INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

Publisher
Sustainability for Regions

RENEWABLE ENERGY CLUSTERS: THE CASES OF LEADING COUNTRIES, LESSONS APPLICABLE TO MOROCCO*

Boumediene Amraoui [1], Vaida Zemlickienė [2], Najiba El Amrani El Idrissi [3]

[1,3] Faculty of Science and Technology, Sidi Mohamed Ben Abdellah University, Route d'Imouzzer 30000 Fez, Morocco
[2] The Institute of Sustainable Construction, Faculty of Civil Engineering, Vilnius Gediminas Technical University, Saulėtekio av. 11, LT-10223 Vilnius, Lithuania

E-mails: [1]boumediene.amraoui@usmba.ac.ma; [2] vaida.zemlickiene@vilniustech.lt; [3] najiba.elamrani@usmba.ac.ma

Received 11 August 2024; accepted 6 February 2025; published 30 March 2025

Abstract. Environmental issues have grown from marginal concerns to one of the biggest global challenges for economies and societies. The easiest, quickest and most effective way of driving down greenhouse gas emissions and the best chance to stop climate change's process is by moving to an energy system based on renewables. The development of renewable energy clusters is one of the factors that promote renewable energy production. The primary aim of this paper is to offer valuable insights, catering to the needs of both researchers and practitioners, regarding conditions that supported or hindered the expansion of renewable energy clusters in the leading renewable energy-producing countries, i.e., to present the case study's research on renewable energy clusters. Using statistics and archival analysis, an overview of leading countries in renewable energy and the experience associated with the performance of renewable energy clusters will be provided. The research results and insights apply to the Moroccan case to boost the development of Moroccan renewable energy clusters and economic and political decision-making.

Keywords: clusters; renewable energy; leading countries

Reference to this paper should be made as follows: Amraoui, B., Zemlickienė, V., El Amrani El Idrissi, N. 2025. Renewable energy clusters: the cases of leading countries, lessons applicable to Morocco. *Insights Into Regional Development*, 7(1), 93-108. https://doi.org/10.70132/w8428438283

JEL Classifications: D78, D81, F13

Additional disciplines: ecology and environment, electricity electronic engineering, environmental engineering, energetics and thermo energetics.

* *The research leading to these results has received funding from the project titled "Cluster for innovative energy" in the frame of the program "HORIZON-MSCA-2022-SE-01" under the Grant agreement number 1011298205.*

Funded by the European Union

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

1. Introduction

It is recognized globally that renewable energy is crucial as fossil fuels decline and demand rises (Baus, 2017). The global energy requirements are ever-increasing, and primarily fossil fuels are utilized for energy production. At the same time as fossil fuels are running out, pollution levels worldwide have been elevated to unsafe levels due to the conventional energy production processes. Of all the different approaches to curb pollution, globally, renewable energy is seen as the most potent one (Sudhakar et al., 2017). In a report published by the United Nations, it is stated that if the world's energy sector is not changed, it will be impossible to improve the standard of living in some parts of the world while at the same time being able to decrease CO^2 emissions. The energy sector must urgently change globally, so most countries must invest heavily in renewable energy development.

Morocco has swiftly emerged as one of the most rapidly flourishing hubs for renewable energy across the entire globe. All credit goes to the proactive stance on climate change adopted by the visionary King Mohammed VI. In the early 2000s, the Moroccan government not only formulated impactful policies but also introduced incentivizing measures to foster the growth and development of renewable energies, with a specific emphasis on solar power. The Moroccan government has embraced a comprehensive and well-coordinated approach to promote and facilitate the adoption of green energies, involving various levels of governance and institutions. The development of renewable energy clusters is one of the factors that promote renewable energy production.

The primary aim of this paper is to offer valuable insights, catering to the needs of both researchers and practitioners, regarding conditions that supported or hindered the expansion of renewable energy clusters in the top renewable energy-producing nations. The research results and insights can be applied to the Moroccan case to boost the development of Moroccan renewable energy clusters and economic and political decision-making.

To achieve the goal, the following tasks were formulated:
1) identify the leading countries in the production of renewable energy;
2) review the situation of energy from renewable sources in each country;
3) gather information about the experience of creating and operating clusters and the encouraging and hindering factors.

2. Renewable energy clusters: concept and role

In business, clusters refer to geographic concentrations of interconnected companies, suppliers, service providers, and associated institutions in a particular field. These clusters can enhance the competitive advantage of the entities involved through various means, such as fostering innovation, driving productivity, and encouraging new business formations.

Key aspects of business clusters include geographic proximity, specialization in a particular industry or sector; the proximity of firms allows for a blend of competition and collaboration, often leading to higher levels of innovation and efficiency; entities within a cluster can share resources such as specialized labour pools, suppliers, and infrastructure, which can reduce costs and improve efficiency; clusters promote the exchange of ideas and expertise, leading to increased innovation and the development of new technologies and processes; universities, research institutions, trade associations, and government agencies often play key roles in supporting and sustaining clusters through research, training, and policy support; clusters can drive regional economic growth by creating jobs, attracting investment, and fostering the development of new businesses.

Examples of well-known business clusters include Silicon Valley in California for the technology sector, Hollywood for the film industry, and the financial district in New York City for finance and banking (Porter, 1998).

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

In Polish law, according to the definition specified in art. 2 (15A) of the RES Act, an energy cluster is a civil law contract of a group of stakeholders concluded to accomplish a specific economic objective in the energy context, primarily in the field of electric power generation; a form of contract - entered into in order to strengthen cooperation in the field of electricity management over a large administrative area, covering up to five municipalities or one county. The cooperation includes 1) generation, 2) storage, 3) demand balancing, 4) trading, and 5) distribution - of electricity or fuels (Green Encyclopedia, 2024).

The fact that the contract is a civil law agreement means that such a cluster may comprise companies, research institutes, foundations, local government units and individuals. This provides an unprecedented capability to build complex logistic chains that could support the RES power delivery process.

Bare definitions will not help you understand the structure of a cluster. The whole concept is to combine, at the local level, the means for the generation and consumption of power in order to ensure the maximum transmission of energy among the cluster components and, at the same time, to minimize outbound and inbound transmission. Considering the economics of the entire undertaking, the cluster should be as self-sufficient as possible. Here, an example may be the cooperation of once isolated power-generating entities operating independently, such as owners of wind turbines and solar panels and local consumers, to adjust the generation profile to the consumption profile. The aim of a project is to best match both these profiles (Trendy w energetyce, 2018).

3. The case study of top countries for renewable energy production: energy clusters experiences, public policies and regulatory framework

3.1. Methodology of case study

It was decided to use the best practices of leading countries in the field of sustainable energy production and energy clusters to gain practical insights applicable to Morocco. The first step to achieving the goal is to identify the countries with the largest renewable electricity production based on statistical analysis. In the subsequent analysis of archival data, the experience of renewable energy clusters operating in leading countries will be reflected. Answer the question: How have past and current government policies and local conditions supported or hindered the expansion of a particular energy cluster?

