UNIVERSITI PUTRA MALAYSIA

# *EFFICIENCY, SOCIO-ECONOMIC FACTORS AND MARKET ANALYSES OF HYDROPOWER INDUSTRY IN THE EU REGION*

ZUBAIR AZEEM OLUWASEYI

SPE 2021 19

**EFFICIENCY, SOCIO-ECONOMIC FACTORS AND MARKET ANALYSES OF HYDROPOWER INDUSTRY IN THE EU REGION**

By

**ZUBAIR AZEEM OLUWASEYI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**December 2020**

# DEDICATION

To God
And
My Parent

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**December 2020**

**Chairman : Associate Professor Abdul Rahim Abdul Samad, PhD**
**School : Business and Economics**

The hydropower industry is a crucial catalyst for improving the European Union's National Renewable Energy Action Plan (NREAP), energy efficiency, and mitigation of greenhouse gas (GHG) emissions. Meanwhile, the hydropower industry's deteriorating status, from conventional to marginal renewable technology, is currently struggling head-on with other sustainable energy sources. Several factors are causing the struggle; the installed capacity cost of the EU hydropower industry is high compared with other key countries or regions, lack of additional installed capacity in many EU countries, policy and public support, among others.

The thesis, therefore, builds on secondary data from 26 European Union (EU) member countries from the World Development Indicators (WDI), Food and Agriculture Organization of the United Nations statistics (FAOSTAT), European Union statistics (Eurostat), Organization for Economic Co-operation and Development (OECD), Economic Policy Uncertainty (EPU), and AQUASTAT. The dataset for this research covers the period from 1990-2018. Throughout the empirical sections, we divided the EU26 member countries into EU15 (developed) & EU11 (developing) countries.

The first objective investigates the hydropower industry's cost efficiency and the role of socio-economic factors on cost efficiency in the EU region. This is a two-stage analysis where the first stage calculates the cost efficiency (CE) and its decomposition, i.e., technical efficiency (TE) and allocative efficiency (AE), using a multi-stage approach of data envelopment analysis (DEA). The second stage investigates socio-economic factors on cost efficiency, using the Fixed Effect (FE) model. The first stage result indicates a cost inefficiency level in the EU hydropower industry due to technical inefficiency. The fixed effects results reveal that capital,

research & development (R&D), and total renewable electricity output played a positive and significant role in improving cost-efficiency. Moreover, regulatory uncertainty plays a deleterious impact on the hydropower industry's cost efficiency in the EU region over the study period.

The second objective investigates the hydropower industry's technical efficiency and the role of socio-economic factors on technical efficiency in the EU region. This is a two-stage analysis where the first stage calculates the technical efficiency (TE) and its decomposition, i.e., pure-technical efficiency (PTE) and scale efficiency (SE), using a multi-stage data envelopment analysis (DEA) techniques. On the other hand, the second stage investigates socio-economic factors on technical efficiency, using the panel data approach of the Random Effects (FE) model. Results showed that the technical efficiency level is weak due to weak pure-technical efficiency. The panel model outcomes unravel that economic growth, capital and research & development played a positive and significant role in the hydropower industry's technical efficiency. However, regulatory uncertainty and temperature change significantly reduced the hydropower industry's technical efficiency in the EU region.

The third objective analysed the drivers and forecasted the hydropower industry market in the EU region, using the two-stage least square (2SLS) and autoregressive integrated moving average (ARIMA) models. The supply side's analytical results, input resource, and price are positive hydropower drivers, while high input cost significantly reduced them. As for the demand side, findings show that hydropower's price is negative and significantly reduced demand. Substitute price and income are positive drivers of hydropower demand in the EU region. The forecasted market results demonstrate that supply would variably be enough to cater to hydropower demand in the European Union region until 2030.

