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Renewable Energy Potential Across the World: A Classification-Based Regional Assessment

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Abstract
The world is on the pace of increasing the share of renewable energy source at a great extent at early as possible otherwise it will grasp in the hands of climate change and hence the destruction of life and biodiversity. The world is full of possibilities like solar energy, wind energy, bio energy, hydropower, Geothermal energy, ocean energy etc. but the possibilities are unevenly distributed over the whole world. Some regions may grateful to wind energy like Thar deserts, Sahara deserts etc. and some may win the possibility of hydropower and solar power etc. The present study aims to classify the possibilities of renewable energy production with respect to various geographical regions. The study aims to assess the current and future potential of all renewable energy sources and classify global regions by their resource richness and hence it will find out the easy to access technology for various countries.

Keywords: *Potential of renewable energy, Solar Energy, Wind Energy, Hydropower Potential, World classification*

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I. Introduction:

At this time the world is standing at such a place from where neither we can turn back nor we can stop moving forward. If we look back then we can see how many problems we have created and how much destruction we have caused in the name of development in the last few years. Today in the name of development many types of pollution have established their place and this increasing pollution has surrounded us with many problems, one of the biggest problems of which is the greenhouse effect. Moving away from the greenhouse effect means that we do not use non-renewable sources for energy production. This will get rid of the greenhouse effect but the entire global economy will be unable to support its large population. This way only the population will survive which can survive comfortably with the remaining resources. And in this way, we can become a part of a static economy, which is based on no growth. Obviously, we do not want to be a part of such an economy.

A large population of us will not be in favour of this at all. So, the other side is to just stop here. There should not be any demand for more than this, consequently there should not be any more energy production. Energy production should be sustained here. But the method that the world wants and which is being worked on, is to increase the share of renewable energy, along with adopting green technology and implementing artificial methods of carbon sequestration. Another thing that should be done is to keep the absolute and relative share of non-renewable energy sources limited; i.e. not let it exceed a limit. One thing that creates regional imbalance is our greed. We work together where we feel that pollution is harmful not only for others but also for us and do not work together where we feel that pollution is harmful only to others and not us and we dump our loss on others. For example, put your garbage in front of others' house because they are not capable of fighting you, so dump it on them. Worst wrong way. The powerful countries of the world have done the same and they are doing the same.

To increase the source of renewable energy, it is very important to know its possibilities. When we know the possibilities of all the countries, then we can make those countries aware of the same kind of investment, can do funding, in this way that employability will also be created and the share of renewable energy will also increase.

Objectives:

1. To know the possibility/potential of renewable energy sources.
2. To classify the world based on renewable energy sources.

II. Literature Review:

Rybár, R., et. al. (2015): This study highlights the importance of context – time, place and technology – in classifying energy sources, legal definitions and mixed characteristics (like in biomass or nuclear) further add complexity. There is no globally unified definition of renewable energy. The existing classification systems of renewable energy oversimplify or ignore key aspects like source lifecycle, technological advancement & environmental feedback. The study says the future classification should consider carrier type, accumulation ability, thermodynamic quality and spatial and temporal context.

Mammadov, N. S. et. al. (2022): According to this report the wind energy has a potential of one third of world's electricity needs by the year 2050 whereas mere less than 25% of technical hydropower potential has been used.

Srinivasan, G., & Muthukumar, P. (2021): This paper aims to evaluate the economic and environmental performance of solar greenhouse dryers and highlights that the economic viability like payback time, cost, and drying cost etc. should be analyzed together with the environmental sustainability like CO2 reduction, mitigation, carbon credits embodied energy etc.

Noor, M. M. et. al. (2023): The paper aims to review and map two decades of solar energy business economics research through scientometric methods, and it concludes that the field is growing, multidisciplinary, and requires broader research that bridges various disciplines for continued growth.

Pourasl, H. H., et. al. (2023): This study aims to review the worldwide status and potential of solar energy and concludes that while solar power is rapidly expanding and may meet a quarter of global electricity demand by 2050, significant gaps remain in deployment and research, which requires stronger global efforts.