3.2. Leading countries for renewable energy production

Different organizations measure the progress of renewable energy production differently; however, the lists of leading countries based on specific rankings can often be surprising in their differences. In order to find out the leaders of renewable energy production, it is worth examining the results of the evaluation and ranking of different organizations.

Two years ago, the Climate Council (2022) announced that 11 countries were leading the charge on renewable energy. Sweden: In 2012, Sweden reached their target of 50% renewable energy 8 years ahead of schedule. This puts them right on track to achieve their 2040 goal of 100% fossil-free renewable electricity production. They use their natural resources to combine wind, bioenergy, solar, and even body heat. In Stockholm, for example, body heat from commuters passing through the central station is used to heat a nearby building. Costa Rica: In 2022, Costa Rica produced a whopping 98% of its electricity from renewable sources for over eight years in a row. Costa Rica also holds the world record for most consecutive days using solely renewable energy – 300 in 2018 and breaking their record of 299 days in 2015. Costa Rica combines hydro, geothermal, wind, biomass and solar power to get the job done. In some years, they have even been able to export the excess power they have generated to countries in Central America's regional electricity market, such as Guatemala, Nicaragua, Panama, Honduras, and El Salvador. United Kingdom: The UK is the global leader in offshore wind energy. It has more capacity installed than any other country, with offshore wind powering over 7.5 million homes. A plan to increase this fourfold by 2030 will go a long way to the government's plan to decarbonize its power system by 2035.

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

Iceland: The land of fire and ice has unique access to a range of renewable resources. In 2015, hydropower and geothermal power combined provided almost 100% of Iceland's electricity production. Geothermal power heats 9 out of 10 homes, and Iceland is among the world's top ten global producers of geothermal energy. The UN has even suggested their transition could provide a model for other countries to make the switch. Germany: In 2022, Germany's new government set their self-described "most significant energy policy reform in decades" during their first 100 days in government. What's so special about it? Renewables sit at the centre, with targets of 80% renewable power by 2030 and close to 100% by 2035. Renewables accounted for 46.9% of German power consumption in 2022 (a 4.9% increase from 2021) and it looks like it's only going up from here. Uruguay: Since 2007, Uruguay has undergone a renewable energy revolution. Back then, imported fossil fuels provided more than a third of energy generation, but decades of transformation have resulted in Uruguay generating 91% of all its electricity from renewable sources in 2022. Between 2013 and 2018, Uruguay increased its wind power from 1% to 34% of its electricity mix in five years – the fastest any country has achieved. The majority of this comes from hydropower, complemented by wind, solar and biofuels. In some years, Uruguay will generate much renewable energy to export to its South American neighbours, Argentina and Brazil. And they're still on the lookout for extra ways to put it to use. Kenya: Kenya is home to Lake Turkana Wind Power Project, Africa's largest wind farm. With over 310 MW of capacity – enough to supply energy to one million homes. The project also attracted the largest private investment in Kenya's history $650 million. Africa has huge renewable energy potential – home to 60% of the best solar resources globally, however, the continent receives less than 3% of energy investments worldwide. China: it appears the world's largest carbon emitter can also be a leader in renewable energy. It may seem counter-intuitive, but China is the global renewable energy leader, hosting nearly half its total operating wind and solar capacity. China is on track to double its utility-scale solar and wind power capacity, shattering the central government's ambitious 2030 target of 1,200 GW five years ahead of schedule. They're also the biggest investor in renewable energy worldwide, where nearly half of the world's low-carbon spending took place in China in 2022 (US$546 billion). Now, they need to get those emissions down. Morocco: Morocco has harnessed the power of its ample sun supply to become a world leader in solar energy. It's home to the world's biggest concentrated solar farm, the Noor-Ouarzazate complex in the Sahara Desert, which has a capacity of 580 MW. The farm is the size of 3,500 football fields and generates enough electricity to power a city twice the size of Marrakesh. New Zealand is doing great things about renewables. 84% of New Zealand's electricity usage is renewable. New Zealand has set a target for 50% of total energy consumption from renewable sources by 2035, and 100% renewable electricity by 2030. Norway: As of 2016, 98% of electricity generation in Norway came from renewables, with hydropower leading the charge. They've been harnessing power from rivers and waterfalls since the late 1800s, so it's easy to see how this natural resource has been a critical part of Norway's power profile. Over the years, they've also added thermal and wind energy to the mix.

According to The World Economic Forum (2024), advanced economies are generally the top performers in the Energy Transition Index (ETI), with Sweden, Denmark, Finland and Switzerland leading the rankings. France, meanwhile, has entered the top five performers due to its effective energy efficiency policies, resulting in a 12% reduction in energy intensity. France is followed by Norway, Iceland, Austria, Estonia and the Netherlands in the Energy Transition Index (ETI). The top 10 countries collectively only represent 2% of the global population and contribute just 1% of energy-related CO_2 emissions. Still, the report shows that major emerging economies like China and Brazil have also made significant progress. It highlights that China commissioned as much solar photovoltaic (PV) capacity in 2023 as the entire world did in 2022. Meanwhile, Brazil's long-term plan for hydropower and biofuels has been key in attracting investment.

Common characteristics of the top performers include enhanced energy security through a diverse mix of sources, improved energy intensity, an increasing share of clean energy, a carbon pricing mechanism and a supportive regulatory environment.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

Statistical Review of World Energy provided by Ember (2024), Energy Institute – (Our World in Data, 2024a) may seem very informative at the beginning (Fig. 1); however, when contrasted with other statistical data, the situation becomes more explicit and more reflective of reality. It shows how much energy different countries produce from various energy sources. However, all countries are presented here as equals, although, for example, China produces 22 times more renewable energy.

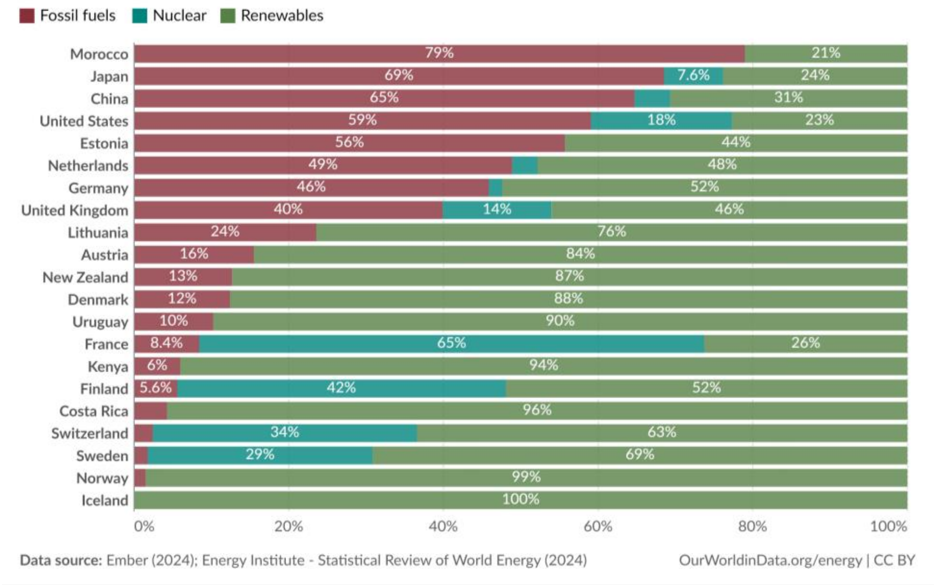

Figure 1. Electricity generation from fossil fuels, nuclear and renewables, 2023
Source: (Our World in Data, 2024a)