There is indisputable evidence of slow technological progress for the hydropower industry in the EU region; thus, innovative initiatives focused on hydropower generating technology are needed. Regulators should make clear and be consistent with the requirements for investing in hydropower. The EU hydropower regulators should encourage the inefficient hydropower industry to use efficient ones to benchmark cost efficiency improvement. Besides, the industry is also faceted with a managerial challenge, pointing to more technical knowledge is needed. Therefore, an organisational strategy (PTE) that emphasises improvements in hydropower's installed capacity should be encouraged. It is also essential to define and prioritise extended-term investment plans for flexible hydropower facilities, especially in EU countries, where the technical feasibility of hydro is abundant. The climate change adaptation framework of COP21 should be preserved, so the negative impact of temperature change on hydropower's technical efficiency could be minimized. It would be beneficial if the EU could make the transmission grid of hydropower a national project, so hydropower can easily accessible for consumption, thus avoiding waste in electricity generations.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**KECEKAPAN, FAKTOR SOSIO-EKONOMI DAN ANALISIS PASARAN INDUSTRI HIDROKUASA DI RANTAU EU**

Oleh

**ZUBAIR AZEEM OLUWASEYI**

**Disember 2020**

**Pengerusi : Profesor Madya Abdul Rahim Abdul Samad, PhD**
**Sekolah : Perniagaan dan Ekonomi**

Industri hidrokuasa adalah pemangkin penting untuk memperbaiki Pelan Tindakan Tenaga Boleh Diperbaharui Nasional Kesatuan Eropah (NREAP), kecekapan tenaga, dan pengurangan pelepasan gas rumah hijau (GRK). Sementara itu, dengan kemerosotan status industri hidrokuasa, daripada konvensional kepada teknologi marjinal yang boleh diperbaharui,industri ini sedang bersaing dengan sumber tenaga lestari yang lain. Terdapat beberapa faktor yang menyebabkan Persaingan tersebut, antaranya ialah Kapasiti kos pemaasangan bagi industry hidrokuasa di negara EU adalah lebih tinggi berbanding negara atau wilayah yang lain, Kekurangan kapasiti pemasangan tambahan di kebanyakan negara EU, dasar serta sokongan dari masyarakat.

Objektif umum kajian ini adalah untuk menganalisis kecekapan, faktor sosio-ekonomi dan pasaran industri hidrokuasa di rantau EU. Walau bagaimanapun, objektif khusus penyelidikan ini adalah untuk mengkaji kecekapan kos industri hidrokuasa dan peranan faktor sosio-ekonomi terhadap kecekapan kos, mengkaji kecekapan teknikal industri hidrokuasa dan pemacu sosio-ekonomi, dan menganalisis pasaran domestik industri hidrokuasa.

Oleh itu, tesis ini menggunakan data sekunder bagi 26 negara anggota Kesatuan Eropah (EU) dari Indikator Pembangunan Dunia (WDI), statistik dariPertubuhan Makanan dan Pertanian Pertubuhan Bangsa-Bangsa Bersatu (FAOSTAT), statistik dari Kesatuan Eropah (Eurostat), Organisasi Kerjasama dan Pembangunan Ekonomi (OECD), dan AQUASTAT. Set data penyelidikan ini meliputi tempoh dari 1990-2018. Bagi bahagian empirikal, ahli kesatuan negara EU26 dibahagikan kepada negara EU15 (maju) & negara EU11 (membangun).

Objektif pertama bagi kajian ini adalah untuk menyiasat kecekapan kos bagi industri hidrokuasa dan peranan factor sosio-ekonomi terhadap kecekapan kos di rantau EU. Kajian ini menggunakan pendekatan analisis pengumpulan data (DEA) tahap-berganda, dimana pada peringkat pertama, kecekapan kos (CE) dan penguaraiannya seperti kecekapan teknikal (TE) dan kecekapan peruntukan (AE) dikira menggunakan kaedah pelbagai peringkat. Manakala pada peringkat kedua, kajian ini menyiasat factor sosio-ekonomi pada kecekapan kos, dengan menggunakan model Kesan Tetap (FE). Hasil yang diperolehi pada peringkat pertama kajian ini mendapati bahawa tahap ketidakcekapan kos pada industry hidrokuasa di EU adalah disebabkan oleh ketidakcekapan teknikal. Hasil dari model Kesan Tetap menunjukkan bahawa modal, kajian dan pembangunan (R&D), serta jumlah output elektrik yang boleh diperbaharui memainkan peranan positif dan signifikan bagi memajukan kecekapan kos. Tambahan pula, ketidakpastian peraturan memainkan kesan buruk terhadap kecekapan kos bagi industri ini di rantau EU sepanjang tempoh kajian.

