increased by about 4.1% per year, and in the next decade, according to forecasts, it will be 6% per year (Charles et al., 2019; Pathak et al., 2022). This makes India one of the countries with fastest growing energy demand.

India's energy sector uses fossil fuels, including oil, gas, and coal and renewable energy. About 74% of the energy demand is provided by coal and oil. That makes India is one of the largest consumers of coal in the world (World Energy, 2013). India spends 30-40% of all import costs on the import of hydrocarbons (Babicheva et al., 2021). Thus, aaccording to the report of the Center for Monitoring the Indian Economy (Blondeel and Van de Graaf, 2018), in 2013-2014, the country imported 171 million tons of coal, in 2014-2015 — 215 million tons, in 2015-2016 — 207 million tons, in 2016-2017 — 195 million tons and 213 million tons in 2017-2018. Despite that traditional resources, particularly oil, gas and coal, have dominated the supply and covered most demand growth in the past (Schiffer et al., 2018), they can no longer cover the rapidly growing demand, especially for country with limited resources. Therefore, a radical change is needed today.

According to the National Decarbonization Strategy, it is expected that by 2030, 50% of India's electricity will be generated from renewable energy sources (RES), and their capacity will increase to 500 GW by 2030. In general, it is planned to reduce the economy's

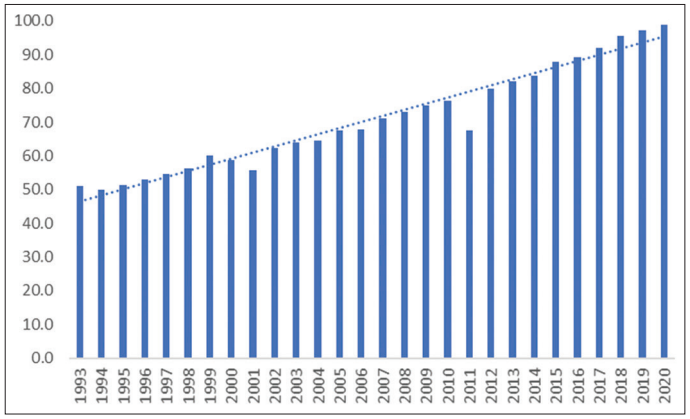
carbon intensity by 45% by 2030 (MEA, 2021; CEEW-CEF, 2021). According to British Petroleum Company (BP) forecasts, by 2050, the share of coal in India's energy sector should decrease (depending on a more or less active transition to clean energy sources) from 11% to 39%, and the share of gas will grow from 5% in 2019 to 8-12% in 2050 (BP, 2022). Therefore, there is an urgent need to find alternative sources of electricity generation. A rapid and global transition to renewable energy technologies is necessary to achieve sustainable growth and national climate policy goals.

Significant shift in energy policy of India began with the Electricity Law adoption in 2003, which created a favourable environment for encouraging private sector participation and competition by providing similar conditions. This has led to significant investments in electricity production, transmission, and distribution. Over the years, electricity generation has increased from about 5.1 billion kWh in 1950 to 1491.9 billion kWh (including imports) in 2021-22. Regional grids have been integrated into a single national grid since December 31, 2013, ensuring electricity free flow through strong interregional AC and DC connections. As a result, unsatisfied peak demand across India and under-supplied energy are steadily declining. The peak power deficit in 2021-2022 was 1.2%, and the energy deficit was only 0.4%. The contribution of renewable energy sources (including large hydroelectric power plants) to installed capacity increased from 5.8% in 2006-2007 up to 39% in 2021-2022 fiscal year (FY), and their contribution to total production increased from 1.5% in 2006-07 to 21.54% in 2021-2022 FY.

Over the past 30 years, the share of the population with access to electricity has grown from 50% in 1993 to almost 99% (Figure 1). However, in fact, at the moment, this actual number is 81% due to the quality of the statistics provided. Today, about 235 million citizens of India-mostly in rural areas-do not have electricity. This makes India the country with the largest population living without electricity.

There is currently no nationwide energy system (NES) in India due to natural reasons, such as the presence of impassable forest and mountainous areas, considerable distances and a reasonably long rainy monsoon season. The creation of an NES with long transmission lines is a complex and expensive task. For this reason, it seems justified to implement the concept of distributed generation, based on RES. In India, the energy cost from renewable sources, considering the latest technological advances in solar and wind generation, becomes competitive compared to imported fossil fuels. In order to accelerate the socio-economic development of individual regions of India, the preferred mode that provides reliable and affordable access to electricity is the microgeneration format as a microgrid with several suppliers (Bhanja et al., 2020). Therefore, the development of microgeneration based on renewable energy is a promising direction for India from a technical, economic, and environmental point of view. As a result of the growing demand for electricity, the demand for energy storage systems is also growing. A critical component of any successful energy storage system is the Power Conversion System (PCS). The PCS is an intermediate device between the storage element, typically large batteries (DC) and the power grid (AC). There is growing interest in power conversion

Figure 1: Access to electricity (% of the population)



system (PCS) in India to supply households with electricity. Such systems should be designed with efficiency and turnover in mind (Muthuvel et al., 2016).