In 2022, China installed roughly as much solar capacity as the rest of the world combined, then doubled additional solar in 2023 (Hilton, 2024). Currently, China produces 31% of global renewable electricity, followed by the United States (11%), Brazil (6.4%), Canada (5.4%) and India (3.9%) (IRENA, 2024).

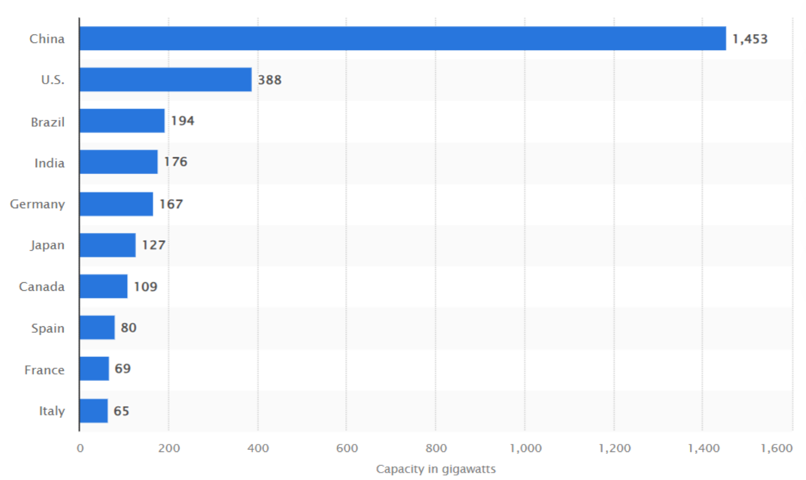

Figure 2. Leading countries in installed renewable energy capacity worldwide in 2023 (in gigawatts).
Source:(IRENA, 2024)

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

China was the leader in renewable energy installations, with a capacity of around 1,453 gigawatts. The U.S., in second place, had a capacity of around 388 gigawatts. Renewable energy is essential in addressing climate change and mitigating the consequences of this phenomenon.

3.3. The renewable energy generation and clusters performance in China

3.3.1. Overview of renewable energy generation in China

Hydroelectricity is China's largest renewable energy source and the second after coal. According to the International Hydropower Association, China is the world's largest producer of hydroelectricity. In 2024, China's installed hydroelectric capacity was 426 GW (IHA, 2024).

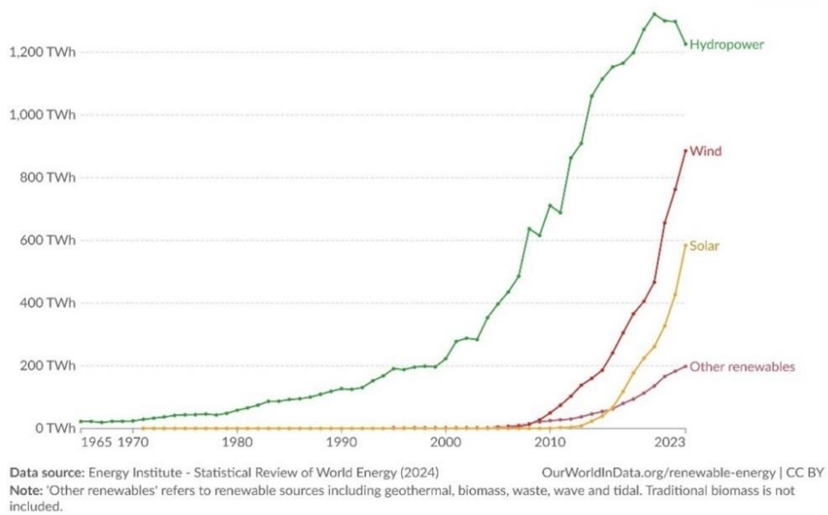

Figure 3. Renewable energy generation China
Source: (Our World in Data, 2024b)

After 2009, China began to carry out extensive wind and solar energy demonstration projects coordinated by the National Development and Reform Commission. These projects used the "flat-plate mechanism," which involved subsidies from the central government, concessions in the transmission grid, feed-in tariffs, tax incentives, and other supportive measures.

3.3.2. Renewable energy clusters in China

In 2015, China announced the "Enhanced Actions and Measures on Climate Change", which has set the goal of lowering carbon dioxide emissions per unit of GDP by 60 to 65% from the 2005 level. Achieving this goal necessitates fundamental changes in current coal-based energy systems. In January 2017, the Chinese government published the "13th Five-Year Development Plan for Renewable Energy (2016–2020)", and it is estimated that till 2020, a total investment of 2.5 trillion CNY (about US$0.4 trillion) will be allocated to developing renewable energy. Against this background, China's much more rapid transition toward renewable energy-based energy systems is seemingly taking shape (Fuller & Guo, 2017; Huang & Liu, 2017; Su & Fan, 2022).

Regarding Dong et al. (2016) from the geographical distribution, it was concluded that after several years of development, in general, there were four renewable energy clusters formed: (1) Bohai rim areas, including Beijing, Tianjin, Heibei, Shandong, etc; (2) Yangtze River Delta region, includes Shanghai, Jiangsu, Zhejiang, Fujian, etc; (3) Middle China region, includes Henan, Jiangxi, etc; (4) Western China region, includes Sichuan, Inner Mongolia, Xinjiang, Gansu, etc. Two clusters are located in eastern China, one in central China and one in

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

western China. Among the above regions, Jiangsu presented the highest output value, mainly due to the highly developed solar PV industry. Zhejiang, Sichuan, Shandong, Hebei, and Beijing also have high output values. Those regions were also industrially developed areas (coastal eastern regions with higher GDP per capita and industries).