Objektif kedua bagi kajian ini adalah untuk mengukur tahap kecekapan teknikal dan peranan factor sosio-ekonomi terhadap kecekapan teknikal di rantau EU. Denagn menggunakan analisis dua peringkat, dimana pada peringkat pertama, kecekapan teknikal (TE) dan penguraiannya iaitu kecekapan teknikal tulin (PTE) dan kecekapan skala (SE) dikira menggunakan teknik analisis pengumpulan data (DEA). Bagi peringkat kedua pula, kajian ini menyiasat factor sosio-ekonomi terhadap kecekapan teknikal, dengan menggunakan pendekatan data panel iaitu, model kesan rawak (RE). Hasil kajian menunjukkan bahawa kecekapan teknikal bagi industry ini adalah lemah dan sumber kelemahannya adalah disebabkan oleh kecekapan teknikal tulin. Hasil kajian panel menunjukkan bahawa pertumbuhan ekonomi, modal dan penyelidikan dan pembangunan memainkan peranan positif serta signifikan dalam kecekapan teknikal industri kuasa hidro. Walau bagaimanapun, ketidakpastian dalam pengawalseliaan dan perubahan suhu mengurangkan kecekapan teknikal industri kuasa hidro di rantau EU.

Objektif ketiga tertumpu kepada Analisis pemacu dan meramalkan pasaran industri hidrokuasa EU dengan menggunakan model kuadrat terkecil dua peringkat (2SLS) dan model *purata bergerak* autoregresi *bersepadu* (ARIMA). Dari sisi penawaran, dapatan analisis menunjukkan bahawa sumber input dan harga merupakan pemacu yang positif bagi industri hidrokuasa di zon Kesatuan Eropah. bagi sisi permintaan pasaran pula, dapatan statistik menunjukkan bahawa bagi sisi permintaan pasaran pula, hasil kajian mendapati bahawa harga bagi kuasa hidro adalah negative dan signifikan untuk mengurangkan permintaan. Manakala harga pengganti dan pendapatan merupakan pemacu yang positif bagi permintaan kuasa hidro di rantau EU. Hasil dari ramalan pasaran menunjukkan bahawa bekalan akan berubah dan mencukupi untuk memenuhi permintaan di Kawasan EU sehingga tahun 2. Siri sejarah dari segi permintaan pasaran hidrokuasa menunjukkan bahawa tidak akan berlaku kekurangan dari 2019-2030. Ini menunjukkan bahawa bekalan adalah cukup untuk memenuhi permintaan hidrokuasa di wilayah Kesatuan Eropah sehingga 2030.

Terdapat bukti yang tidak dapat dipertikaikan mengenai kemajuan teknologi yang perlahan bagi industri hidro kuasa di rantau EU. Oleh itu, inisiatif inovatif yang tertumpu kepada teknologi penjanaan kuasa hidro amat diperlukan. Pengawal selia haruslah jelas dan konsisten mengenai syarat untuk melabur dalam industry kuasa hidro. Mereka harus mendorong industri kuasa hidro yang tidak efisyen untuk menjadikan industry yang efisyen sebagai penanda aras bagi kemajuan dalam kecekapan kos. Selain itu, industry ini juga berdepan dengan cabaran pengurusan, menunjukkan bahawa lebih banyak pengetahun teknikal diperlukan. Oleh itu, strategi pengurusan (PTE) yang menekankan tentang peningkatan pemasangan kapasiti kuasa hidro harus digalakkan. Perkara ini amat penting bagi menentukan, serta memberi keutamaan kepada rancangan pelaburan jangka panjang untuk kemudahan kuasa hidro yang fleksibel, terutamanya pada negara-negara EU, dimana kebanyakan kemudahan teknikal hidro di sana terabai. Kerangka adaptasi perubahan iklim COP21 harus dipelihara, sehingga dampak negatif perubahan suhu terhadap kecekapan teknikal tenaga hidro dapat diminimumkan. Ianya akan lebih bermanfaat sekiranya EU dapat menjadikan grid transmisi kuasa hidro sebagai projek nasional, justeru kuasa hidro boleh di akses dengan mudah untuk digunakan sekali gus mampu mengelakkan pembaziran dalam penjanaan elektrik.