However, despite the availability of favourable conditions and opportunities, the experience of other countries suggests that various barriers can hinder the development of microgeneration based on renewable energy. Most researchers emphasize that the main barriers are monetary and financial, which deal with costs and investments required for the prosumer to acquire the necessary technologies and equipment (Balcombe et al., 2014; Botelho et al., 2021). The results of a study by Indian scientists of barriers to the introduction of biomass-based microgeneration have shown that the "technological and infrastructural" barrier ranks first among the main categories, followed by economic and financial, political and institutional, cultural and behavioural and meteorological barriers (Irfan et al., 2022). Therefore, direct stimulating and integrating policies, education, and training are the most appropriate strategies in the appropriate sequence to eliminate RES barriers (Asante et al., 2022).

The lack of necessary infrastructure, underdevelopment of institutions, as well as the lack of information, knowledge, and awareness are also severe barriers preventing the broader spread of microgeneration (Karytsas and Choropanitis, 2017; Tseng et al., 2021; Zahira et al., 2022). However, unlike financial barriers, which are difficult to overcome without government assistance (in the form of subsidies or tax benefits), infrastructure and information barriers can be significantly reduced or even eliminated completely by the private sector (Palm, 2016; Lerman et al., 2021). As the experience of other countries shows, companies that sell equipment for microgeneration also provide services for its installation, technical service and post-warranty maintenance. In addition, through their advertising campaigns, they perform educational functions and train the population.

The purpose of this study is a comprehensive analysis of the barriers to developing the market of microgeneration equipment based on the most advanced renewable energy technologies – photovoltaics and wind energy. The study was conducted in two stages. In the first stage, the current status of energy sector development and the current system of state regulation of renewable energy were studied. In the second stage, the offer from

the microgeneration equipment market was analyzed by studying the official websites of companies offering autonomous and backup power supply solutions.

The rest of the paper is organized as follows. Section 2 describes the method of companies' analysis and evaluation of their role in market development. Section 2 reviews existing legal acts and government policies for adopting RES and microgeneration in India. Section 4 reports the results of the empirical analysis. Section 5 discusses the revealed problems in the development of microgeneration based on PV and wind. Section 6 concludes.

2. MATERIALS AND METHODS

Data from open sources on the Internet and research presented in the scientific literature served to analyze the current status of renewable energy development. We have studied reports and official documents of the Ministry of Energy of India, the Ministry of New and Renewable Energy Sources (MNRE), the Central Electricity Authority (CEA), the National Agency for Promotion and Promotion of Investments (Invest India), UNECE publications on energy, the Climate Change Program, as well as speeches and statements by representatives of government agencies at official international events.

To study the actual and potential barriers to the development of microgeneration in India, we selected and studied the websites of 28 Indian companies offering solutions for autonomous and backup power supply. Data collection was carried out in 2022; the search was carried out according to the keywords "buy/install solar panels/solar heater/wind generators". Google was used as the most universally used search engine. Further, the links led to the company's official website providing services for the sale and/or installation of microgeneration equipment. Further, the study included an analysis of the available text and online documents presented on companies' websites. The presence of experience in implementing projects for the installation of microgeneration equipment at the company, the availability of a detailed online guide on the selection of equipment on the website, the availability of calculators that allow calculating the cost of equipment and installation, the range of equipment and services offered, the availability of warranty service and its term, the availability of the possibility to dispose of used equipment, etc. To clarify individual information, the method of the telephone interview and mystery shopper method. To assess the quality of the information presented on the site, a point scale and rules for awarding points were developed depending on the degree of structuring, accessibility and clarity of the information provided from the perspective of a potential client.

3. GOVERNMENT POLICY TO PROMOTE RENEWABLE ENERGY DEVELOPMENT IN INDIA

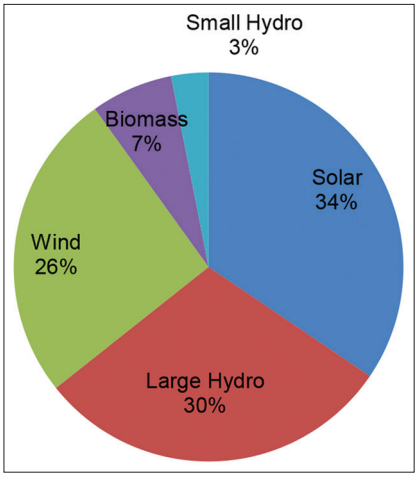
3.1. Brief Overview of the Indian Renewable Energy Sector

The country has a significant potential for generating renewable energy sources. According to the National Electricity Supply Plan (NEP), the Government of India has set a goal to achieve a renewable energy capacity of 500 GW by 2030. This ambitious plan is the world's most extensive expansion plan in the field of renewable energy. Today, India ranks third in the world in total renewable energy capacity increase from 15.4 GW in 2021 after China (136 GW) and the United States (43 GW).

