DOI: 10.20472/EFC.2022.017.016

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ANALYSIS OF THE STATE OF THE HYDROPOWER MARKET IN MODERN CONDITIONS: THE CASE STUDY OF THE BRICS COUNTRIES

Abstract:

Today, hydropower remains its position as the main source of renewable energy in the world, though the share of it in the energy mix has decreased with the increase of other alternative sources such as wind and solar. On the hydropower market, the BRICS countries hold four positions out of the top-10 leading countries by overall installed capacity and electricity generation, with China being the absolute leader, followed by Brazil in the 2nd, Russia in the 5th and India in the 6th places3. This article aims to analyse the dynamics of hydropower development in these countries, seeing as together they make up more than half of the market (55.8% in 2021, an increase of 16.4 p.p. from 2012). The authors assess indicators such as electricity generation and capacity, as well as identify the overall role hydropower holds in the energy mix of these countries and on the world hydropower market. It is noted that over the past 10 years, China has been the key player amongst the BRICS countries, followed by Brazil.

Keywords:

Hydropower, renewable energy sources, BRICS, electricity, developing countries

JEL Classification: L94, Q42, Q25

Introduction

The past decade has seen a significant change in the structure of electricity generation by source, mainly because of numerous global, national and regional initiatives that set standards for corporate performance in the context of transitioning to a low-carbon economy, such as The Sustainable Development Goals (SDGs). As a result, electricity generation by coal, oil and nuclear sources has decreased in the world electricity mix, while renewable "green" sources (bioenergy, solar, wind, hydropower) have grown (Savchina et al., 2021). Today, hydropower remains the main source of renewable energy, although the share of this source in the energy mix has significantly decreased.

The BRICS countries are expected to remain the key players on the energy market. Forecasts show that by 2040, the energy balance structure will change: the share of renewable energy, natural gas and nuclear energy will grow, with a decrease of the share of coal and oil consumption (Barykina et al., 2022). Together, the BRICS countries are creating modern and environmentally clean energy systems, and hydropower is one of the key areas of growth. This is connected to the fact that the BRICS countries are among the leading producers and consumers of natural resources and emitters of pollutants and are a part of numerous initiatives in sustainable development (Sakharov A., Andronova I., 2021). Although their role on the renewable energy source market is significant, researchers today note that the BRICS countries are in need of redefining their energy policies upon their existing geographical, economical, societal and environmental conditions (Pathak L., Shah K., 2019).

Research has also shown a positive impact of hydropower energy consumption on economic growth in both the long and short run, and a negative association with CO_2 emissions in the long run (Ummalla et. al, 2019). This corresponds with studies showing how coal and gas energy assist in the development when their share in the energy mix is small, while over-consumption hampers economic development (Wang et al., 2022).

Brazil has always had a large potential for renewable energy resources, especially hydropower – in the second half of the 20th century, hydropower could already supply 20% of the total energy consumption in Brazil. The development of this resource was rapid; however, it did have negative effects on the environment due to serious floods harming the forests of the country (Zeng et al., 2017). Common droughts are also an issue – for example in 2014, the drought had decreased Brazil's hydro reservoirs by more than 60%. In Russia, hydropower was also the main and only renewable energy source consumed until 1994. China's hydropower development has four historical periods: 1949-1979 (slow hydropower development in rural areas); 1980-1989 (construction of large and medium-sized hydropower stations on the Yellow River); 1990-1999 (additional construction of small hydropower stations) and 2000-2015 (peak growth rates of large hydropower stations and the largest small hydro capacity in the world). India started developing minor hydroelectric stations since the 1990s – further development has been slow and steady. South Africa started its renewable energy development with solar and wind power.

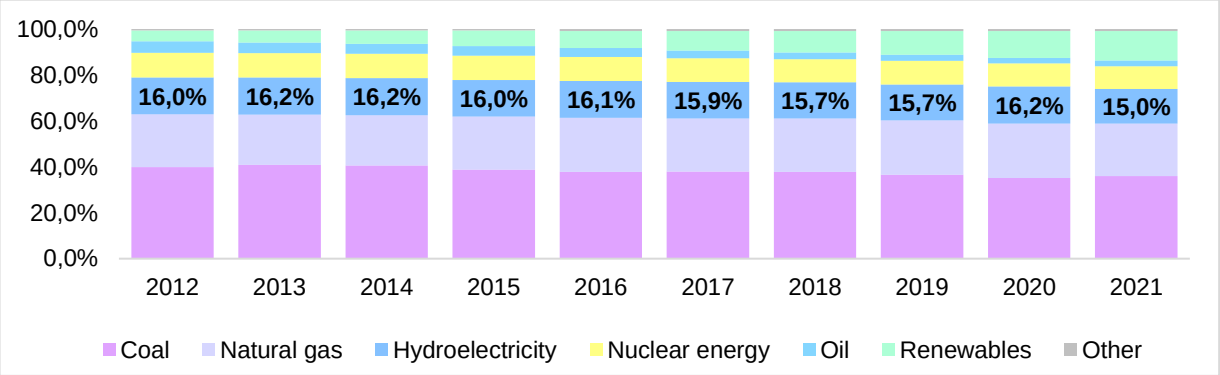
In 2020, the share of renewable electricity capacity to non-renewable electricity capacity was 41:59, 30:70, 20:80, 17:83 and 17:83 for China, India, Russia, Brazil and South Africa, accordingly (International Renewable Energy Agency, www). For most of these countries, hydroelectricity was the main renewable source in the structure of their renewable electricity capacity (93% for Russia, 73% for Brazil, 38% for China and 34% for India). South Africa is the only BRICS country where hydroelectricity is not the most dominant (only 8%, solar and wind energy sources have a joint share of 89% in overall renewable electricity capacity). The latest policies, programmes and legislation for these countries have been the developing of supply and gasification of regions for Russia (2021); the National Policy of payment for environmental