## ACKNOWLEDGEMENTS

Alhamdulillahi Rabbil A'alameen.

First and foremost, I thank Allah immensely, who in His infinite Love and Mercy has given me the strength to reach the end of this beautiful journey. Secondly, I would like to thank my supervisor, Associate Professor Dr. Abdul Rahim Abdul Samad, a phenomenal individual who always allowed me to be the independent researcher that I could be. The immense amount of knowledge that I have gained from our interactions will benefit me greatly in my life and professional career—many thanks.

Thank you so much for being a part of my Committee to Associate Professor Dr. Lee Chin and Dr. Nor Yasmin binti Mhd Bani. I am fortunate to tap from your immense knowledge and passion for quality research. You were both an invaluable resource to my research—many thanks.

To three incredible individuals; Dr. Mohd Alsaleh, Dr. Mohammed Ashraful Mobin and Dr. Sulaiman Chindo. Each of you is talented and provides enrichment to my research; many thanks for your supports and encouragement. I would like to sincerely thank the School of Business and Economics staff for their assistance and support.

I want to thank all of my colleagues in UPM, especially my cohort, Ali Madina Dankumo. We struggled and prevailed together—best wishes for your future endeavours. I would also like to thank Dr. Shehu Ibrahim Akinfalabi for being such a great friend and supporter. You genuinely exemplify statesmanship principles and good morals, best wishes on the rest of your journey in life. I sincerely appreciate Mr Hammed Alomasojo for his support and encouragement.

To my wife, Ayisat Annabel Zubair (nee rare), you are my heart. You supported me throughout my career. Thank you for every word of encouragement, for every thumb wrestling battle, for everything. To my children, Al-Amin and Binta, your unending questions and curiosity about my Doctoral research program have genuinely encouraged me to always push hard for success during this journey. I am blessed to have you all in my life. To my brother, Muritala Olaniyi Zubair, you always inspire me. Your kind heart and selflessness are admirable. Continue to challenge yourself and grow.

I would like to sincerely thank my incredible parent, Mutiat Zubair and Dauda Zubair (late). Thank you for your prayers and support. Both of you are the first that comes to mind when I think of a leader. The various lessons that you instilled in me are priceless.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Abdul Rahim Abdul Samad @ Iammi, PhD**
Associate Professor
School of Business and Economics
Universiti Putra Malaysia
(Chairman)

**Lee Chin, PhD**
Associate Professor
School of Business and Economics
University Putra Malaysia
(Member)

**Nor Yasmin binti Mhd Bani, PhD**
Senior Lecturer
School of Business and Economics
Universiti Putra Malaysia
(Member)

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**ZALILAH MOHD SHARIFF, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 06 May 2021

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| Abbreviations | Description |
|---|---|
| AE | Allocative Efficiency |
| ARIMA | Autoregressive integration moving average |
| BNEF | Bloomberg new energy finance |
| BPLM | Breusch-Pagan Lagrangian Multiplier |
| CE | Cost Efficiency |
| DEA | Data envelopment analysis |
| DEAP | Data Envelopment Analysis Program |
| DMU | Decision making unit |
| DSM | Demand Side Management |
| EC | European Commission |
| EEC | European Economic Community |
| EERE | Energy efficiency and renewable energy |
| EPU | Economic policy uncertainty |
| EU | European Union |
| FE | Fixed Effect |
| FAO | Food and Agriculture Organization |
| GDP | Gross domestic product |
| Gwh | Gigawatts per hour |
| GHG | Greenhouse Gasses |
| IEA | International energy agency |
| IHA | International hydropower agency |
| IRENA | International Renewable Energy Agency |
| KTOE | Kilotons of oil equivalent |
| MPB | Marginal Private Benefits |