According to IRENA (IRENA, 2022), India installed 13 gigawatts (GW) of renewable energy in 2021, increasing its capacity by more than 53 GW over the past 5 years. This result makes it one of the fastest-growing renewable energy markets in the world. With its vast renewable energy potential, India is striving to become a significant producer of not only solar and wind energy but also green hydrogen to support the decarbonization of its industrial economy. Currently, the share of green hydrogen is relatively insignificant, but according to IRENA, by 2050, hydrogen will account for about 12% of the total energy supply at a temperature of 1.5°C. The Government of India is making every effort to use the available potential, and as of March 31, 2022, the installed capacity from renewable energy sources amounted to 156598.40 MW. The share of solar and wind energy is more than 50% in the distribution of the total installed capacity for RES (Figure 2).

India is actively developing a modern direction using "Green hydrogen" in the energy sector. In August 2021, the Government of India announced the launch of a National Mission on the Use of Hydrogen in Energy. The main goal is to establish the production of green hydrogen (produced using renewable energy sources) and increase production to 5 million tons by 2030. It is expected that 4.1 million tons of annual Green Hydrogen production will be produced as part of the Green Hydrogen mission. Currently, India consumes 8-9 million tons of hydrogen annually (for example, it is used to produce fertilizers). For its production, fossil fuels are mainly used, which implies emissions of about 9 tons of CO_2 per 1 ton of hydrogen produced (PV-magazine, 2022). Within the framework of the program, in particular, quotas for the mandatory use of green hydrogen in some industries (oil refining, fertilizer production) have been announced (MoP, 2016). The hydrogen energy development concept, adopted in early 2022, also benefits producers (Powermin, 2022).

Figure 2: Distribution of total installed capacity by RES (2021, GW), based on data (Invest India, 2022)



Over the past few years, the popularity of electric vehicles has grown. According to the Federation of Car Dealers of the country (FADA, 2022), 4.3 million units of electric vehicles were sold in the 2021-2022 fiscal year, which is 3 times more than in the previous one (1.3 million). Most sales are not cars but more affordable scooters and three-wheeled auto-rickshaws popular in India (2.1 million and 1.7 million, respectively) (PIB, February 2015). According to Arthur Little, by 2030, the EV market in India will grow to 10 million units per year (about a tenth of the world), and two- and three-wheeled vehicles will remain the most popular (Bloomberg, 2022). The sector receives official support. Since 2015, there has been a program of subsidizing electric vehicles (FAME — Faster Adoption and Manufacturing of Hybrid and Electric Vehicles in India) (IEA, 2022). The second stage of the program ended in March 2022; its purpose was to create economic incentives for the use of the population, including electric scooters and mopeds. An incentive program for battery manufacturers was also launched in 2021 (PIB, 2022).

3.2. Institutional Support of the Industry

Institutional support for the renewable energy industry has been established in India, and a special Ministry of New and Renewable Energy (MNRE) has been formed, thanks to which the renewable energy sector is actively increasing capacity, with an annual growth rate of 17.5% in the period from 2014 to 2020. The share of renewable energy sources in the total energy balance of India is significantly strengthening its position in the structure of the energy sector of the economy; over the past 5 years, the share has grown from 6% to 10%.

Several ministries are responsible for regulating the energy industry in India. In addition to the Ministry of Energy in India, there is a separate Ministry for New and Renewable Energy, responsible for new technologies and unconventional energy sources. In parallel, the Ministry of Coal, the Ministry responsible for Oil and Gas, and the Department of Nuclear Energy also function. Thus, two ministries are responsible for the "big" and distributed energy. According to the Act of 2003, the CEA has formed a National Plan for the Development of the Electric Power Industry (CEA, 2022), which corresponds to the National Policy in the field of Electric Power (National Electricity Policy).