services for Brazil (2021); the Ratle Hydro Power Project, Go Electric Campaign and Renewable energy investment for India (2021): the Carbon neutrality target before 2060 and Interim rules for carbon emissions trading for China (2020 and 2021); and AFD Green Fund and South African Carbon Tax for South Africa (2019).

This article seeks to identify the role of hydropower as the main energy source, the dynamics of hydropower in the BRICS countries and the main trends for today and prospects for the development of this sector in these countries in the future.

Hydropower as the main energy source

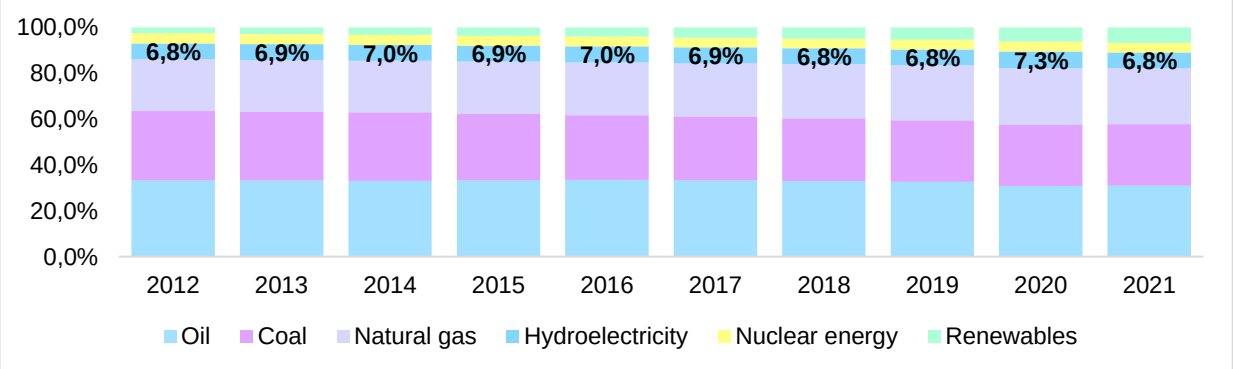
Figure 1: Structure of electricity generation by fuel, (2012-2021/%)



Source: compiled by the authors according to BP https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Hydroelectricity serves as one of the main energy sources: in 2012-2021 it consistently ranked the 3rd in overall electricity generation, and the 4th in overall electricity consumption. However, it is noted that the share of this source in electricity generation has dropped by 1 p.p. over the past 10 years, while the share of it in the electricity consumption has remained stable (Figure 1). Another important trend is the rise of renewable energy sources as a whole: in 2012, 78.7% of electricity generation was from non-renewable energy sources (coal, natural gas, nuclear energy and oil) – by 2021 the share of such sources has decreased by 7.4 p.p., totaling to 71.3%. The same can be said for electricity consumption: the share of non-renewables has dropped by 4.1 p.p. from 90.6% in 2012 to 86.5% in 2021 (Figure 2).

Figure 2: Structure of electricity consumption by fuel, (2012-2021/%)