Haidi, T., & Cheddadi, B. (2022): The paper aims to evaluate the evolution, impacts, and future prospects of wind energy worldwide, and it concludes that while wind power has grown rapidly and offers huge potential for clean energy and job creation, stronger international collaboration and policy shifts are essential to meet global climate goals.

Wasti, A., Ray, P., et. al. (2022): This paper investigates the impacts of climate change on global hydropower and finds that climate change will neither reduce nor increase hydropower potential but it will become less predictable, more location dependent, and riskier to manage. It requires adaptive planning stronger forecasting and integration with other renewables.

Azimov, U., & Avezova, N. (2022): This study reviews the status, potential and prospects of small and micro scale hydropower in central Asia and it finds that the central Asia holds large, underutilized small hydropower potential that could deliver affordable clean electricity.

III. Methodology:

In this research paper the geographical possibilities of different types of energy production namely solar energy, wind energy and hydropower energy of the whole world are studied and classified accordingly. For data collection secondary sources like various national and international reports and research papers have been used. The data analysis contains observational method for trends, and some minor calculations have done.

Analysis:

The world is classified according to various studies. If the purpose is the study of history, the world is classified on the basis of various subjects on which historical events took place, if the purpose is to study the climate of the world, then the classification is done on the basis of climatic zones, and if the purpose is to study economic development, then the world is classified on the basis of stages of development. Each classification gives an ease to study various phenomenon. Nomenclature of cold war era (1945-1980) is first world, second world, third world countries based on living standard and economic development. Immanuel Wallerstein's (1979) classified the world in to powered nations and subordinate nations based on economic hierarchy to study economic inequality. World bank classifies the world economies into three classes based on per capita income i.e. low-income nations, middle income nations and high-income nations.

In the present research paper, the target is to study the nations' potential to implement the renewable energy sources so that the nations can formulate the policies accordingly. For the same we need the picturization of the needs of various climatic conditions required for the implementation.

Solar Energy:

Solar panel needs solar energy in sufficient amount to generate electricity. There are the tropical and subtropic regions where the suns heat is absorbed. Tropical zone (23.5^0N – 23.5^0S) is the most favourable region for solar energy whereas temperate zone 23.5^0N - 66.5^0S is less feasible than the Tropical zone. Polar regions (66.5^0N – 90^0S) are not feasible for solar energy. Tropical zone gains direct sunlight and hence has highest intensity of light while temperate zone receives mid inclined sunlight rather than direct and hence has high moderate level of sun's heat but polar region oblique sunlight and hence are cold which does not make solar energy feasible in this area.

Table 01: Countries lie in tropical region

Asia	Africa	South America	Central America & Caribbean	Oceania
India (Southern part)	Nigeria	Brazil	Mexico (southern part)	Papua New Guinea
Indonesia	Kenya	Colombia	Guatemala	Kiribati
Thailand	Ethiopia	Peru	Honduras	Fiji
Malaysia	Uganda	Ecuador	Nicaragua	Solomon Islands
Sri Lanka	Democratic Republic of the Congo (DRC)	Venezuela	Costa Rica	Samoa
Philippines	Ghana	Bolivia	Panama	Vanuatu
Vietnam	Tanzania	Suriname	Cuba	
Bangladesh	Angola	Guyana	Jamaica	
Myanmar	Cameroon		Haiti	
Maldives	Somalia		Dominican Republic	
Cambodia	Ivory Coast		Trinidad and Tobago	
Laos	Zambia			
Brunei	Madagascar			
	Equatorial Guinea			

Table 02: Countries lie in temperate zone

Asia	Europe	North America	South America	Africa	Oceania
China (mainly temperate)	United Kingdom, Slovakia, Hungary, Ukraine, Romania, Bulgaria	United States (except Florida and parts of Texas/Arizona)	Argentina (central and southern)	South Africa (southern part—e.g., Cape Town area)	New Zealand
Japan	Germany, Norway, Sweden, F	Canada (southern part)	Chile (central and southern)	Lesotho	Australia (southern regions like Melbourne, Sydney, Adelaide, Tasmania)
South Korea	France, Denmark, Greece, Ireland	Mexico (northern part)	Uruguay	Swaziland (Eswatini) (partially)	
North Korea	Italy (northern and central)		Paraguay (southern)	Northern Morocco, Algeria, Tunisia (Mediterranean coastlines)	
Turkey	Spain (north and central)		Southern Brazil		
Georgia	Portugal				
Armenia	Netherlands				
Azerbaijan	Belgium				
Kazakhstan (southern part)	Switzerland				
Iran (north and central parts)	Austria				
Nepal (mid-hills and north)	Poland				
Bhutan (mid-hills)	Czech Republic				

