

Green Energy Intensity: Development of Renewable Energy Generation and Consumption in Major Economies

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Abstract

This study attempted to identify common trends for the “green” economic development of the major developed and developing countries as well as exceptions to these trends. It investigated these economies’ renewable energy growths in the last 10 years. Drawing on the traditional concept of “energy intensity,” this study developed the term of “renewable energy intensity” or “green energy intensity” to test the hypothesis that its increase indicates an economy’s advancement in the sustainable economic development. It examined the major economies’ renewable energy intensities both with and without hydropower. The results revealed however that only a few EU countries passed both tests. Based on the major economies’ renewable energy intensities, the study discussed their policy implications for these economies’ green economic transformation.

Keywords: renewable energy, green energy intensity, carbon reduction, energy transition, green transformation, sustainability

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A. Introduction

Many studies argued that the green economic transformation has become necessary; it could not only help reduce the carbon emissions of the economic activities and the related impact on global warming and climate change but also contribute to increasing the technological innovation for energy efficiency and renewable energy generation and consumption, and to sustaining the real economic growth and reduce its ecological impact on the planet (WBCSD 2000, Omer 2008, Chen et al. 2011, Garg et al. 2011, Kaygusuz 2012, Mansoor 2013).

However, the major economies under investigation behaved and performed differently in this transformation, some proactively and the others reactively. Because of their economic powers in the world economy and the crucial role they have played and will continue to play in determining the direction of future globalization and climate change, their behaviors and performances have substantial economic and climate political impacts on the world economy.

In other words, the major economies' moves will set the course for the further development of the globalization and climate and determine if the global economy and climate will evolve in a sustainable way or in an unsustainable way with irreversible consequences. At the same time, their green moves will impact their individual competitiveness in the future green economic transformation and determine if and how competitively they will perform in this green transformation.

This study attempted to explore this issue. It reviewed and analyzed the statistical data of major economies' renewable energy growth in the last ten years to see how these economies have transformed in terms of changes in their renewable energy generations and consumptions.

The rest of the paper is structured as follows: Section B discusses the findings of the increasing renewable energy generations and consumptions in these economies. It first examines the major economies' total installed cumulative wind power and solar power capacities and total renewable energy consumptions with or without hydropower in the period from 1997 to 2011. Then it compares the major economies' total renewables consumptions per capita and their renewable energy intensities with or without hydropower in this period. The concluding Section C discusses the policy implications of these findings.

B. Green Energy Intensity

Existing research showed that the increased input of traditional carbon-based energy decreased an economy's technical efficiency and the increased consumption of renewable energy improved technical efficiency. Chien and Hu (2007) compared non-OECD economies and OECD economies in terms of renewable energy's contribution to their technical efficiency and economic performance in the period of 2001-2002. They found that OECD economies had higher technical efficiency and a higher share of geothermal, solar, tide, and wind fuels in renewable energy and non-OECD economies had a higher share of renewable energy in their total energy supply than OECD economies.

Since their study covered an early and relative short period, it is interesting to examine if the general trends they identified were also valid for a longer and more recent period. This section will present the results of the examination of the renewable energy generation and consumption in major economies as part of their effort to decarbonize their economies and the impact of this development on the green transformation.

1. Wind Power

First, the investigation looked at the cumulative wind power installations in China, the United States, Germany, Spain, India, and the rest of the world in the period from 1997 to 2011. The data revealed that with its cumulative installed wind power capacities growing by 20.8 percent a year, Germany was an early leader in wind power installation from 1997 to 2008.