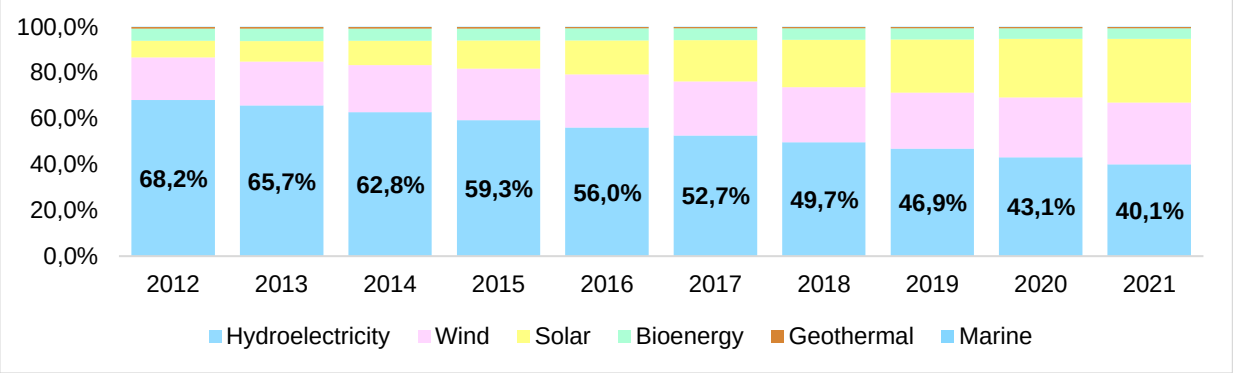


Source: compiled by the authors according to bp https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Amongst renewables, hydropower remains the main source in terms of overall installed electricity capacity, followed by wind and solar sources (Figure 3). However, the share of hydroelectricity has sharply decreased, mainly because of the rapid growth of wind and solar energy: during the last 10 years, hydropower has decreased its share by 28.1 p.p. (from 68.2% in 2012 to 40.1% in 2021), while wind and solar have increase their shares by 8.4 p.p. and 20.6

p.p., accordingly. Other renewable sources, such as bioenergy, geothermal and marine have also decreased their shares or stayed stable (-0.7 p.p., -0.2 p.p. and 0 p.p., accordingly).

Figure 3: Structure of electricity capacity by renewable energy source, (2012-2021/%)

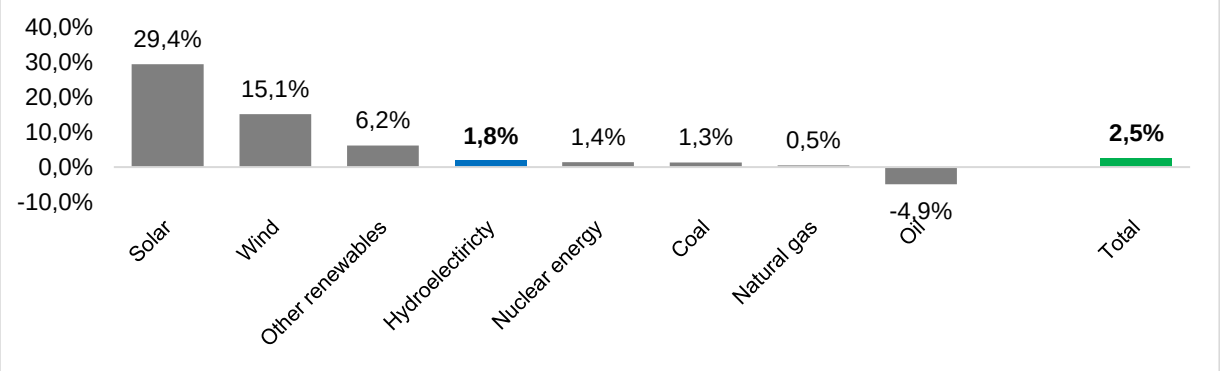


Source: compiled by the authors according to the International Renewable Energy Agency (IRENA) https://www.irena.org/

When analyzing the compound annual growth rates of electricity generation by source, we can also note that renewable sources are on the rise: solar, wind and other renewables (bioenergy, geothermal and marine) had CAGRs of 29.4%, 15.1% and 6.2% in 2012-2021, accordingly. Hydroelectricity grew slower, as it is an older source which had reached its peak growth rates in the late 20th century – the CAGR for this source amounted to 1.8% in 2012-2021, lower than the overall growth of electricity generation for this period by 0.7 p.p. (Figure 4). Coal and natural gas also had positive compound annual growth rates – 1.3% and 0.5%, accordingly; while electricity generation from oil has decreased, with its CAGR totaling to -4.9%.

Although hydroelectricity has not been growing at the same speed as other renewable energy sources (primarily wind and solar), it remains the largest renewable source of electricity – the total generation of electricity from this source is more than the generation from all other renewable sources (International Energy Agency, www). Currently, industry experts note that significant efforts are required for hydropower to reach its Net Zero Emissions by 2050 goal of an average annual generation growth rate of 3% between 2020 and 2030. Most of these efforts have to do with policy adaptation, which is necessary to stop the expected slowdown of growth for this energy source.