Jiangsu Solar PV Clusters: The Chinese province of Jiangsu is a leading global manufacturer of solar PV cells and modules driven by supportive government policies. Jiangsu has solar PV production plants that have among the largest capacity in the world and an extensive supply chain of supplier companies and raw materials inputs. Jiangsu is an emerging technology centre, with R&D conducted by universities, firms, and government laboratories. The province has several science parks with solar PV companies and R&D firms. The massive increase in global demand for solar PV after the mid-2000s, resulting from the rapid expansion of PV deployment in Germany and other countries, including China, led to the rapid growth of the Jiangsu manufacturing cluster, which had much lower labour costs than developed countries. The provincial government provided subsidies for land, installation of factories, electricity, and finance. Jiangsu also rapidly scaled its manufacturing capacity and built an extensive domestic supply chain. However, the glut in solar PV manufacturing in 2011 led to financial difficulties, bankruptcy, and consolidation of the PV manufacturing industry in Jiangsu. In addition, the United States and the European Union imposed anti-dumping tariffs on imports of solar PV products from China beginning in 2012, adversely affecting Jiangsu-based manufacturers. Following a two-year slump, the Jiangsu solar PV manufacturing cluster began to recover, helped by the growing demand for solar PV installations in China (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

Another case is the development of the wind power industry in Jiangsu province. He et al. (2016) gave a detailed discussion on wind industry clusters in Jiangsu province. Specifically, three clusters within Jiangsu province have emerged: Yancheng, Nantong, and Lianyungang. During the evolution process of the three clusters, a relatively complete wind power equipment industry has taken shape, including blades, gearboxes, generators, bearings, towers, and control systems (Huang & Liu, 2017). The rich labour, agricultural, and mineral resources in this area provide a labour force and raw materials for industrial development. Furthermore, the three-dimensional traffic network, which is a combination of railway, highway, port and air, has initially formed, which can provide convenient transportation conditions for the industry. In addition, Jiangsu coastal area also possesses the largest offshore radial sandbanks in the world. About 70 radial sandbank fan-shapely distribute off the mid-coastline of Jiangsu. Among these sandbanks, there are about 1300 km^2 of offshore shallows, where the average wind speed is 8.4 m/s at 70 m high, and the density of effective wind energy at 70 m is above 400 W/m^2; thus, the wind energy can be used to generate power all year around. Jiangsu province severely lacks conventional energy; coal reserves are limited and unevenly distributed. Jiangsu power grid is a pure thermal power grid, with the installed capacity in 2013 being about 76,200 MW, and the power plants within the grid are mainly coal-fired ones, with a single power supply structure; meanwhile, the coal production capacity of Jiangsu is limited, about 80% of the coal demand depends on it allocation and transportation from outside the province. In recent years, electric power companies of Jiangsu have invested 700 million yuan in the construction of wind power integration projects and carried out a number of technical research. The local power grid can absorb 100% of wind power generated, but certain bureaucratic obstacles and lack of investment hinder the development of this project. The excessive intervention by the local government, development issues with wind-power component enterprises, insufficient independent technology innovation, and an imperfect cluster development environment have hindered healthy cluster development (He et al., 2016).

The following case for solar energy development is Shandong province, where a well-known industry cluster has been formed. It is home to Himin, the world’s largest solar water heaters manufacturer. In 2013, there were more than 300 solar water heaters manufacturers in Shandong, with an annual output of more than 10 million heaters, comprising over 40% of the total production output of the country. The solar thermal power industry has established a complete industry chain covering the production of silica sand, rough pipe, vacuum tubes, heat

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

collectors, and heat collecting systems. Half of the ten representative solar water heaters enterprises in China are located in Shandong province. A strong industrial foundation plays an imperative role in promoting the use of solar energy. The application of solar energy is very advanced in many cities in Shandong province, such as Rizhao and Dezhou. Solar energy penetrates local people's everyday lives and is widely applied in other industries such as paper making, machinery, and textiles.

3.4. Renewable energy generation and cluster performance in the USA

3.4.1. Overview of renewable energy generation in the USA

In 2023, about 4,178 billion kWh (or about 4.18 trillion kWh) of electricity was generated at utility-scale electricity generation facilities in the United States. About 60% of this electricity generation was from fossil fuels—coal, natural gas, petroleum, and other gases. About 19% was from nuclear energy, and about 21% was from renewable energy sources. Renewables: Wind – 10.2%; Hydropower – 5.7 5.7%; Solar - 3.9%; Biomass – 1,1%; Geothermal - 0.4%. The U.S. Energy Information Administration estimates that an additional 73.62 billion kWh of electricity generation was from small-scale solar photovoltaic systems in 2023 (EIA, 2024).

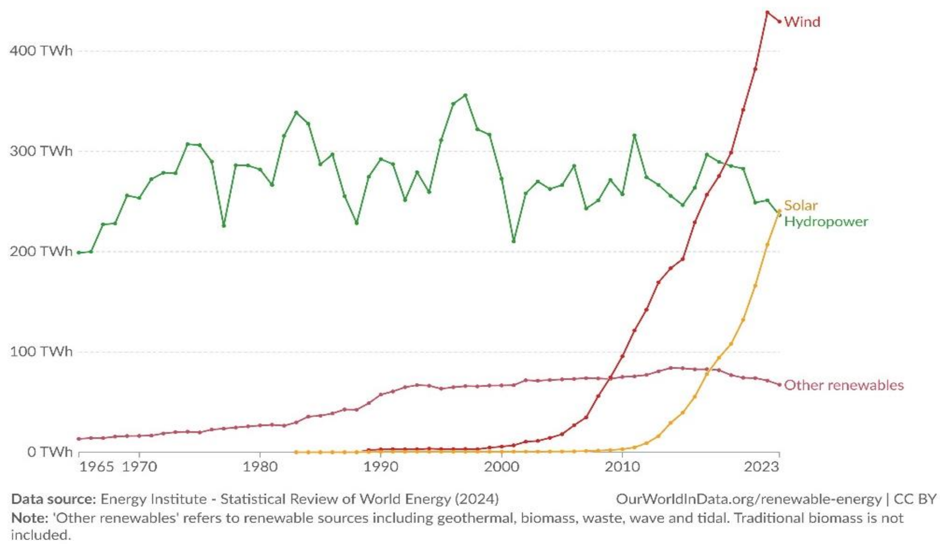

Figure 3. Renewable energy generation. United States
Source: (Our World in Data, 2024e)

Currently, six U.S. cities are already running on 100% renewable electricity: Aspen, Burlington, Georgetown, Greensburg, Rock Port, and Kodiak Island. These cities are all at the forefront of the clean energy initiative (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

3.4.2. Renewable Energy Clusters in USA

California’s solar PV innovation cluster is a leading-edge technology cluster that currently has no associated large-scale manufacturing. The cluster originated more than four decades ago, driven by state government policies supporting solar. California is a leader in solar PV electricity generation, with a 5% share of global solar PV cumulative capacity installed as of 2015. Input of the California Research Centers and Silicon Valley's venture capital investment in solar PV technologies encouraged the establishment of renewable energy clusters. However, California’s current PV manufacturing activity is limited to small-scale fabrication of prototypes of next-generation solar PV technologies. Although several multinational solar PV companies have offices in California, their solar PV manufacturing primarily occurs offshore in Asian countries.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