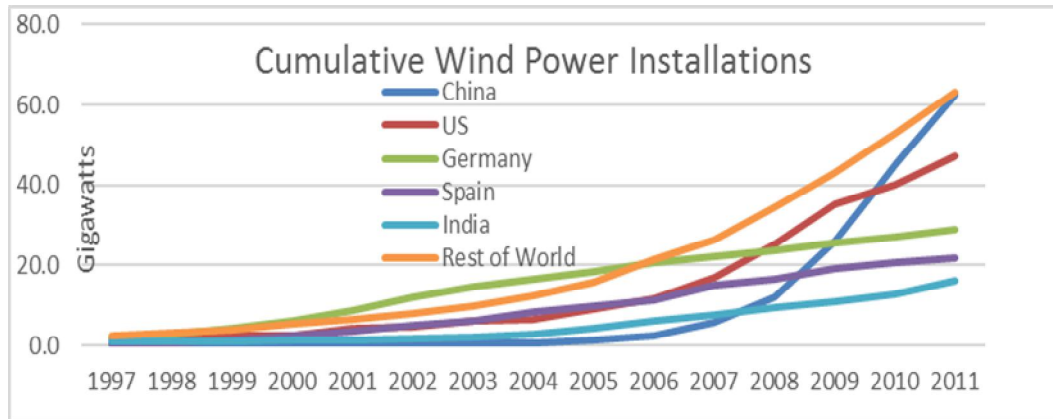


Fig.1 Cumulative Wind Power Installations of Selected Economies (1997-2011),
Sources: BP 2012

However, this top wind power generator position was then taken over first by the United States during the financial crisis in 2008 with the help of government financial support provided by the American Recovery and Reinvestment Act (ARRA 2009), and then by China in 2009 with the help of legislation and also massive government financial support (Facts and Details). As a result, China took over the United States as the leader in wind power installation in 2010.

At the same time, it should be noted that the rest of the world, i.e. other countries beside the major economies examined also experienced a significant and constant growth of wind power installed capacities. These countries collectively “overtook” Germany as the world’s top wind power installer already in 2006, whose top position in cumulative wind power installations was unchallenged until China overtook it in 2011.

2. Solar Power

Next, this study moved on to examine the cumulative installed solar PV capacities of the major economies. The examination used the data of the world’s top solar power installers—Germany, Italy, Japan, the United States, Spain, and China—in the period from 1997 to 2011.

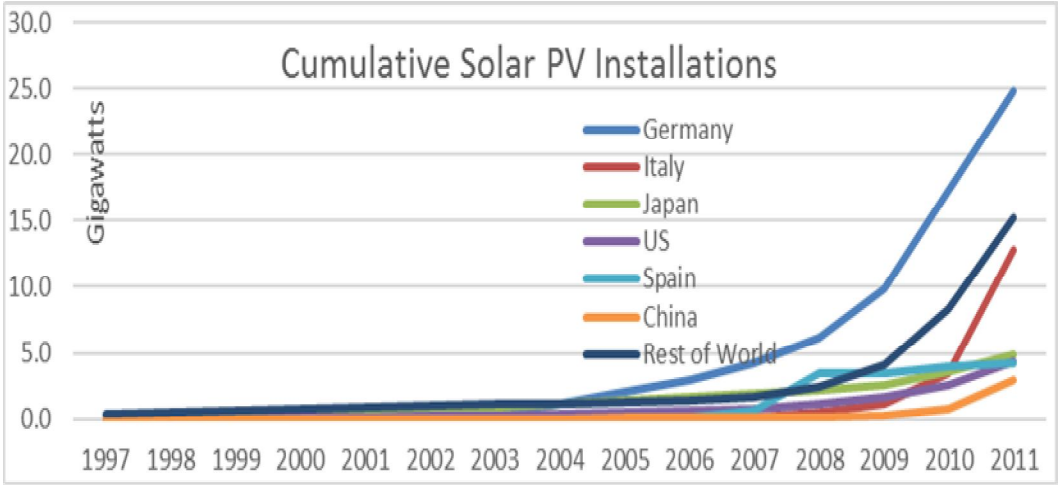


Fig.2 Cumulative Solar PV Installations of Selected Economies (1997-2011), Sources: BP 2012

The results revealed that unlike in the wind power industry where the United States and China played the most decisive role in the recent years, Germany and other EU countries were major players in solar power industry, dwarfing the two world's biggest economies.