Figure 4: Compound annual growth rates (CAGR) of electricity generation by source, (2012-2021/%)



Source: compiled by the authors according to bp https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

The top leading countries in hydropower electricity generation over the past 10 years have not changed significantly: since 2012, only Venezuela had left the top-10 (the 8th in 2012, with an overall share of 2.2%), losing three positions (the 11th in 2021, with an overall share of 1.4%,

0.8 p.p. lower than in 2012). On the contrary, by 2021 Vietnam had entered the top-10 countries by overall hydropower electricity generation, currently siting at the 9th (1.7% share). China, US and Russia have saved their positions – the 1st, the 4th and the 5th, accordingly; Canada, India and Japan have increased their rankings – from the 3rd to the 2nd, the 7th to the 6th and the 10th to the 8th, accordingly; while Norway and Sweden have decreased their positions – from the 6th to the 7th and from the 9th to the 10th, accordingly (Table 1).

Out of the current top-10 leaders in hydropower electricity generation, China, Russia, India, Vietnam, Canada, Norway and Japan have increase production – by 437 TWh, 51 TWh, 45 TWh, 23 TWh, 1 TWh, 1TWh and 1TWh, accordingly. On the other hand, Brazil, Venezuela, the United States and Sweden have decreased hydropower electricity generation – by 53 TWh, 21 TWh, 16 TWh and 7 TWh, accordingly. We can note that the BRICS countries, especially China, have been the main key drivers of growth in hydropower electricity generation.

This fact is also evident when looking at the share of the BRICS countries in hydropower electricity generation – it has increased by 4.9 p.p. from 42.8% in 2012 to 47.7% in 2021, mainly thanks to China (+6.7 p.p. share increase), Russia (+0.5 p.p. share increase) and India (+0.2 p.p, share increase). Hence, this is why there is an increased interest in analyzing the state of the hydropower market of these countries in particular – Brazil, Russia, India, China and South Africa.

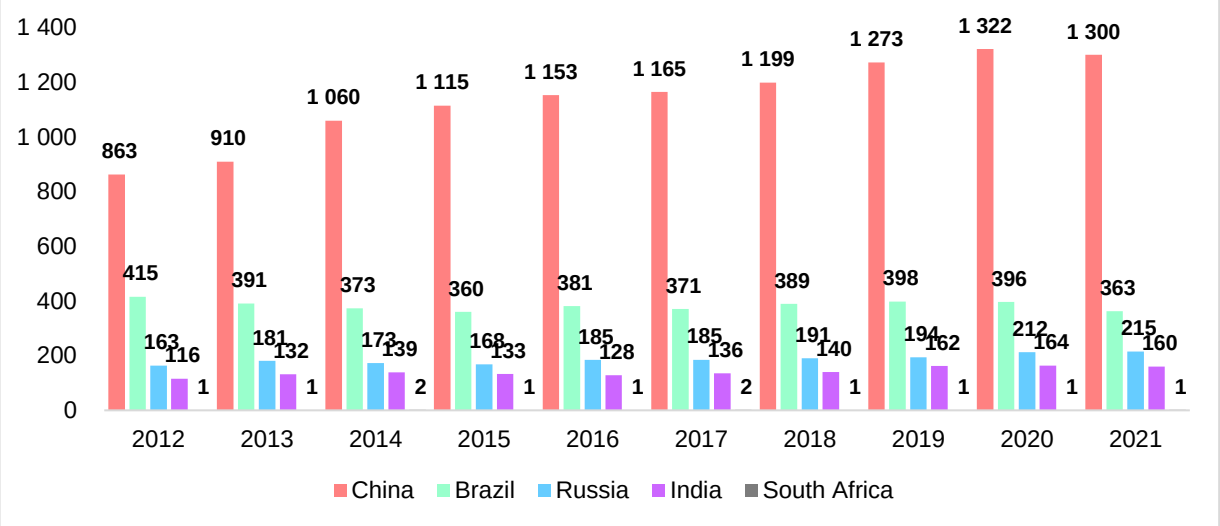
Table 1: Top-10 leading countries in hydropower electricity generation, (2012-2021/TWh and %, where applicable)

Country/Indicator	Generation (TWh)			Positions in top-10			Share in electricity generation (%)		
	2012	2021	Change	2012	2021	Change	2012	2021	Change
China	863	1 300	437	1	1	=	23,7%	30,4%	6,7%
Canada	380	381	1	3	2	+1	10,4%	8,5%	-2,0%
Brazil	415	363	-53	2	3	-1	11,4%	8,9%	-2,5%
United States	274	258	-16	4	4	=	7,5%	6,0%	-1,5%
Russian Federation	163	215	51	5	5	=	4,5%	5,0%	0,5%
India	116	160	45	7	6	+1	3,2%	3,3%	0,2%
Norway	142	143	1	6	7	-1	3,9%	3,8%	-0,1%
Japan	77	78	1	10	8	+2	2,1%	1,4%	-0,7%
Vietnam	53	76	23	13	9	+4	1,5%	1,7%	0,2%
Sweden	79	71	-7	9	10	-1	2,2%	1,8%	-0,4%
Venezuela	82	61	-21	8	11	-3	2,2%	1,4%	-0,9%
Total Top 10 Share:							**71,1%**	**70,9%**	**-0,3%**
Total BRICS Share:							**42,8%**	**47,7%**	**4,9%**