California's more than 40-year-old solar PV cluster had a global first-mover advantage driven mainly by concerted and supportive policies by the state government. The state government has provided a number of market-based and financial incentives over the last four decades to encourage residential and commercial solar PV installation. The federal government's investment tax credit also stimulated the installation of solar PV. California became a major solar PV manufacturing centre in the 1980s and 1990s when the United States was a major global solar PV manufacturer. Starting in the early 2000s, California lost market share to other countries and U.S. states as PV manufacturing outside of California dramatically increased. California also did not provide sufficient incentives to manufacturers to maintain its solar PV manufacturing base. Several other U.S. states provided more appealing tax and other financial incentives. They successfully attracted solar PV manufacturing with manufacturing centres in Washington, Oregon, Michigan, and Mississippi, with the bulk of global manufacturing in Asian countries (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

The Great Lakes region comprises eight U.S. states - Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin—and the Canadian province of Ontario. The Great Lakes region has substantial wind energy capacity, with a 4% global share of cumulative installed capacity. The innovation cluster comprises research institutes, universities, and industries that perform or fund wind energy R&D and technological development. The U.S. Department of Energy has funded wind R&D activities in several Great Lakes states. Western University in Ottawa has the world's most advanced wind tunnel. The Great Lakes manufacturing cluster primarily manufactures wind subcomponents that supply assembly plants of the main components—blades, nacelles, and towers—located in several states, including Texas, Iowa, and Colorado, and in other countries (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

Key technology demand-side policies that have supported this wind cluster include the renewable portfolio standards adopted by the eight Great Lakes states and other U.S. states, as well as Ottawa's 2009–2013 feed-in tariff program. Government policies that encourage manufacturing have included the U.S. government's investment tax credit and, various tax incentives and other programs implemented by the Great Lakes states during and following the 2008–2009 recession. Ottawa's feed-in-tariff program had a domestic content requirement that spurred the construction of wind manufacturing plants. Some wind components (blades, towers) are large and challenging to transport thus providing an incentive to be made within the country of installation; however, the subcomponents within the nacelle are more easily transported and the retention of the manufacturing of these technologies appears to be supported by a strong cluster of skilled labour and relevant supply chains. The Great Lakes region's pre-eminence in other manufacturing industries—automotive, fabricated metal parts, and machinery manufacturing—played a key role in the development of the wind industry through the transfer of technology, use of skilled labour from these industries, and use or conversion of plants in these industries (Fuller & Guo, 2017; Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

3.5. The renewable energy generation and clusters performance in Germany

3.5.1. Overview of renewable energy sources in Germany

Renewable energy in Germany is mainly based on wind and biomass, plus solar and hydro. Germany had the world's largest photovoltaic installed capacity until 2014; as of 2023, it has over 82 GW. It is also the world's third country by installed total wind power capacity, 64 GW in 2021 (59 GW in 2018) and second for offshore wind, with over 7 GW. Germany has been called "the world's first major renewable energy economy".

Germany has been the global pioneer in applying renewable energy and environmental technologies for decades. In 2019, 46% of the country's electricity mix came from wind, solar, biomass and hydroelectric sources. That's up 5.6 percentage points over 2018.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

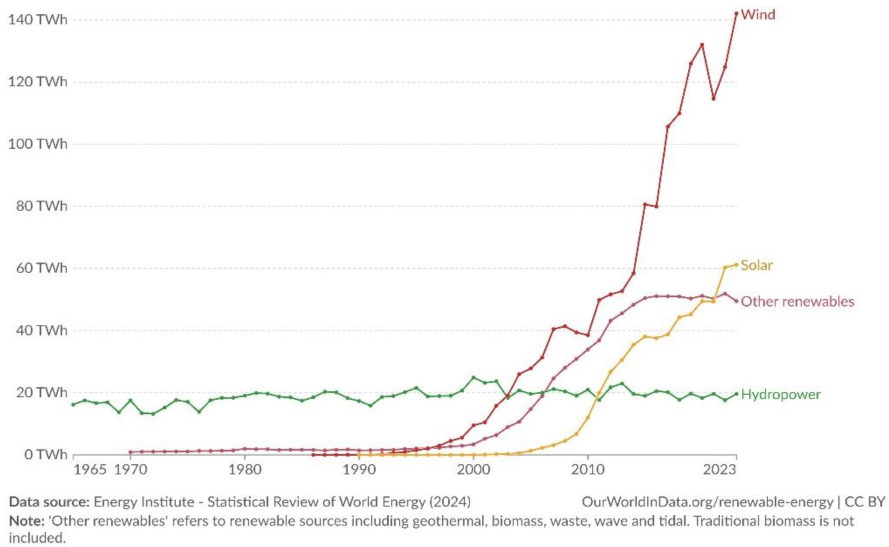

Figure 4. Renewable energy generation. Germany
Source: (Our World in Data, 2024c)

The bulk of the clean power came from onshore and offshore wind capacity (24.4%), followed by solar (9%) and biomass (8.7%), with the remainder stemming from hydropower. All in all, 238.37 terawatt hours of electricity were generated by all renewable technologies.

3.5.2. Renewable Energy Clusters in Germany

Research and innovation in the energy sector in Germany are a high priority. As a result, the Federal government spent around 1.22 billion Eur on research, development of new technologies, and demonstration of pilot projects (Singh et al., 2023). Northwest Germany, including the states of Niedersachsen, Nordrhein-Westfalen, Sachsen Anhalt, and Schleswig-Holstein, is a leading wind turbine innovation cluster that benefited from supportive government policies. Germany today is a leading country in wind energy generation, with a global share of 10% of cumulative installed capacity (REN21, 2017). Germany has had long-term, consistent, and supportive policies that made it an early leader in wind capacity and generation and wind technology manufacturing. Most of these government policies have been on the demand side (such as feed-in tariffs), with coordination by federal and state governments and cooperation and input from labour and industry. The wind innovation cluster emerged as the number of wind turbine installations increased rapidly, starting in the 1980s. Turbine manufacturers, wind farm operators, and research institutions agglomerated in a strong cluster in northwest Germany.