To be more exact, Germany, a geographically relatively small and not particularly favorably located country, continuously led the rest of the world in the world solar power installation and generation since 2004. This unchallenged position was followed by Italy, another EU, geographically even smaller, country, in 2010 and 2011.

The results could surprise those who trusted nothing else than market forces and believed that government had no role to play in the sustainable development. The contrast of the EU countries' solar power success and the world's largest economies' lagged solar power performances would appear to be an even bigger paradox if one compared the much larger geographic sizes and the sun-shine locations of the United States and China with those of the individual EU countries examined in terms of their solar power generation potentials.

Germany and other EU countries' achievements in solar power generation exemplified the indisputable market-influencing effectiveness of these countries' renewable energy promotion policies such as Germany's "Grid Feed-In Law for RES" in 1991 and its updated version "Renewable Energy Act" in 2000 to promote renewable energy installation and generation (Burgermeister 2009, Weigt 2009, Gipe 2011).

The achievements of the German solar power development over the last fourteen years had not only an excellent textbook value for understanding the importance of enacting and carrying out green economic policy for the sustainable development of the respective countries, but also provided to any government striving for sustainable development a practical, proven policy innovation model for what constituted well-designed, proactive, progressive, and efficient renewable energy policies and how these policies could effectively and efficiently influence a country's sustainable economy.

3. Top Solar Power Installers

Next, this study took a closer look at the major economies' shares in solar power installations.

This investigation used the data of the cumulative installed solar photovoltaic power capacities of the top solar power installers, Germany, Italy, Japan, the United States, Spain, China, and Czech Republic, in 2011.

The results indicated that Germany and other EU countries took the lion's share in the pie of installed solar power capacities. While the cumulative solar PV power capacities in Germany alone made up 36 percent of the world's total, the EU countries examined collectively took 68 percent.

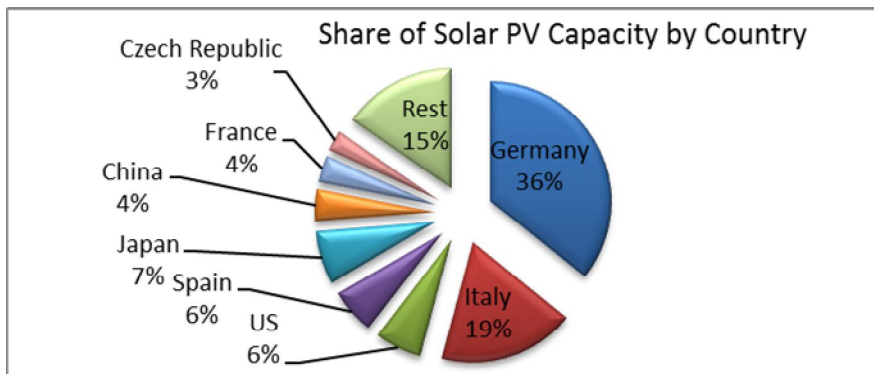


Fig.3 Cumulative Solar PV Installations in Major Economies in 2011, Sources: BP 2012

The policy innovations that led to the European achievements in solar power generation could be best showcased by EU eco taxes on the fossil fuels and the market incentives for renewable energy sources in the German Feed-in Renewable Energy Policy. While the eco taxes caused markets to reduce the extraction and consumption of fossil fuels (“bads”), the feed-in policies, which guaranteed the long-term, degressive, technologically differential above-market feed-in prices, provided market incentives for electricity generated from renewable energy sources (“goods”) (Mendonça 2007, Rickerson and Grace 2007, de Jager and Rathmann 2008, Klein, *et al.* 2008).

The results also indicated that with its small share of 6 percent of the world's cumulative solar power installations, the United States—the world's top economy—lagged behind several smaller economies in solar power generation. Germany and other EU countries set an excellent example for the United States in how to deliver more effective renewable energy promotion policies to more effectively promote solar power installations and generation.

Considering its world number one economic power and its much larger geographic size than those individual EU countries, the United States has a great potential to make a giant stride in catching up and making a much greater contribution to the world green energy transformation and sustainable economic development.