Source: compiled by the authors according to bp https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Hydropower market dynamics in the BRICS countries in 2012-2021

Figure 5: Hydropower electricity generation in the BRICS countries, (2012-2021/TWh)

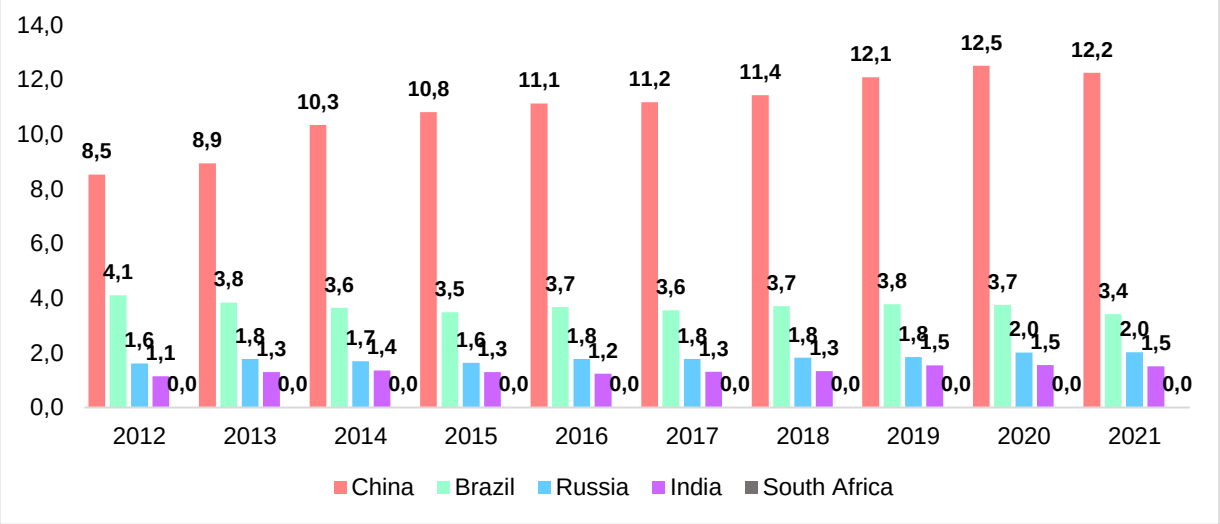


Source: compiled by the authors according to bp https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

In 2012-2021 amongst the BRICS countries China was the absolute leader in hydropower electricity generation, surpassing the next leader, Brazil, by 3.6 times. The CAGR of China hydropower electricity amounted to 4.7%, which is the highest value for the BRICS countries. India, South Africa and Russia also had positive growth rates: 3.7%, 3.6% and 3.1%, accordingly. Brazil was the only country with negative compound growth rates (-1.5%). This can be explained by the ongoing droughts and climate conditions in the country (Figure 5).

The same trends can be seen for hydropower electricity consumption – China is the absolute leader, surpassing Brazil by 3.6 times. The CAGR of electricity consumption by hydropower for China in 2012-2021 amounted to 4.1%, for India, South Africa and Russia – 3.1%, 3.1% and 2.5% (Figure 6), accordingly. As with electricity generation by hydropower, the CAGR for hydropower electricity consumption for Brazil was negative in 2012-2021 (-2.0%).

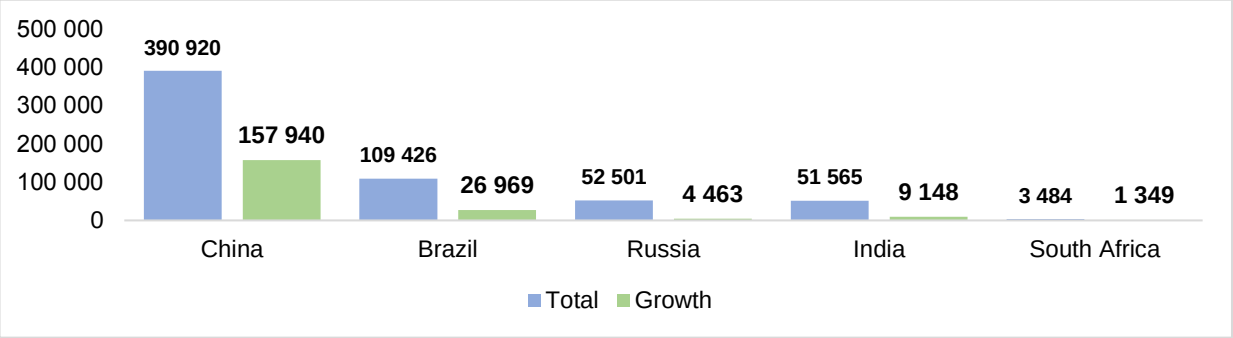
Figure 6: Hydropower electricity consumption in the BRICS countries, (2012-2021/EJ)