Energy clusters in Germany are organized in a top-to-bottom approach (Singh et al., 2023). Germany's wind turbine innovation cluster is a network of large German and foreign corporations, small and medium-sized firms, federal and state government agencies, and various research organizations. The government’s demand-side policies combined with government-sponsored economic development in key states with existing but declining industry sectors spurred an increase in wind manufacturing and led to the build-up of an extensive supply chain of subcomponents that utilized and transferred skills and equipment from Germany’s turbine and machine-building manufacturing industries. This cluster is a major global producer with highly productive and technologically sophisticated firms that manufacture the main components - blades, nacelles, and towers - and an extensive supply chain of firms that manufacture subcomponents. Technology transfer and use of skilled labour, equipment, and plants from Germany's turbine and machine-building manufacturing industries played a key role in the success of this cluster. Germany is a major exporter of wind turbine components, especially throughout Europe, attesting to

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

its high-quality advanced technology and the global competitiveness of its industry. Germany is a major player in the technology and manufacturing of offshore wind turbines that are concentrated in the Baltic and North Sea (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

3.6. The renewable energy generation and clusters performance in Morocco

3.6.1. Overview of renewable energy sources in Morocco

Morocco is considered a "high-risk, low-capacity country" as it suffers from significant climatic, political and institutional vulnerabilities (Ainou et al., 2022). Morocco experiences relatively large territorial disparities in terms of access to energy resources as it possesses very limited fossil resources (already imported at a 97% rate in 2012) versus a high degree of solar irradiance, wind speed and biomass availability. This situation has led Morocco to develop diverse energy options, including large renewable power projects. Since 2009 this growing sector has emerged as complex a green business cluster in Morocco with a faster-than-average economic growth rate (Amungo, 2020; Benida et al., 2023; Boukhars, 2021; Boulakhbar et al., 2020; El Hafdaoui et al., 2024; El Iysaouy et al., 2019; Fragkos, 2023; Haddad et al., 2022; Kettani et al., 2021; Mahdavi & Vera, 2023; Nakach et al., 2023; Sellers et al., 2015; Vidican, 2015; Zemlickienė et al., 2024).

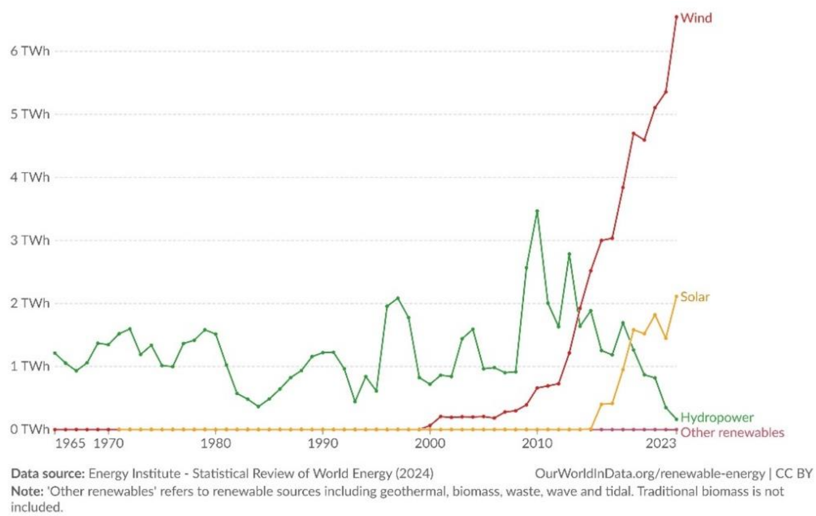

Figure 5. Renewable energy generation, Morocco
Source: (Our World in Data, 2024d)

Morocco still faces fundamental challenges – its geographical position in a warming hotspot makes it vulnerable to the impacts of climate change. This vulnerability manifests itself in the lack of water and the disappearance of rivers, which affects the decrease in the electricity produced by hydroelectric power plants, as shown in Figure 5.

3.6.2. Renewable energy clusters in Morocco

Initially, Morocco engaged in cluster development policy through the Pacte National pour l'Emergence Industrielle. In 2009, this pact aimed to develop 15 national cluster initiatives. Today, Morocco's cluster program consists of the “Stratégie Maroc Innovation” program, which seeks to improve R&D and promote innovation targeting triple-helix agents.

The cluster program combines a top-down and bottom-up approach: state support and, at the same time, initiating cluster competition. Further cluster organizations are promoted by other stakeholders, such as the solar cluster or the Industrial Cluster for Environmental Services (CISE). Additionally, Morocco will actively pursue an industrial

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

policy plan ("Plan D'acceleration industrielle") until 2020, which includes the development of cluster organizations and cluster policy (ECCP, n.d.).

Morocco is actively developing renewable energy clusters to leverage its abundant solar and wind resources. Here are some key initiatives and developments:

Cluster ENR: This renewable energy and climate innovation centre fosters innovation and capacity building in the renewable energy sector. It has been recognized internationally, winning the Emirates Energy Award for its efforts in education and capacity building (IEA, n.d.).

Noor Solar Complex: Located near Ouarzazate, the Noor Solar Complex is one of the world's most extensive solar power facilities. It consists of multiple phases combining photovoltaic and concentrated solar power (CSP) technologies, with a total capacity of 580 MW (Forrester, 2024). In 2015, Morocco established one of the largest solar power plants in the world, the Noor-Ouarzazate plant, with an ultimate capacity of 580 MW, adjoined with large-scale Concentrating Solar Power (CSP) plants, a unique solution between photovoltaic and solar technologies. The cluster's development should be State-led due to a lack of local entrepreneurial and financial resources, policy capacity, and awareness of local technologies and selection mechanisms (Ainou et al., 2022).

National Energy Transition Consortium: Recently launched, this consortium aims to drive Morocco’s transition to sustainable energy. It brings together various stakeholders, including public and private entities, to coordinate efforts to advance renewable energy projects and policies (Simpara, 2024).

These efforts are part of Morocco's broader strategy to increase its renewable energy capacity and reduce carbon emissions, aligning with its National Energy Strategy targets for 2030. The country aims to have 52% of its installed power capacity from renewable sources by this year.

3.7. Experience and influencing factors of renewable energy clusters

The reasons for Jiangsu Solar PV cluster's success are the supportive government policies, the largest capacity in the world, an extensive supply chain of supplier companies and raw materials inputs, the considerable increase in global demand for solar PV after the mid2000s, much lower labour costs relative to developed countries; subsidies for land, installation of factories, electricity, and finance; an extensive domestic supply chain. However, this cluster also experienced difficulties: the glut in solar PV manufacturing in 2011 led to financial challenges and imposed anti-dumping tariffs by the United States and the European Union.

In the case of wind industry clustering in Jiangsu, local governments have acted as a strong enabling factor, either by initiating the construction of wind farms or by planning large wind power-related industrial parks. In the Jiangsu case, top-down planning undertaken by the local governments is believed to be a solid enabling factor in the development and evolution of clusters (Huang & Liu, 2017).

In the case of the solar industry in Shandong, pioneering enterprises such as Himin have played an important role during the early stage of cluster emergence since "successful imitation is most likely to take place in close geographical proximity to the pioneering firms”. In the Shandong case, a bottom-up formation process can be observed, in which the role of pioneering enterprises is imperative.

California’s more than 40-year-old solar PV cluster was driven by state government policies supporting solar energy, input from the California Research Centers, and Silicon Valley's venture capital investment. In the early 2000s, its market share was lost to other countries and U.S. states. California state did not incentivize manufacturers to maintain its solar PV manufacturing base.