There are some countries of which a part or territory lie in the northern polar region (called Arctic Circle) like Canada, Russia, United States (Alaska), Sweden, Finland, Iceland, Greenland. No country owns land in Antarctic Region. Antarctic Region is governed by Antarctic Treaty System and no country owns land in this region rather here scientific research stations are maintained by several countries.

Wind Energy:

Wind energy is useful in generating electricity with no carbon emission. This technology requires ideal wind speed of 6-25 m/s whereas the best speed is 12-15 m/s. Below 4m/s there is no power generation. Since wind speeds are higher at greater altitudes so tall towers help to power generation more efficiently. Wind should be smooth and steady it should not be gusty or erratic, high turbulence can damage turbines and reduce efficiency. Turbines work best in non-extreme climates, it should not be too hot which can damage electronics, and it should not be too icy which affects blades. It needs power grid connection to transmit electricity. The Wind farms require moderate space and can coexist with agriculture, grazing and with offshore fishing.

(C. Jung and D. Schindler, 2021) developed a Wind Farm Potential index that integrate wind energy and accessibility of wind farms so that one can know the sitting of wind energy farms in a region. WPI depicts the accessibility but it does not classify wind energy accessibility in broad way for the world. Still using WPI the

potential of wind energy can be find out. The possible amount of electricity that can be generated from the wind at a given location based on wind speed, area available, turbine type and weather patterns. Meteorological, geographical, technical, economic and socio-political constraints are considered in developing WPI. Potential wind farm sites decrease with the increase in number of constraints. Since WPI ranges 40-100 suitable for wind farms with some and without limitations whereas WPI ranges 0-40 unsuitable for the wind farm installations. Below are the details-

Table 03: Suitable and unsuitable regions for Wind Farms Installation

WPI RANGE FROM 40-100			**WPI RANGE FROM 0-39**	
WPI CLASS 5 EXCELLENT (ABOVE 80)	**WPI CLASS 4 GOOD (60-79)**	**WPI CLASS 3 SUITABLE UNDER LIMITATIONS (40-59)**	**WPI CLASS 2 MOSTLY UNSUITABLE (20-39)**	**WPI CLASS 1 UNSUITABLE (LES THAN 20)**
Kazakhstan	Central Europe	Virtually in any country	Near the equator	
Northeast of China	Brazil		Northern Russia	
Mongolia	SouthAfrica		Northern Canada	
Southern Argentina	Southwestern Russia		Himalayan Region	
Few parts of Sahara			Densely Populated Areas of Europe	
Central United States				
Southeastern Austraalia				
Iceland				
Ireland				
UK				

Hydropower:

Hydroelectricity is a renewable energy source that generates electricity using the movement of water, the installations used to harness this energy is called hydropower plant. Hydropower is a major source of renewable energy and expected to play a critical role in decarbonising the power system. However, other renewables like solar and wind can overtake hydropower but it is a dispatchable and controllable power source and hence backup for variable renewables. Hydropower accessibility not only depends on geographical potential but also on economic, environmental, social, and policy factors.

The theoretical hydropower potential depends on water flow rate & hydraulic head with existing water resource which is reduced by limitations and efficiencies. Technological and practical constraints reduce the theoretical potential which is further reduced by economic constraints which again further reduced by environmental and social constraints. While harnessing water energy the factors ecological integrity, water security, social and cultural values, potential for competing water demands, potential generation needs, climate change impacts etc should be considered (Directory, S., n.d.).