4. Total Renewable Energy Consumption

Next, this study examined the total consumption of renewable energy of selected economies. This investigation included the data of both hydropower consumption and all other renewable energy sources, such as wind, geothermal, solar, biomass and waste, and not accounting for cross border electricity supply. Countries included in this investigation were China, the United States, Brazil, India, Russia, Germany, Japan, Spain, Sweden, Italy, Austria, Australia, Denmark, and South Korea. The data considered covered the period from 1990 to 2011.

The results disclosed several interesting trends. First, although both top economies—the United States and China—were logically top renewables consumers in recent years, their rankings in total renewable energy consumption did not follow their economic sizes or GDP rankings, but were rather reversed.

Second, China's performance in growing renewables capacities stood out by advancing from the third place behind the United States and Brazil in 1990 to the first place and leading by a big margin of 47 percent ahead of the second top installer of renewable capacities—the United States.

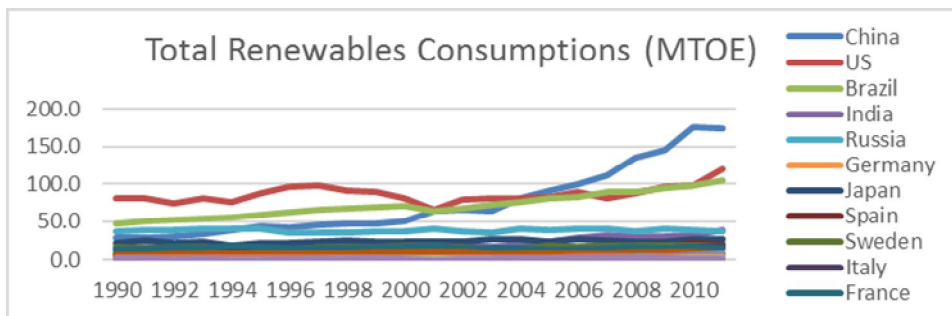


Fig.4 Total Renewable Energy Consumptions of Major Economies (1990-2011),
Sources: BP 2012

Third, China's rather unique take-off took place at the turn of the millennium. This upward trend continued after a two-year consolidation in 2003 until 2011 when China's renewables consumption experienced a slight drop.

Fig.5 Renewable Energy Consumption Excluding Hydra Electricity in Major Economies (1990-2011), Sources: BP 2012

These observations showed that China's renewable energy production and consumption depended mainly on hydropower, and its renewables consumption significantly lagged behind its installations of renewable energy capacities. This indicated that China needs to develop more effective policies that aim at accelerating the generation and consumption of renewables other than hydropower and promoting renewables consumption to reduce the gap between the renewable energy production and the renewable energy consumption.

6. Total Renewables Consumption Per Capita

Next, this study reviewed how major developed and developing economies were doing in their total renewables consumption on a per capita basis. The results ranked the three smaller EU countries Sweden, Austria, and Denmark as the top renewable energy consumers per capita. Sweden led with 2.03 tons of oil equivalent far ahead of all other economies, Austria achieved a level half Sweden's, and Denmark a level half Austria's.