Source: compiled by the authors according to bp https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

By 2021, China had 390 920 MW of installed hydropower electricity capacity, surpassing Brazil by 3.6 times. Although China had installed the most capacity in 2012-2021 in absolute values, it was only the 2nd in terms of CAGRs (5.1%), behind South Africa (5.6%). China is followed by Brazil (2.9%), India (2.0%) and Russia (0.6%) in terms of CAGRs. When looking at absolute values, Brazil held the 2nd place with 26 696 MW installed capacity, followed by India, Russia and South Africa with 9 148 MW, 4 463 MW and 1 349 MW of installed capacity, accordingly (Figure 7). It is important to note that during the COVID-19 crisis, hydroelectricity capacity growth had reached its peak value of growth since 2014 – in 2021, the capacity for these countries grew by 21 711 MW, the key driver of such an increase was China, who installed 20 760 worth of hydropower electricity capacity.

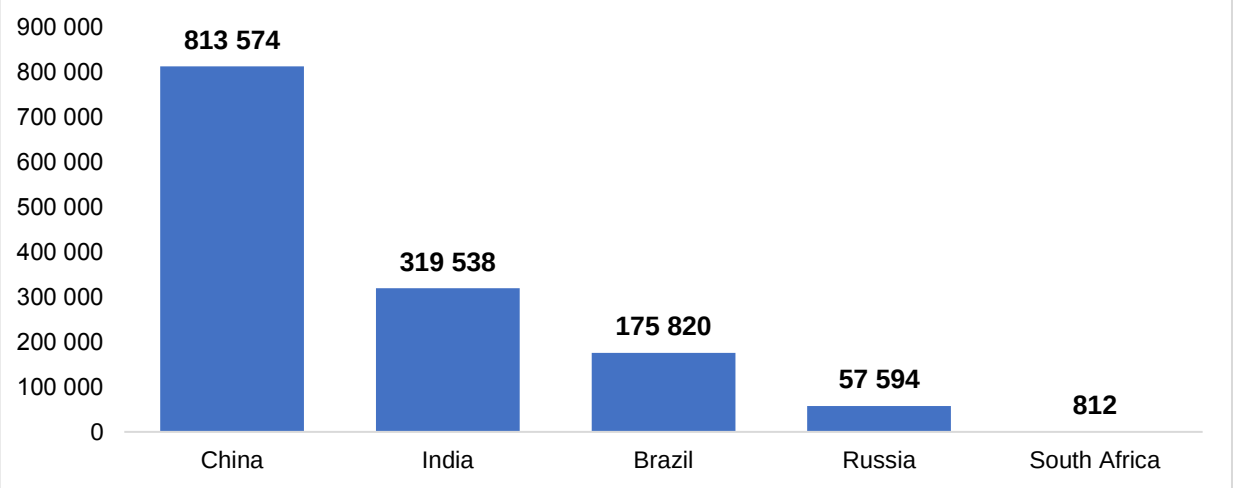
Figure 7: Hydropower electricity capacity in the BRICS countries – total by 2021 and growth, (2012-2021/MW)



Source: compiled by the authors according to the International Renewable Energy Agency (IRENA) https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Country-Rankings

The social impact of hydroelectricity in the BRICS countries is also evident: over 1.3 million people were employed in this sector in 2020, which is 62.7% of the total workforce in employed in hydroelectricity. As with other indicators, the leader is China with 813 thousand people employed, followed by India, Brazil, Russia and Africa with 320 thousand, 176 thousand, 58 thousand and 812, accordingly (Figure 8).

Figure 8: Number of people employed in hydropower electricity sector in the BRICS countries, (2020/PPL)