There is also a system of tariff regulation; for this, the National Plan in the field of the electric power industry was adopted, and further improvement of tariff regulation to support the development of renewable energy is carried out within the framework of the National Tariff Policy (National Tariff Policy, NTP) and the National Plan to Combat Climate Change (National Action Plan for Climate Change, NAPCC). The NAPCC National Plan has set a target for using electricity from renewable sources at 5%, with an increase of 1% every 10 years. Various legislative initiatives have been adopted to achieve this indicator-a preferential tariff for electricity from renewable sources (partial compensation from the state to energy producers) and tax incentives have been introduced. Since 2010, all these activities have been combined into a national legislative and certification platform for renewable energy. Companies producing energy from renewable sources receive individual preferences from the state, which include preferential tax treatment for projects in this area, facilitated international and interregional cooperation for the purchase of equipment and construction work, removal of regulatory barriers for new players to enter the market (Central Electricity Regulatory Commission). However, in practice, granting individual preferences does not receive proper development.

The Roof Top Solar (RTS) program was launched at the end of 2015; it was the first phase of the program, under which incentives and subsidies were provided for the residential, institutional and social sectors. Incentives linked to achievements were also provided for the public sector. The second phase of this program was launched in early 2019 with the goal of achieving a combined capacity of 40,000 MW by 2022. The RTS program provides Central Financial Support (CFA) in the amount of 40% for RTS systems with a capacity of up to 3 kW and 20% for capacities over 3 kW and up to 10 kW. For Group Housing Societies (GHS) and Residents' Social Welfare Associations (RWA), the amount of support is limited to 20% for RTS stations to supply electricity to public facilities. It is estimated that more than 3.7 GW of RTS capacity has been installed in the country, and more than 2.6 GW of capacity is under installation in the residential segment.

Even though the reform of the industry has been going on for more than 15 years, its regulation is still far from perfect. Regulatory authorities have generally managed to solve problems in the field of "large generation" and partly backbone networks ("ultra-megaprojects"). The share of the population without access to electricity has decreased from 41% to 19%, but distribution networks remain a bottleneck. The fact that "ultramegaprojects" cannot fully solve the problems of the end-user forced the regulator in recent years to increasingly shift the focus of attention towards new technologies and distributed energy, although this transition is not easy.

However, experts consider regulation to be insufficiently effective since the actions of established state regulatory bodies, such as the Central Electricity Authority (CEA), the Central Electricity Regulatory Commission (CERC), as well as the State Energy Regulatory Commissions (SERCs), do not are always consistent. The tasks of the regulatory authorities were to regulate the market, protect the interests of consumers, as well as develop further proposals to improve market management. However, producers and consumers lack coordination in making practical decisions in practice.

The result of the development of renewable energy in India is manifested in the growth of the total installed capacity of renewable energy sources (except for large hydroelectric power plants), which in 2021 amounted to 92.54 GW (Table 1). From April 2014 to January 2021, the installed capacity of renewable energy in India increased by two and a half times, and the installed capacity of solar energy increased by 15 times over the same period. Today, India ranks 4th in the world in terms of renewable energy capacity, 4th in wind power and 5th in solar power.

As can be seen from the table, the share of RES from the total installed capacity increased from 14.36% in 2014-2015 to 24.34%

in 2020-2021. This became possible thanks to state regulation and support of renewable energy. The renewable energy industry in India has a relatively short history, which began with the adoption of the Electricity Act 2003 in 2003. The privatization of the Indian electricity industry and the subsequent reforms in the energy sector created a competitive electricity market in the country. The analysis of existing projects has led to the conclusion that India has made significant progress in developing renewable energy in general, but India's tasks extend not only to large-scale state projects. One of the unresolved problems is to provide remote areas from industrial centers, where most of the country's population lives, and to provide small and medium-sized enterprises with electricity.

The solution to this issue is possible by using microgeneration facilities operating based on renewable energy sources without diesel generators. The fact is that the operation of facilities operating based on renewable energy sources does not require fuel consumption and can be carried out without any costs on the part of the owner of the microgeneration facility during the entire period of the active phase of the energy source (wind, sunlight, etc.), forming excess energy that is advisable to sell. That is why the microgeneration facility is increasingly associated with using renewable energy sources. The basis for the development of microgeneration in India is mainly solar and wind energy. Therefore, in our review, we consider mainly these types of energy for microgeneration.

3.3. Solar Energy

Per capita electricity consumption growth increased from 1992 to 2019 by more than 20 times, according to UNdata, from 44 kWh/person in 1992 to 944 kWh/person in 2019. Microgeneration solar projects across the country may be the best solution to the problem of electrification of the whole country and the Indian village in particular. By 2030, the installed capacity of renewable energy sources in India will be 500 GW; the main bet is on solar and wind energy. To achieve the planned objectives, the construction of 45 solar parks with a total capacity of 37 GW has been started in India; solar parks in Pavagada (2 GW), Kurnula (1 GW) and Bhadla-II (648 MW) are among the top 5 operating solar parks with a capacity of 7 GW in the country, the largest in Gujarat is being built in the world's renewable energy park with a capacity of 30 GW, a hybrid project of solar energy and wind. India also offers an excellent opportunity to invest in the renewable energy sector, where projects for billions of dollars are being implemented.