The Great Lakes region has substantial wind energy capacity, with a 4% global share of cumulative installed capacity. Key technology demand-side policies, feed-in tariff programs, the U.S. government's investment tax credits and various tax incentives have supported this wind cluster. The Great Lakes region's pre-eminence in other manufacturing industries—automotive, fabricated metal parts, and machinery manufacturing—played a key role in developing the wind industry through the transfer of technology, use of skilled labour from these industries, and use or conversion of plants in these industries.

The German wind innovation cluster emerged as the number of wind turbine installations increased rapidly, starting in the 1980s. Turbine manufacturers, wind farm operators, and research institutions agglomerated in a strong cluster in northwest Germany. Now, it is a leading wind turbine innovation cluster that benefited from supportive government policies. Most of these government policies have been on the demand side (such as feed-in tariffs), with coordination by federal and state governments and cooperation and input from labour and industry. Technology transfer and use of skilled labour, equipment, and plants from Germany's turbine and machine-building manufacturing industries played a key role in the success of this cluster.

Conclusions

The supportive Government policy, the feed-in tariff program, the Government's Investment tax credit and different tax incentives are essential for the success of renewable energy clusters; this factor was emphasized in all examined cases.

Increased or decreased demand, which is challenging to regulate, can still affect the survival or viability of the existing cluster. It positively impacted the Jiangsu Solar PV, The Great Lakes region, and Germany clusters, while it negatively impacted the California PV cluster. However, fluctuations in demand must be supported by state policy.

Pre-eminence in other manufacturing industries /industrial foundations should also be an important factor, as in the case of the Shangdon Solar Cluster or the Great Lakes Cluster, or lower labour costs in the case of the Jiangsu Solar PV Cluster.

References

Ainou, F. Z., Ali, M., & Sadiq, M. (2022). Green energy security assessment in Morocco: Green finance as a step toward sustainable energy transition. *Environmental Science and Pollution Research*, *30*(22), 61411–61429. https://doi.org/10.1007/s11356-022-19153-7

Amungo, E. (2020). The Lions Driving the Development of Africa: A Detailed Look at the Contributions of African Multinationals Enterprises to Africa Economic Development. In E. Amungo, *The Rise of the African Multinational Enterprise (AMNE)* (pp. 209–238). Springer International Publishing. https://doi.org/10.1007/978-3-030-33096-5_11

Baus, D. (2017). *Production of Energy and Environmental Protection as a Prerequisite for Sustainable Development*. https://academicworks.cuny.edu/gc_etds/1907

Benida, O., Allali, K., Ramou, H., & Fadelaoui, A. (2023). *The economic dimension in regional division in Morocco: Analysis of the convergence of regions*. https://doi.org/10.5281/ZENODO.8270666

Boukhars, A. (2021). Sino-Moroccan Relations: A Partnership Seeking to Reach its Full Potential. In *China and North Africa: Between economics, politics and security*.

Boulakhbar, M., Lebrouhi, B., Kousksou, T., Smouh, S., Jamil, A., Maaroufi, M., & Zazi, M. (2020). Towards a large-scale integration of renewable energies in Morocco. *Journal of Energy Storage*, *32*, 101806. https://doi.org/10.1016/j.est.2020.101806

Climate Council. (2022). *11 countries leading the charge on renewable energy*. https://www.climatecouncil.org.au/11-countries-leading-the-charge-on-renewable-energy/

Dong, L., Liang, H., Gao, Z., Luo, X., & Ren, J. (2016). Spatial distribution of China's renewable energy industry: Regional features and implications for a harmonious development future. *Renewable and Sustainable Energy Reviews*, *58*, 1521–1531. https://doi.org/10.1016/j.rser.2015.12.307

ECCP. (n.d.). *Morocco*. https://www.clustercollaboration.eu/content/morocco

EIA. (2024). *What is U.S. electricity generation by energy source?*

El Hafdaoui, H., Khallaayoun, A., & Ouazzani, K. (2024). Long-term low carbon strategy of Morocco: A review of future scenarios and energy measures. *Results in Engineering*, *21*, 101724. https://doi.org/10.1016/j.rineng.2023.101724

El Iysaouy, L., El Idrissi, N. E. A., Tvaronavičienė, M., Lahbabi, M., & Oumnad, A. (2019). Towards energy efficiency: Case of Morocco. *Insights into Regional Development*, *1*(3), 259–271. https://doi.org/10.9770/ird.2019.1.3(6)

Forrester, N. (2024). *Catching the rays: My part in Morocco's renewable-energy revolution*. https://www.nature.com/articles/d41586-024-00548-0

Fragkos, P. (2023). Assessing the energy system impacts of Morocco's nationally determined contribution and low-emission pathways. *Energy Strategy Reviews*, *47*, 101081. https://doi.org/10.1016/j.esr.2023.101081

Fuller, J., & Guo, Y. (2017). Comparison between China and the United States in Solar Energy Development. *Studies in Engineering and Technology*, *4*(1), 131. https://doi.org/10.11114/set.v4i1.2578

Green encyclopedia. (2024). *Energy clusters—What are they, what are they about?* https://reo.pl/en/information/green-encyclopedia/15/energy-clusters-what-are-they-what-are-they-about

Haddad, C., Günay, C., Gharib, S., & Komendantova, N. (2022). Imagined inclusions into a 'green modernization': Local politics and global visions of Morocco's renewable energy transition. *Third World Quarterly*, *43*(2), 393–413. https://doi.org/10.1080/01436597.2021.2014315

Hao, F., & Shao, W. (2021). What really drives the deployment of renewable energy? A global assessment of 118 countries. *Energy Research & Social Science*, *72*, 101880. https://doi.org/10.1016/j.erss.2020.101880

He, Z., Xu, S., Shen, W., Long, R., & Yang, H. (2016). Overview of the development of the Chinese Jiangsu coastal wind-power industry cluster. *Renewable and Sustainable Energy Reviews*, *57*, 59–71. https://doi.org/10.1016/j.rser.2015.12.187

Hill, D., & Engel-Cox. (2017). *Energy Innovation Clusters and their Influence on Manufacturing: A Case Study Perspective*. https://www.nrel.gov/docs/fy17osti/68146.pdf

Hilton, I. (2024). *How China Became the World's Leader on Renewable Energy*. https://e360.yale.edu/features/china-renewable-energy

Huang, P., & Liu, Y. (2017). Renewable Energy Development in China: Spatial Clustering and Socio-Spatial Embeddedness. *Current Sustainable/Renewable Energy Reports*, *4*(2), 38–43. https://doi.org/10.1007/s40518-017-0070-8

IEA. (n.d.). *Morocco*. https://www.iea.org/countries/morocco/energy-mix

IHA. (2024). *2024 World Hydropower Outllook. Opportunities to advance net zero.* https://acrobat.adobe.com/id/urn:aaid:sc:us:6ba5f8fc-5ad3-4d52-a83c-0931ce5fa119

IRENA. (2024). *IRENASTAT Online Data Query Tool*. https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/RESHARE_2024_H2.px/

Jägersberg, G., & Ure, J. (2017). *Renewable energy clusters: Recurring barriers to cluster development in eleven countries*. Springer.