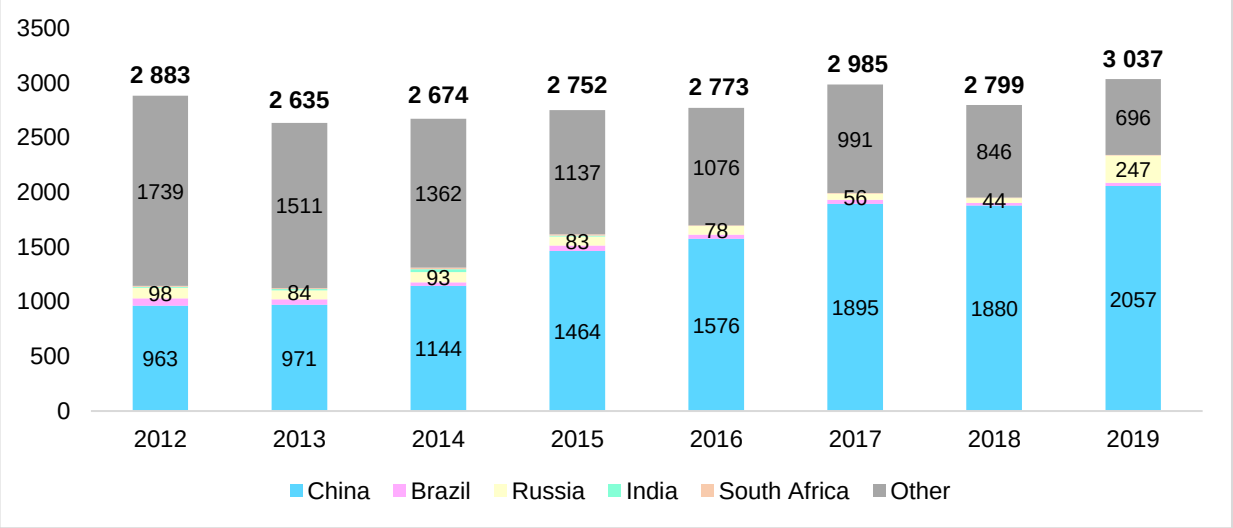


Source: compiled by the authors according to the International Renewable Energy Agency (IRENA) https://www.irena.org/Statistics/View-Data-by-Topic/Benefits/Renewable-Energy-Employment-by-Country

Finally, we can highlight the role of the BRICS countries in innovation and technology development of hydroelectricity (data for net additions of patents in renewable energy is

available up to 2019) – in total, 58.5% of all hydropower electricity patents were from these countries (Figure 9). The absolute leader once again is China (53.0% of all patents), followed by Russia (3.5% of all patents), Brazil (1.5%), India (0.2%) and South Africa (0.3%).

Figure 9: Net additions of hydropower electricity patents, (2012-2019/amount)



In conclusion, we can see that the BRICS countries have saved leading positions on the hydroelectricity market, and are one of the key drivers of growth, especially China. In the next part of the paper, we will conduct a forecast for the next 5 years for each BRICS country of net additions of hydropower capacity using the Least Squares Method.

Prospects for the development of hydropower in the BRICS countries

Considering current market trends and with the help of the Least Squares Method, we will build a forecast for each BRICS country of hydroelectricity capacity net additions in 2022-2025, using previous data from 2001-2021. Below we give an example of such a forecast for China, for other countries only the results will be given (Table 2).

Table 2: Factual and estimated data for building a trend line of hydroelectricity capacity net additions for China (2001-2021/MW)

Year	Y_t	t	t^2	Y_t*t	$Y_t=a+b*t$
2001	3 348	-10	100	-33 480	12 118
2002	3 370	-9	81	-30 330	12 389
2003	8 826	-8	64	-70 608	12 661
2004	10 346	-7	49	-72 422	12 933
2005	12 148	-6	36	-72 888	13 205
2006	12 900	-5	25	-64 500	13 477
2007	17 940	-4	16	-71 760	13 749
2008	24 374	-3	9	-73 122	14 021
2009	23 686	-2	4	-47 373	14 293
2010	19 767	-1	1	-19 767	14 565
2011	16 923	0	0	0	14 837
2012	16 490	1	1	16 490	15 108
2013	30 970	2	4	61 939	15 380
2014	24 420	3	9	73 260	15 652
2015	14 670	4	16	58 680	15 924
2016	12 540	5	25	62 702	16 196
2017	11 704	6	36	70 227	16 468
2018	8 486	7	49	59 405	16 740
2019	5 779	8	64	46 229	17 012

2020	12 120	9	81	109 080	17 284
2021	20 760	10	100	207 600	17 556
Total	**311 568**	**0**	**770**	**209 363**	**-**

Source: compiled by the authors according to the International Renewable Energy Agency (IRENA) https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Country-Rankings

In accordance with the Least Squares Method, we will calculate parameters of a and b from this system of equations:

$$\begin{cases} na + b\sum t = \sum y_t \\ a\sum t + b\sum t^2 = \sum y_t t \end{cases} \quad (1)$$

$$\begin{cases} 21a = 311\,568 \\ 700b = 209\,363 \end{cases} \quad (2)$$

Next, we will express a from the first equation in the system of equations under the second number and then insert the value into the second equation to calculate b. As a result, we receive that a is equal to 14836.6, b is equal to 271.9. By inserting the t values for 2022-2026 (which are equal to 11, 12, 13, 14 and 15, accordingly), we will be able to forecast the net additions of hydropower electricity capacity for 2022-2026 for China. Going through the same steps for Brazil, Russia, India and South Africa, we achieve the results presented in Table 3.