United Nations Industrial Development Organization divided the world continents into various regions like Africa is divided into Eastern Africa, Middle Africa, Northern Africa, Southern Africa and Western Africa; America is divided into Central America, Northern America and Southern America; Asia is divided into Central Asia, Eastern Asia, South Eastern Asia, Southern Asia, Western Asia; Europe is divided into Eastern Europe, Northern Europe, Southern Europe, Western Europe; Carribean and Australia and New Zealand, and generated reports on World Small Hydropower Development for all the regions of world continents. This report contains various variables like population, electricity access, installed hydropower capacity, hydropower generation per year, small hydropower installed capacity, potential hydropower installed capacity etc. Various nations are included for reporting each nation separately. The author calculated installed hydropower capacity per thousand square kilometres to classify the nations into various groups. The outcome obtained from the calculation is given below in the table.

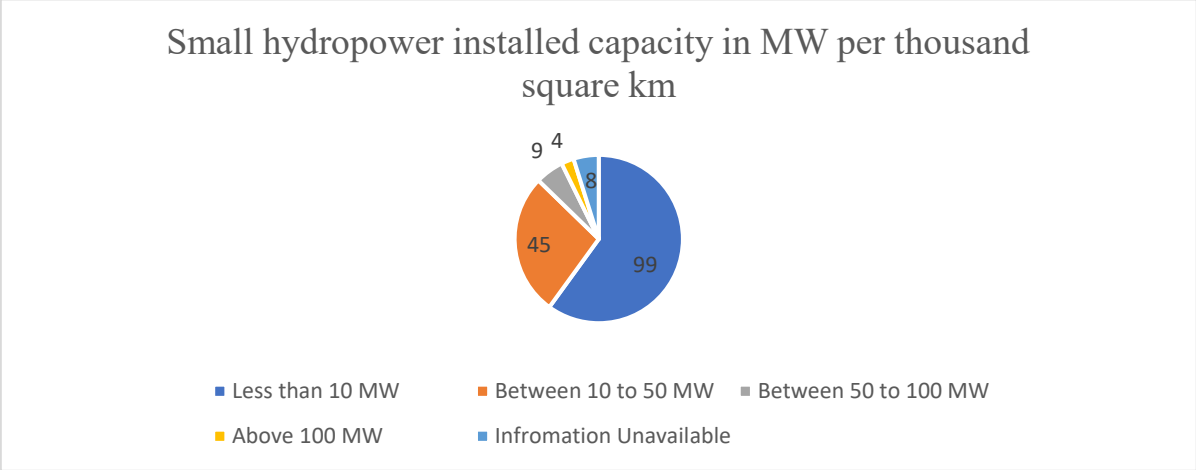
Table 04: Classification based on installed hydropower capacity in MW per thousand square kilometres

Installed Hydropower capacity in MW per thousand square kilometres	No of Countries/territories
less than 10 MW	99
between 10 to 50 MW	46
between 50 to 100 MW	9
greater than 100 MW	4
Information unavailable	8
Total	166

Source: Calculation

There are 99 such countries which are having the installed electricity hydropower potential less than 10MW. General trend of African countries either smaller or bigger is of having less than 5 MW per thousand Km^2 installed capacity. A very few countries are having larger