Kettani, M., de Lavergne, J.-G. D., & Sanin, M. E. (2021). Énergie solaire au Maroc: Vers un leadership régional ? *La Revue de l'Énergie*, *659*. https://www.larevuedelenergie.com/wp-content/uploads/2022/02/659-Energie-solaire-Maroc-leadership-regional.pdf

Mahdavi, M., & Vera, D. (2023). Importance of renewable energy sources and agricultural biomass in providing primary energy demand for Morocco. *International Journal of Hydrogen Energy*, *48*(88), 34575–34598. https://doi.org/10.1016/j.ijhydene.2023.05.246

Nakach, I., Mouhat, O., Shamass, R., & El Mennaouiy, F. (2023). Review of strategies for sustainable energy in Morocco. *Polityka Energetyczna – Energy Policy Journal*, *26*(2), 65–104. https://doi.org/10.33223/epj/163373

Our World in Data. (2024a). *Electricity generation from fossil fuels, nuclear and renewables, 2023*. https://ourworldindata.org/grapher/elec-mix-bar?country=JPN~CHN~USA~GBR~SWE~NOR~FIN~LTU~MAR~NZL~KEN~URY~DEU~ISL~CRI~DNK~CHE~FRA~AUT~EST~NLD

Our World in Data. (2024b). *Renewable energy generation, China*. https://ourworldindata.org/grapher/renewable-energy-gen?country=~CHN

Our World in Data. (2024c). *Renewable energy generation, Germany*. https://ourworldindata.org/grapher/renewable-energy-gen?country=~DEU

Our World in Data. (2024d). *Renewable energy generation, Morocco*. https://ourworldindata.org/grapher/renewable-energy-gen?country=~MAR

Our World in Data. (2024e). *Renewable energy generation, United States*. https://ourworldindata.org/grapher/renewable-energy-gen?country=~USA

Porter, M. E. (1998). Clusters and the new economics of competition. *Harvard Business Review*, *76 6*, 77–90.

REN21. (2017). *Renewables 2017 Global Status Report*. https://www.ren21.net/wp-content/uploads/2019/05/GSR2017_Full-Report_English.pdf

Sellers, B. J., Voltaire, J. A., Gustafson, S. M., & Hartman, W. A. (2015). Energy Sustainability in Morocco. *Energy*.

Simpara, M. (2024). *Morocco Launches National Energy Transition Consortium for Sustainable Future*. https://www.moroccoworldnews.com/2024/05/362524/morocco-launches-national-energy-transition-consortium-for-sustainable-future

Singh, M., Darold, D. L., Klobasa, M., Zielinski, A., & Frietsch, R. (2023). Keeping track of cleantech development using innovation clusters and member's website data: Evidence from leading energy clusters in Germany. *Energy Reports*, *10*, 756–767. https://doi.org/10.1016/j.egyr.2023.07.026

Su, Y., & Fan, Q. (2022). Renewable energy technology innovation, industrial structure upgrading and green development from the perspective of China's provinces. *Technological Forecasting and Social Change*, *180*, 121727. https://doi.org/10.1016/j.techfore.2022.121727

Sudhakar, K., Shukla, A. K., & Baredar, P. (2017). Renewable energy resources in South Asian countries: Challenges, policy and recommendations. *Resource-Efficient Technologies*, *3*, 342–346. https://doi.org/10.18799/24056529/2017/3/140

Trendy w energetyce. (2018). *Energy Clusters*. https://trendywenergetyce.pl/en/energy-clusters

Vidican, G. (2015). The emergence of a solar energy innovation system in Morocco: A governance perspective. *Innovation and Development*, *5*(2), 225–240. https://doi.org/10.1080/2157930X.2015.1049852

World Economic Forum. (2024). *Energy transition index 2024: Top 10 countries*. https://www.weforum.org/agenda/2024/06/energy-transition-index-top-countries-2024/

Zemlickienė, V., Amraoui, B., & El Idrissi, N. E. A. (2024). Analysis of Morocco's renewable energy production and transmission potential. *Insights into Regional Development*, *6*(2), 64–78. https://doi.org/10.9770/IRD.2024.6.2(4)

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 1 (March)
https://doi.org/10.70132/w8428438283

Funding: The research leading to these results has received funding from the project titled "Cluster for innovative energy" in the frame of the program "HORIZON-MSCA-2022-SE-01" under the Grant agreement number 1011298205.

Author Contributions: Conceptualization: *Vaida Zemlickienė*, *Boumediene Amraoui*, *Najiba El Amrani El Idrissi*; methodology: *Vaida Zemlickienė*, *Boumediene Amraoui*, *Najiba El Amrani El Idrissi*; data analysis: *Vaida Zemlickienė, Boumediene Amraoui, Najiba El Amrani El Idrissi;* writing—original draft preparation: *Vaida Zemlickienė*, *Boumediene Amraoui*, *Najiba El Amrani El Idrissi*; writing review and editing: *Vaida Zemlickienė, Boumediene Amraoui, Najiba El Amrani El Idrissi*; visualization: *Vaida Zemlickienė*, *Boumediene Amraoui*, *Najiba El Amrani El Idrissi*. All authors have read and agreed to the published version of the manuscript.

Boumediene AMRAOUI, since 1992, has been working at Sidi Mohamed Ben Abdelah University. He is a senior administrator at the Faculty of Science and Technology of Fes. He received his master's degree in law from the Faculty of Legal, Economic, and Social Sciences of Fez and studied at the same faculty for a doctoral degree. Areas of scientific interest are environmental law, transition processes to a green economy, and the performance of clusters in Morocco. He is a member of the National Office of the Moroccan Association of Victims of Arbitrary Expulsion from Algeria (AMVEAA).
ORCID ID: https://orcid.org/0000-0001-5461-2721

Vaida ZEMLICKIENĖ works at Vilnius Gediminas University of Technology, Faculty of Creative Industries, as an associate professor and at the Institute of Sustainable Construction as a senior research fellow. In 2015, he defended his PhD work on the topic "Evaluation of the commercial potential of technologies". Areas of scientific interest include the evaluation of the commercial potential of technologies, the technology commercialization process, the evaluation of the expediency of advertising formats, and managing renewable energy.
ORCID ID: https://orcid.org/0000-0002-0882-2864

Najiba EL AMRANI EL IDRISSI is a full-time professor at the Laboratory of Signals, Systems and Components, University of Sidi Mohamed bin Abdellah, Morocco. She received her PhD in Electrotechnics and Power Electronics from the Mohammedia School of Engineering in Morocco in 2004. She graduated as an Engineer in the Electrical Engineering specialty of Computer Systems in 1984. Her research interests include electrical engineering, ICT, and electrical power electronics.
ORCID ID: https://orcid.org/0000-0001-5603-1306