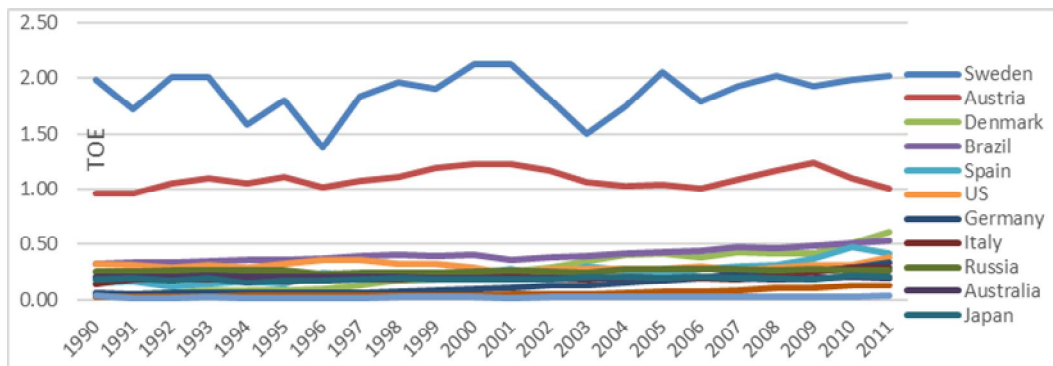


Fig.6 Total Renewable Energy Consumptions Per Capita of Major Economies (1990-2011), Sources: BP 2012, UNDESA 2012

On the per capita basis, Brazil presented the best performance in renewable energy consumption per capita among the developing economies, holding a level half Austria's, but even ahead of other major developed and developing economies, including Spain, the United States, and Germany.

China and India, the two major developing economies with top populations, ranked the bottom three, along with South Korea, a developed economy.

7. Share of Renewable Energy in the Total Energy Mix

Next, this study compared the shares of the renewable energy consumptions in the total primary energy consumptions. For this examination, two separate tests were run, one including hydropower in the renewable energy consumption, and the other excluding it. Two sets of data of the selected countries—renewable energy consumption and total primary energy consumption—in 11-year period from 1990 to 2011 were used. The results revealed several interesting observations.

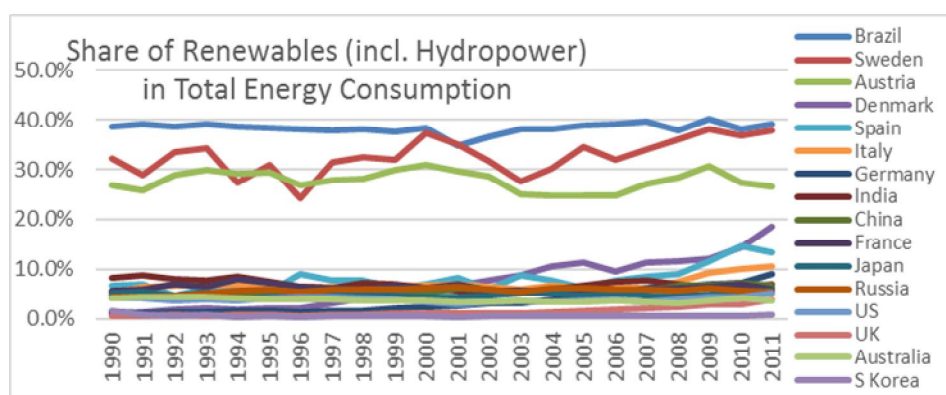


Fig.7 Shares of Hydropower-Inclusive Renewable Energy in Total Primary Energy Mixes of Major Economies (1990-2011), Sources: BP 2012

First, as **Fig.7** indicated, the performance of the three top runners in high renewable energy deployment—Brazil, Sweden, and Austria—stood out in the period under investigation. With their renewables shares of 39.2 percent, 37.9 percent, and 26.6 percent respectively in 2011, these countries led the green energy revolution in this period, significantly ahead of all other major—developed or developing—economies studied.

Second, the next four countries with high renewable energy shares from 18.4 percent to 9 percent were all developed EU economies—Denmark, Spain, Italy, and Germany.

Third, the results also showed that with a renewables' share of 7 percent, India won a higher renewable energy share than China in 2011 because China's renewables consumption slowed down from 7.3 percent in 2010 to 6.7 percent in 2011.

Fourth, the data indicated that with its renewable energy share of 4.3 percent in 2010 and 5.3 percent in 2011, the world's largest economy—the United States—lagged far behind other developed countries in renewable energy deployment and kept its position unchanged as one the three countries under investigation with lowest renewable energy shares.