The Climate Change Response Plan adopted in India in 2008 includes eight areas ("missions") — the use of solar energy, energy conservation, sustainable urban infrastructure, rational use of water resources, conservation of the Himalayan ecosystem, protection and restoration of forest resources, sustainable agriculture and in-depth study of climate change (DST, 2008). India is the second-largest market in Asia for new solar photovoltaic capacity and the third in the world. India also ranked fourth in the total number of panel installations (60.4 GW), overtaking Germany for the 1st time (59.2 GW). In May 2022, the first hybrid solar power plant with a capacity of 390 MW was commissioned in India.

In 2021, the ten largest rooftop solar installation companies accounted for 43% of the rooftop solar market. Leading companies on the market provide a full range of services from production, installation and maintenance, but the vast majority of companies specialize in individual product production, installation and service provision. For example, the leaders in the solar energy segment can be noted as the companies Tata Power Solar, Fourth Partner Energy, Sunsure Energy, Amplus Solar and Jakson Solar, which are the leading manufacturers of solar roofs in India. Tata Power Solar, Sunsure Energy, Jakson Solar, Roofsol Energy and Havells India are the leading Indian solar energy design and production companies. Tata Power Solar is also the leader in the list of rooftop solar panel installers in the country; Sterling & Wilson has been the leader of EPC service providers for a year. Sungrow and Sineng Electric are leading suppliers of solar inverters and linear inverters. The development of solar energy in India demonstrates an increase of 222% in open-access solar installations in 2021.

The success of renewable energy development implies a willingness to build new generating and transmitting capacities and create "smart" networks and other appropriate infrastructure. In other words, green energy is an exceptional capital-intensive industry. World practice shows that the key to its financial viability is the solvent demand of consumers and tariffs exceeding tariffs in the traditional energy sector. Meanwhile, India has entered the energy transition period with a low per capita income (Worldbank, 2022). Thus, financial prerequisites significantly reduce the opportunities for the successful development of alternatives, including renewable energy on a national scale.

3.4. Microgrids

A feature of the Indian microgeneration equipment market is a unique form of microgeneration as a microgrid, which is a smaller version of the standard electrical grid but serves a much smaller and discrete area. Each microgrid consists of at least one source of electricity generation and a distribution system. It is this form of a microgrid that has a great chance to become a solution to the problem of electricity shortage in Indian villages. The microgrid (MG) is a flexible solution for deploying distributed energy resources and a promising avenue for solving energy poverty (Akbari et al., 2022). As a rule, companies are engaged in micro-grids, which compensate for the weak involvement of the local population in the installation of microgeneration systems associated with the high cost of installing equipment. Optimizing the microgrid results in improved performance and, therefore, lower operating costs. Energy management system (EMS) plays a vital role in controlling users' energy consumption, allowing for increased consumer participation in the market (Raju, 2018; Chitra and Balasubramania, 2022).

The market for microgeneration equipment is mainly in the B2B format. In 2021, the ten largest rooftop solar installation companies accounted for 43% of the rooftop solar market. The transformation of the market into the B2C format is hindered by several factors: the presence of high financial barriers, the long payback period for most renewable energy projects, the promises of politicians about universal connection to the backbone network, the issuance of subsidies for equipment are limited by the high requirements

of the Bureau for Standardization, often the issuance of subsidies is not implemented in practice, etc.

Microgrids that were only superficial can become huge in the Indian market, and this is the ideal Public Private Partnerships (PPP) model to achieve 100% access to electricity at the household level by 2024-2025. The usefulness of microgrids will go beyond connecting the last mile and will find its application in industrial and commercial networks and even at the level of clusters of individual residential buildings.

3.5. Wind Power Sector

The wind is an attractive, competitive utility-scale resource in India. On average, the wind LcoE (levelized cost of energy) is about 35% lower than most of the country's existing coal-fired power plants, providing much-needed electricity from renewable sources. Wind energy development contributes to the country by creating jobs, reducing the adverse effects of greenhouse gases and increasing the size of the gross domestic product. India's wind power industry is developing due to private sector investments (Charles et al., 2019). The Government, for its part, supports wind energy in the country through several financial incentives and innovative schemes.