Figure 01



Source: Calculation

ICPTSK (Installed Capacity Per Thousand Square Kilometres). For example, Reunion and Mauritius are very small countries with areas of 2512 km^2 and 1868 km^2 have ICPTSK of 52.95 and 32.12 respectively while there are many big countries are having a very little value of ICPTSK, for example, Mali – 0.25, Namibia – 0.43, Algeria - 0.09, CAR – 0.03, Tanzania – 0.61, Madagascar – 0.28. With respect to small hydropower potential either local or international definition the general trend is smaller countries are having smaller potential and bigger countries have bigger potential but yet there are exceptions because some smaller countries have similar potential to some bigger countries. For example, Guinea, Sierra Leone and Liberia have similar potential to Nigeria, Cameroon, Angola, South Sudan, Tanzania, Mozambique, Madagascar. American countries also have the same general trends with some exceptions. For example, Ecuador, Paraguay, Guatemala, El Salvador, Costa Rica and Panama have higher ICPTSK as follows 19.89, 21.65, 14.33, 27.28, 45.85 and 24 whereas some larger countries like Greenland, Peru, Bolivia and Argentina have lower ICPTSK as follows 0.04, 4.32, 0.98 and 4.08. Canada and USA are very large countries having potential 15000 MW and 10583 MW while Chile not a very large country but has a potential of 35765 MW with 12.85 ICPTSK. Asian Countries show no general trend; it shows that the smaller countries have both higher and very low ICPTSK and larger countries also show that they have both lower and higher values of ICPTSK. Lao PDR, DPRK, RoK, Bhutan, Georgia, Armenia are smaller countries but they show higher values of ICPTSK that is 35.07, 39.74, 64.8, 60.97, 47.68, 45.25 respectively. Whereas the larger countries Turkey, Vietnam, China, Japan, Tajikistan show larger values of ICPTSK that is 38.03, 62.67, 38.56, 132.38, 38.23 respectively. This difference may because the smaller countries of Asia are not much smaller and larger countries are too large comparatively to other continents. In Europe leaving a few countries maximum countries small and big have a higher value of ICPTSK that is more than 10MW. Switzerland and Norway have ICPTSK of 376.58 and 101.95MW. Iceland, Bosnia, Albania, Switzerland, Austria, Poland are smaller countries and have greater than 1000MW small hydropower potential whereas UK, Norway, Spain, Italy, France, Germany and Russian Federation are bigger countries and they also have greater than 1000MW of small hydropower potential. Russia has maximum SHP of 825845MW. Australia with 175MW SHP has ICPTSK of 1.05 and New

Zeland with 489.8MW SHP has ICPTSK of 20.04MW. Caribbean Islands are very small and they have very small SHP with smaller ICPTSK, for example, Cuba with 77MW SHP has 0.58 ICPTSK and Saint Vincent with 7.5 SHP has 15.42 ICPTSK. Under Pacific Island Countries and Territories only Fiji has ICPTSK of 11.75 and all other countries and territories have less than 10 ICPTSK.

Barriers to small hydropower (SHP):

Barriers to small hydropower (SHP) development include limited funds, expertise, and hydrological data, along with political instability and poor coordination among government agencies. Governments often prioritize large hydropower or fossil fuel plants over SHP. Other challenges are high upfront costs, long project timelines, and lack of awareness, skilled workforce, and local manufacturing capacity for turbines and components. Geographic isolation, difficult terrain, extreme weather, and unstable water flow further increase costs. Legal and regulatory gaps, land acquisition hurdles, poor infrastructure, and lack of clear incentives also slow SHP growth.

IV. Discussion:

The countries which are most suitable for wind energy are Kazakhstan, Northeast of China, Mongolia, Southern Argentina, Central United states, Southeastern Australia, Iceland, Ireland, UK, Central Europe, and Southwestern Russia but they are not the part of tropical zone. Few parts of Sahara - Chad, Egypt, Libya, Mali, Mauritania, Niger, Sudan - Brazil and northern part of South Africa lie in tropical zone and also lie in most suitable class 5 and 4 of WPI. Brazil is the only country which is suitable for all three energy sources solar water and wind. The countries Kazakhstan, Northeast of China, Mongolia, Southern Argentina, Central United states, Southeastern Australia, Iceland, Ireland, UK, Central Europe, and Southwestern Russia lie in temperate zone hence they are good enough for both sources of energy solar and wind. Out of these USA, China, Czech Republic, Slovakia, Slovenia, Austria, Germany and Switzerland are also good enough in Water energy. Costa Rica, Guatemala, Ecuador, Venezuela, Lao PDR, Malaysia, Philippines and Vietnam are the countries which lie in tropical zone and also good enough in per square kilometre of small hydropower. Some countries are found to be suitable for solar energy and wind energy, some are found to be suitable for solar energy and water energy, and some are found be suitable for wind energy and water energy.

V. Conclusion:

This study is limited to available secondary sources of data and based on this data it is hard to classify all the world economies into one suitable classification of all energies but each energy potential can be classified separately. What is obtained from this study is the countries are not good enough for all the energy sources but they are good at one or two energy sources. There is high potential of renewable energy sources but due to some barriers (leaving the natural barriers) the countries remain unable to implement and extend the potential of energy sources. These barriers are lack of fund, long project timeline, lack of awareness, political instability etc.

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