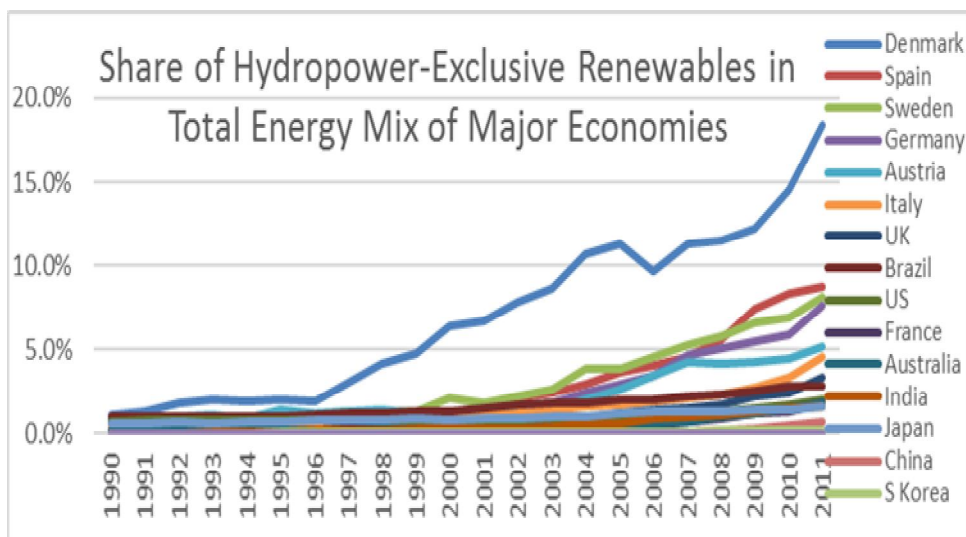


Fig.8 Shares of Hydropower-Exclusive Renewable Energy in Total Primary Energy Mixes of Major Economies (1990-2011), Sources: BP 2012

In comparison with the major economies' shares of hydropower inclusive renewable energy consumptions in their total energy mixes, these economies' shares of hydropower exclusive renewable energy consumptions in their total energy mixes presented a distinctively different picture. Here, the small developed economy Denmark led indisputably far ahead of all other economies and almost 10% ahead of the second top runner, Spain.

Second, the investigation also revealed that all six top runners were developed EU countries, which indicated that Chien's and Hu's observation that non-OECD economies had a higher share of renewable energy in their total energy supply than OECD economies in 2001-2002 (Chien and Hu 2007) was no longer valid for the most recent development of renewable energy consumptions.

The developed countries' energy mixes had instead much higher shares of renewable energy components than the developing countries'. This was especially true if only the technologically novel renewables were included and the technologically mature hydropower was excluded from the calculation model.

8. Renewable Energy Intensity

Last but not least, this study examined the "renewable energy intensity" of the selected countries. Renewable energy intensity, considered an indicator of renewable energy's contribution to a country's economic performance, was measured in this study by dividing the total annual renewable energy consumption by the annual GDP of these countries. This measure was adapted from that to calculate the energy intensity.

The assumption or hypothesis of this study was that while economic growth and technological advancement would reduce a country's energy consumption and thus its energy intensity, the economic growth and technological advancement would also reduce the costs of renewable energy generation and thus increase the deployment of the renewable energy technologies and thus the renewable energy's share in the total energy mix and the economy's renewable energy intensity.

To help better understand the renewable energy intensity, this study compared both the renewable energy intensities of selected economies with hydropower and their renewable energy intensities without hydropower. The two comparisons presented very different pictures. The results of the investigated economies' renewable energy intensities with hydropower revealed several interesting findings.