India is the fourth-largest onshore wind energy market in the world by some installations, and this resource is the second most competitive energy source in the Indian energy system. Tamil Nadu is the largest producer of wind energy with a total installed capacity of 7455.2 MW, followed by Maharashtra (4450.8 MW), Gujarat (3645.4 MW) and Rajasthan (3307.2 MW). Nevertheless, the pace of implementation of wind energy projects has been slowing down recently. Unlike solar energy, which has recently begun to gain momentum. A big problem for the development of wind energy is the need for large plots of land and the availability of the possibility of connecting to the grid, wind turbines located far from urban centers. Also, offshore wind technology requires particular infrastructure, ships and submarines, and capital-intensive technologies.

Hybrid solutions are considered a good solution, so at the end of 2020, the construction of a giant wind-solar complex with a capacity of 30 gigawatts (GW) in Gujarat began. In May 2022, Adani commissioned India's first hybrid wind-solar power plant with 390 megawatts (MW) installed in Rajasthan. The combination of solar and wind generation is becoming an increasingly popular solution with many advantages. It allows for a smooth production profile with small daily and seasonal fluctuations. The joint placement of solar and wind installations ensures the rational use of land resources and savings on network infrastructure and components.

4. RESULTS OF EMPIRICAL STUDIES OF THE INDIAN MARKET FOR EQUIPMENT AND SERVICES FOR MICROGENERATION

Within the framework of this study, 28 companies were found using search engines, which became the basis for analyzing the development of microgeneration in India. All the studied companies deal with a wide range of renewable energy technologies, from solar modules, roofs and hybrid energy storage solutions, as well as small wind turbines. 22 out of 28 companies (78.6%) are engaged in the production of solar panels in addition to design and installation. The remaining six companies carry out the design, installation, and maintenance of solar panels and wind turbines, cooperating with various manufacturers, mainly Indian, European (in the field of wind energy) and Chinese. All surveyed companies have experience, 18% of young companies formed in the last 5-7 years, and the rest have significant experience in this sector.

However, the current form of microgeneration in India, the microgrid, is characterized by low involvement of the local population in the private sector, the high cost of installation of equipment, and the promises of politicians for universal connection to the main grid, which inhibits the desire of the population to use local generation technologies. So a good solution in India is to have a range of solar microgrid companies providing services in different states of India.

In Karnataka, the SELCO Foundation has deployed remote microgrids with solar energy storage to provide access to the energy of several settlements, each of which is a DC microgrid. Mera Gao Power Company builds, owns and operates solar microgrids in Uttar Pradesh, India, primarily serving autonomous villages. The Mera Gao Power model aims to provide electricity at a low price, which makes it viable for households. Gram Power builds 5-10 kilowatt microgrids in remote villages of Rajasthan and provides users with "smart meters" to regulate energy consumption. In addition to Indian companies, large multinational corporations such as ABB, GE, Schneider Electric, Caterpillar and Siemens are widely represented in the microgrid market and invest heavily in developing microgrids throughout the region.

There are quite a lot of companies in India that provide products and services in the field of providing autonomous energy supply using renewable energy sources. As our research has shown, most companies mainly provide products and services for large industrial enterprises. About 50% of installations are in the industrial segment, 35% in the commercial segment, and 13% in the residential segment.

Among those investigated by us, Inox Wind has one of the largest order catalogues in the industry, with numerous repeat orders. The website provides extensive information on how the company is strengthening its position and increasing market share among independent energy projects (IPPs), state-owned public sector enterprises (PSUs), utilities, corporations and retail customers. Based on a detailed assessment of wind resources, the company has a significant land bank and the most extensive list of project sites in wind-rich states and currently has a sufficient land bank to install a combined capacity of more than 5,000 MW. Companies that install wind turbines have much experience. However, there is practically no information on the sites that the consumer could use to decide on the installation; mainly, the information is of an

advertising nature, designed for a narrow circle of specialists; the sites also do not present a portfolio of projects.

The analysis of the sites showed that six companies (21%) do not have projects in their portfolio. However, all projects are very general, primarily large-scale projects of which it is difficult for a private investor to imagine implementing a small-format project. The majority of 78% of companies represent solar energy, and only 21% specialize in wind energy; 1% of companies work with a wide range of equipment for agro-industrial enterprises.

Very little attention is paid to the issue of certification since only 21% of the surveyed companies have ISO 45001 and ISO 9001 management system certificates, 3% of companies provide certificates for solar panels (for example, UL or TUV certificates), 7% of companies have eco-labelling, and another one (Tata Power Solar) has a certificate of appreciation for best practices in security systems.

An online guide for selecting equipment and calculating the approximate cost of a solar installation is posted on their website by 1% of companies, and mostly this information is only on request. 78% of companies have a list of services provided, but it is not detailed enough; it is aimed at a narrow circle of specialists. The distribution of expert assessments of the level of trust in the information provided on the company's website, as well as assessments of the completeness of information about services and products, are shown in Figure 3.