Table 3: Estimated net additions of hydroelectricity capacity for BRICS countries (2022-2026/MW)

Year	t	yt=a+bt (Capacity growth)					Total capacity				
		China	Brazil	Russia	India	SA	China	Brazil	Russia	India	SA
2022	11	17 827	2 716	310	613	176	408 747	112 142	52 811	52 178	3 660
2023	12	18 099	2 754	304	555	188	426 847	114 896	53 116	52 733	3 848
2024	13	18 371	2 792	299	496	199	445 218	117 688	53 414	53 229	4 048
2025	14	18 643	2 829	293	438	211	463 861	120 517	53 707	53 667	4 258
2026	15	18 915	2 867	287	380	222	482 776	123 384	53 994	54 047	4 480

China, Brazil and South Africa, according to our forecasts, will have an upward trend of yearly growth in installed hydroelectricity capacity – capacity will grow by 91 856 MW (482 776 MW total by 2026), 13 958 MW (123 384 MW total by 2026) and 996 MW (4 480 MW total by 2026), accordingly. Russia and India will have a downward trend of yearly growth for this indicator – capacity will grow by 1 493 MW (53 994 MW total by 2026) and 2 482 MW (54 047 MW total by 2026), accordingly. The estimated forecasted values also confirm the ongoing key role of China in hydropower development, though all BRICS countries have a significant role on the market.

Conclusion

The interest for developing renewable energy sources is as relevant as ever. The BRICS countries contribute a large role in this development, as together they hold high positions in renewable electricity generation, consumption and capacity. For most of these countries, hydroelectricity is the main source of renewable energy, and though the share of it has dropped, forecasts conducted by the authors show that it will continue to grow. It is important to note that

policy modernization is a must for achieving the yearly growth rates necessary for reaching net-zero goals.

References

BARYKINA Y.N.; CHERNYKH A.G. AND BAO N. (2022) Energy production as a basis for sustainable development in BRICS countries. *IOP Conf. Ser.: Earth Environ. Sci.* 2022, 990 012016, 6 p.

International Energy Agency – Hydropower Special Market Report – Analysis and forecast to 2030. https://iea.blob.core.windows.net/assets/4d2d4365-08c6-4171-9ea2-8549fabd1c8d/HydropowerSpecialMarketReport_corr.pdf (accessed 24 July 2022).

International Renewable Energy Agency – Energy Profile – Brazil. https://www.irena.org/IRENADocuments/Statistical_Profiles/South%20America/Brazil_South%20America_RE_SP.pdf (accessed 25 July 2022).

International Renewable Energy Agency – Energy Profile – China. https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/China_Asia_RE_SP.pdf (accessed 25 July 2022).

International Renewable Energy Agency – Energy Profile – India. https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/India_Asia_RE_SP.pdf (accessed 25 July 2022).

International Renewable Energy Agency – Energy Profile – Russian Federation. https://www.irena.org/IRENADocuments/Statistical_Profiles/Eurasia/Russian%20Federation_Eurasia_RE_SP.pdf (accessed 25 July 2022).

International Renewable Energy Agency – Energy Profile – South Africa. https://www.irena.org/IRENADocuments/Statistical_Profiles/Africa/South%20Africa_Africa_RE_SP.pdf (accessed 25 July 2022).

PATHAK L. and SHAH K. (2019). Renewable energy resources, policies and gaps in BRICS countries and the global impact. *Frontiers in Energy.* 2019, Vol. 13, p. 506-521.

SAKHAROV A. and ANDRONOVA I. (2021). BRICS' Contribution to the Global Transition to Sustainable Consumption and Production Patters. *International Organisations Research Journal.* 2021, Vol. 16, №1, p. 7-28.

SAVCHINA, O.V.; PAVLINOV, D.A. and SAVCHINA, O.V. (2021) Financial Stability of Electricity Companies in the Context of the Macroeconomic Instability and the COVID-19 Pandemic. *International Journal of Energy Economics and Policy*. 2021, Vol. 11, №5, p. 85-98.

UMMALLA M.; SAMAL A. and GOYARI P. (2019). Nexus among the hydropower consumption, energy growth and CO2 emissions: evidence from BRICS countries. *Environmental Science and Pollution Research.* 2019, Vol. 26, №1.

WANG H.; AMJAD M.A.; ARSHED N.; MOHAMMED A.; ALI S.; HAIDER JAFRI M.A. and KHAN Y.A. (2022). Fossil Energy Demand and Economic Development in BRICS Countries. *Frontiers in Energy Research.* 2022, Vol. 10,

ZENG S.; LIU Y.; LIU C and NAN X. (2017) A review of renewable energy investment in the BRICS countries: History, models, problems and solutions. *Renewable and Sustainable Energy Reviews*. 2017, Vol. 74, p. 860-872. 15 p.