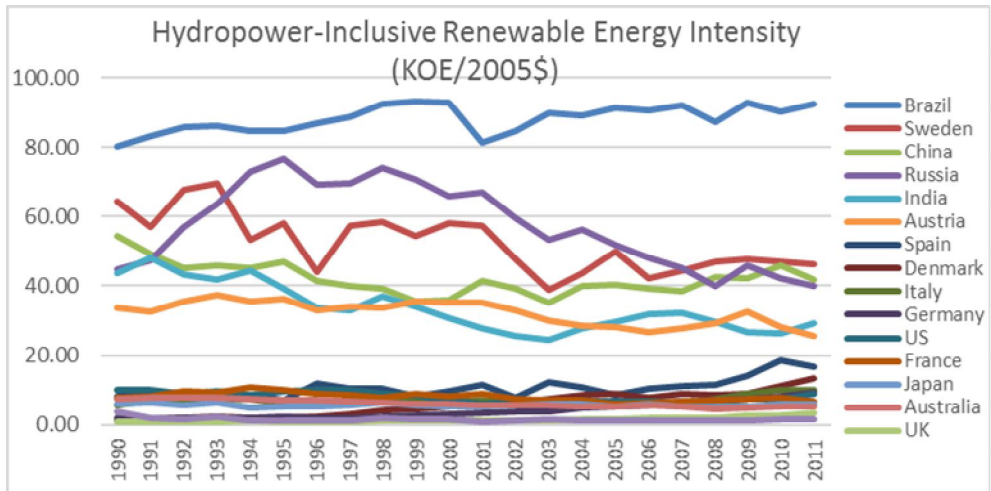


Fig.9 Hydropower-inclusive Renewable Energy Intensities of Major Economies (1990-2011), Sources: BP 2012, IMF 2012, USDA 2012, World Bank 2012

First, four out of the five top runners with highest hydropower inclusive renewable energy intensities—Brazil, China, Russia, and India—were either developing or transitional countries with high energy intensities. Second, Brazil had the highest renewable energy intensity of 92.33 kg oil equivalent (KOE) in 2011, which was twice as much as Denmark’s renewable energy intensity of 46.22 KOE that year.

Third, the general trend was decreasing hydropower inclusive total renewable energy intensities, which was true not only for developed countries, but also for developing countries.

However, Denmark, Germany, Spain, Italy and Brazil were the exceptions to this general decreasing trend, and their total renewable energy intensities increased by almost 12 times, 3.73 times, 104 percent, 86 percent, and 15 percent respectively from 1990 to 2011.

The exploration in hydropower-exclusive renewable energy intensities of major economies generated several observations that diverged from those of the hydropower-inclusive renewable energy intensities. First, the four top runners—Denmark, Spain, Sweden, and Germany—of the hydropower-exclusive renewable energy intensity in 2011 were all developed EU countries instead of developing countries.

Second, the general trend was that hydropower-exclusive renewable energy intensities were increasing instead of decreasing, which was the opposite to the trend of hydropower-inclusive renewable energy intensities. In addition, there was no exception to this trend and the difference existed only in the degree of increase of the intensity, ranging from 2344 times for China to only 90 percent for the United States in the period under investigation.