As seen in Figures 3-5, all estimates of various aspects of information accessibility for consumers of the surveyed companies are pretty high. Most companies' websites cover in detail the issues of the principles of operation of equipment for solar and wind microgeneration using visual illustrations and tell about the features of various types of equipment. Nevertheless, a few companies inform potential consumers about the technical characteristics of solar panels and wind turbines. For example, only three companies (11%) provide information about the equipment's service life and warranty availability. All companies provide only information about the installation cost upon request; there are not even approximate estimates in the public domain. The approximate installation dates are not indicated on any of the websites of the companies under study. No company provides information about the environmental properties of materials and raw materials and the possibilities of recycling decommissioned or defective solar panels.

Nevertheless, the development of renewable energy has several problems; for example, different states of India are differently provided with opportunities to produce energy from renewable sources, and in some states achieving the required indicators has proved very difficult (for example, in Delhi), while in others (for example, in Rajasthan and Tamil Nadu) it is the value was significantly exceeded by (Soonee et al., 2016). Another significant obstacle to the development of renewable energy in India remains the high cost of energy production, as well as the problematic predictability of generation volumes and the complexity of integrating renewable energy sources into existing energy systems.

Figure 3: Expert assessments of the quality and completeness of the information provided on the company's website

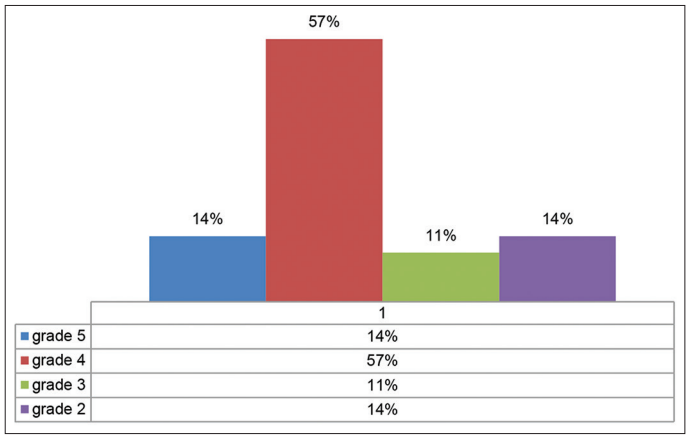


Figure 4: Expert assessments of the sufficiency of information about services provided on the company's website

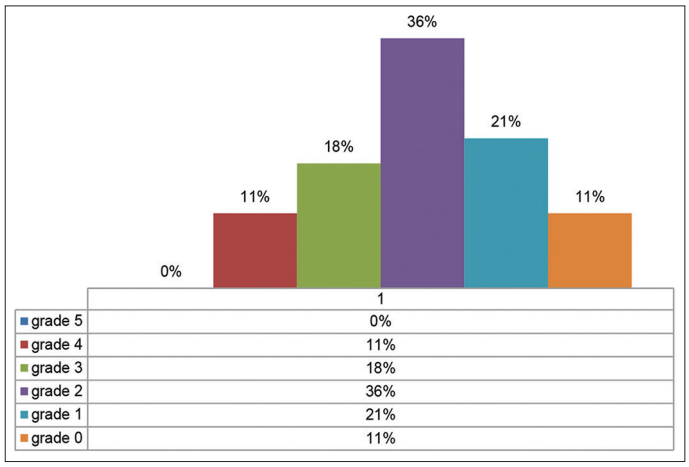
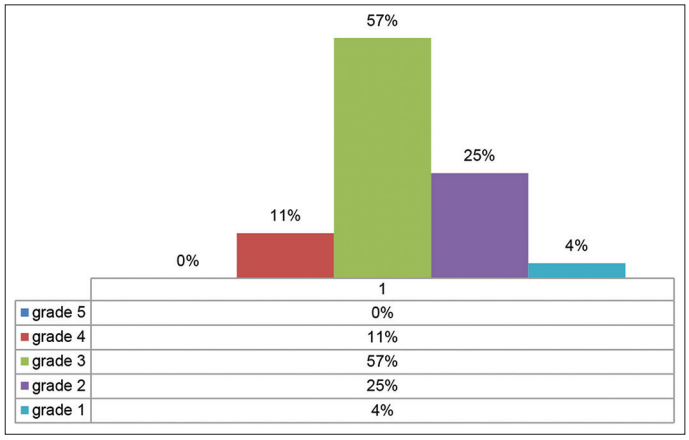


Figure 5: Expert assessments of the sufficiency of information about products provided on the company's website



Traditional non-market regulatory mechanisms (tax incentives, preferential tariffs, etc.) cannot effectively solve the complex of these problems. To stimulate investment and achieve targets, the Government of India has taken several measures, such as the introduction of an additional tax on coal producers to finance environmental projects (Pearson, 2010), as well as a fundamentally new, market-based mechanism to support the industry, which