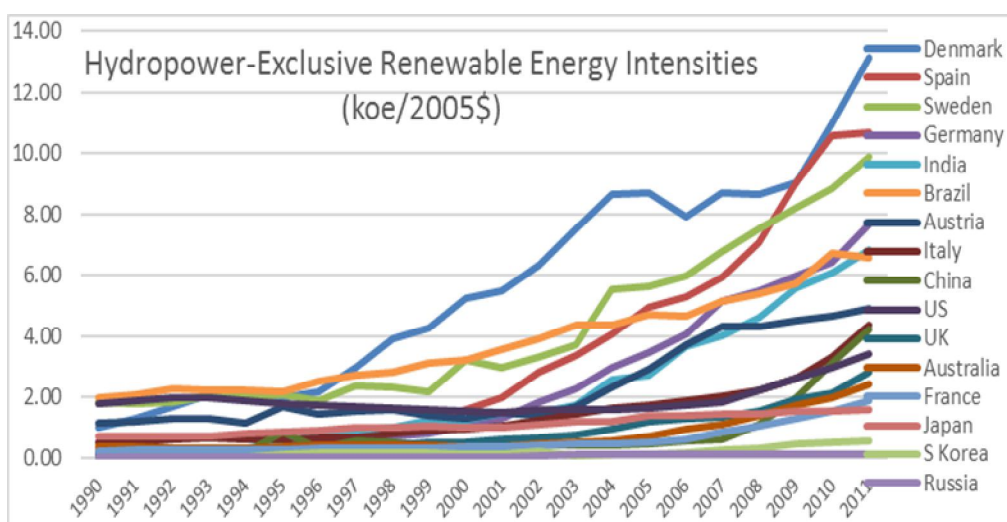


Fig.10 Renewable Energy (excl. Hydropower) Intensities of Major Economies (1990-2011), Sources: BP 2012, IMF 2012, USDA 2012, World Bank 2012

These observations indicated that the hypothesis of this study was tested completely true for hydropower exclusive renewable energy intensity, but in the case of the hydropower inclusive renewable energy intensity only exceptionally true for Denmark, Germany, Spain, Italy and Brazil. What was common in both analyses was that the renewable energy intensities of Denmark, Germany, Spain, Italy and Brazil were increasing both including and excluding hydropower in the period between 1990 and 2011.

C. Conclusions

This study examined major economies' efforts to reduce carbon dependences and carbon emissions by reviewing the data of their fossil fuel consumptions and development of renewable and alternative energy in the past.

The inquiries of their development of renewable and alternative energy revealed the potential keys to a successful green economic transformation.

This paper explored the 14 major economies' performances in growing renewable energy installation and consumption over the last ten years. When analyzing the data of these economies' renewable energy installations and consumptions, the study examined the relationships of their renewable energy installations and consumptions with their individual populations, existing energy mixes, and economic performances as displayed in GDPs.

While the various examinations displayed various economies' attitudes, performances, and achievements in the green economic transformation, the GDP based renewable energy analysis resulted in so-called "renewable energy intensities" of these economies.

The renewable energy intensity examinations tested the hypothesis that a country's economic growth and technological advancement would reduce its energy consumption and thus its energy intensity, but might also reduce the costs of renewable energy generation, increase the deployment of renewable energy technologies, and thus the consumption of renewable energy (with and without hydropower) in the total energy mix, the economy's renewable energy intensity (with and without hydropower) would be increased.

To prove this hypothesis, the renewable energy intensity study was conducted twice; in the first analysis, hydropower was included in the total renewable energy consumption, and in the second analysis, hydropower was excluded in the total renewable energy consumption. The two analyses yielded following different results.

- a) While all major economies' hydropower-exclusive renewable energy intensities were increased as shown in (see **Fig.8**), most major economies' hydropower-inclusive renewable energy intensities were reduced (see **Fig.7**).
- b) The only major economies whose renewable energy intensities were increased in both the analysis of hydropower-inclusive renewable energy and the analysis of hydropower-exclusive renewable energy were economies with exemplary achievements in hydropower-exclusive renewables—Denmark (by almost 12 times), Germany (by more than 3.7 times), Spain, Italy, and Brazil (see **Fig.9**).

To understand why the hydropower-inclusive renewable energy intensity was declining and the hydropower-exclusive renewable energy intensity was rising, this study took a closer look at the growth rates of hydropower consumptions and the growth rates of the hydropower-exclusive renewable energy consumptions, and compared them with the GDP growth rates of these economies. It turned out that hydropower as a relatively mature and inexpensive technology and a major component of the current renewable energy mix for many major economies already reached their peaks and did therefore not keep pace with these countries' economic growths.

In contrast, the reason for hydropower-exclusive renewable energy intensity being rising was that the growth rates of hydropower-exclusive renewables—a novel and thus more expensive technology and a minor component of the current renewable energy mix for most major economies—were faster than these countries' GDP growth rates.

As a result, it can be concluded that that the economies that presented increasing renewable energy intensities in both the hydropower-inclusive and -exclusive tests were the true renewable energy leaders and their renewable energy policies should be exemplary for other major economies.

Last but not least, this paper demonstrated statistically that hydropower-exclusive renewable energy intensity should be used to measure an economy's relative green performance in the green economic transformation.

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