Table 1: The share of renewable energy in the energy sector of India (according to (MNRE, 2022))

Year	Installed renewable energy capacity (in GW)	% Share of RES in total installed capacity	Generation from renewable sources (in billion units)	Total generation from all sources (in billion units)	% Share of renewable energy in generation
FY 2014-15	39.55	14.36	61.78	1110.18	5.56
FY 2016-17	57.90	17.68	81.54	1241.38	6.56
FY 2018-19	78.31	21.95	126.76	1375.96	9.21
FY 2020-21	92.54	24.53	111.92	1017.81	11.00

was called the Renewable Energy Certificate – REC (CERC, 2010; Soonee et al., 2012). Both of these measures were put into circulation in 2010 by a particular order of the CERC and proved quite effective. However, after some time, the effect of these measures turned out to be insufficient for the necessary growth of the renewable energy industry.

In the period 2007-2015 India has introduced many measures to develop the production of solar photovoltaic systems: encouraging investment, protective duty on imported solar cells and modules, and mandatory BIS certification. However, these measures did not lead to a significant increase in production in the domestic market, as companies under the incentive scheme did not benefit; since incentives under these schemes could not be paid, the protective duty led to an increase in the cost of the project, which in turn led to a slowdown in the Indian market of photovoltaic systems. Moreover, currently, India is dependent on Chinese manufacturers.

Another problem is that renewable energy alone (without storage devices and micro-grid management technologies) cannot solve the problems of energy supply to remote settlements, and also negatively affects the reliability of energy supply and dramatically increases the requirements for the management of distribution networks. When making important decisions for the development of the production of energy storage, it is necessary to take into account the results of studies that show that the use of a battery energy storage system will help improve the overall reliability of the microgrid (Tiwari et al., 2022). Understanding these difficulties, the Government is trying to implement several initiatives in the field of intelligent energy, including the development of smart grids ("National Smart Grid Mission"), a program for developing a microgrid. The Ministry has developed legislation to stimulate the development of microgrids, which determines the interaction of participants (including investors in regional distribution grids). Microgrids are divided into four categories-from 10 kW to mini-grids with an installed electric capacity of more than 250 kW.

Husk Power, which in 2020 became the first company in the world to install 100 public mini-networks and serve 5,000 business customers, operates in India without subsidies, relying on a diversified business model that concerns both the supply side (solar mini-networks for access, small and medium-sized enterprises) and the demand side (retail sale of production equipment and microfinance).

Despite the clear prerequisites for the use of storage in India, the first major project for the construction of a 10 MWh grid storage was implemented by the company Applied Energy Services (AES) only in January 2022. Considering the high rates of commissioning of solar generation and the shortage of peak capacities, the demand for accumulation in the country will grow rapidly. Central Electricity Authority – the government organization responsible for the development of capacities, including hydro- plans to introduce 100 GW of pumped storage station capacity, but the realism of such plans is questionable. In addition, the PSPS obviously will not be able to ensure the integration of renewable energy in isolated areas and ensure the reliability of energy supply to the end user. Therefore, the potential market for chemical storage in the country may grow dramatically in the next 5 years.

5. CONCLUSION

A feature of the development of microgeneration based on renewable energy in India is that for many territories, microgeneration is not an additional but the only way to provide electricity for the local population. Therefore, higher technical requirements are imposed on it than, for example, in those countries where microgeneration is an addition to the primary method of energy supply. In particular, for the full development of microgeneration, parallel development of microgrid management technologies and energy storage technologies is necessary. This creates additional technical, infrastructural and financial barriers to development and reduces the role of an individual consumer–prosumer. Due to the low importance of individual consumers, companies selling and servicing microgeneration equipment are more focused on the B2B work format, manifested in the strategy of their representation on the Internet.

In general, the Indian renewable energy sector requires clear policies and legal procedures to attract the attention of investors. Approval of private sector projects is delayed due to the lack of a clear policy. The country should take measures to attract private investors. Inadequate technologies and the lack of infrastructure necessary to create renewable energy technologies must be overcome by allocating significant funds to support research and innovation in this sector. There are not enough competent personnel to train, demonstrate, maintain and operate renewable energy facilities, so initiative should be taken in training the workforce.

Insufficient facility maintenance and poor technology reliability reduce consumer confidence in some renewable energy technologies and therefore prevent their choice. Governments should support investments in expanding renewable energy sources to accelerate the commercialization of such technologies. The Indian government should announce a well-developed fiscal assistance plan, such as loan provisions, loan deductions and

tariffs. The findings of the study add to a growing body of literature on decarbonization in developing countries and will be helpful to policymakers, investors, stakeholders, and researchers.

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