| | |
|---|---|
| MSB | Marginal Social Benefits |
| MW | Megawatts |
| MTOE | Metric Tons Oil Equivalent |
| NREAP | National renewable energy action plan |
| OECD | Organisation for Economic Co-operation and Development |
| POLS | Pooled ordinary least square |
| PTE | Pure-technical efficiency |
| RE | Random Effects |
| RES-E | Renewable Energy Technologies for Electricity |
| R&D | Research and development |
| RES | Renewable energy sources |
| SE | Scale efficiency |
| SHP | Small hydropower plants |
| TWh | Terawatts per hour |
| UNEP | United Nations environment programme |
| UNFCCC | United Nations Convention for Climate Change |
| USD | United States Dollar |
| WDI | World development indicators |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the study

Hydropower is a renewable energy source derived from moving water at force through dams and reservoirs to generate large amounts of electricity (Gaudard and Romerio, 2014). The hydropower industry plays a crucial role in applying the Renewable Energy Directive (RED), contributing to the EU 2020-2030 objective for the National Renewable Energy Action Plans (NREAPs). In 2011, the EU registered around 23,000 hydropower projects, with 91% being small hydropower (<10 megawatts) and just 9% large hydropower (European Commission, 2018). However, the small hydropower plants produced 13% of the total hydropower outputs, while the large hydropower plant generated about 87%.

The use of renewable fuels in extensive, centralised electricity generation facilities has been regarded as clean and sustainable (see Rowlands, 2005). Several factors have driven these interests, including but not limited to oil price volatility and ever-increasing environmental concerns, particularly those related to CO2 emissions (see Schut et al., 2010; Abila, 2012; Mintz-Habib, 2013; Suranovic, 2013). These were the key reasons behind the movement for sustainable energy sources, such as hydropower plants, wind turbines, solar panels, and biomass generators - the most commonly cited examples of ways of using renewable fuels (see Kaygusuz, 2001; Demirbaş, 2006). The European Commission released its Renewable Energy for All Europeans in November 2016 and recast this as the Renewable Energy Directive (RED) 2018/2001/European Union, which took effect in December 2018 (UPDATE, 2018). The amended document requires that by 2030, 32% of total energy consumption must be green energy sources, in which the hydropower industry has a significant role in reaching such target.

The hydropower industry was the cornerstone of the Industrial Revolution and the transition from an agricultural-based economy to an industrial one, most notably in England, where Richard Arkwright established the Cromford Mill in Derwent valley 1771, mainly for coal-fired steam engines and further generated electricity (IHA, 2016**)**. Numerous countries such as the United States, France, China, Brazil, Germany, England, and Austria, to mention but a few - have used hydropower to transform and increasingly set economic development in motion.

A French engineer, Benoit Fourneyron, developed a turbine capable of producing about six horsepower in 1827, while a British–American engineer, James Francis, came up with the first modern water turbine in 1849 (Energy Efficiency and Renewable Energy-EERE, 2018). The Francis turbine was recognised worldwide and is still in use today. Lester Allan Pelton, an American inventor, developed the Pelton wheel, an impulse water turbine, and patented it in 1880. Just over a decade later, in 1891, Germany produced the first three-phase hydroelectric system, and in 1895, Australia launched the first publicly-owned plant in the Southern Hemisphere. The hydropower industry witnessed rapid development in the 20th century. Professor Viktor Kaplan, an Austrian, invented the Kaplan turbine in 1913, a propeller-type turbine with adjustable blades (EERE, 2018).

As explained by Kaygusuz (2016)**,** the hydropower industry uses plants to harness energy from moving water in a river (large hydro) or flood (small hydro) coupled with simple mechanics to turn it into electricity. Essentially, a hydropower plant uses water flowing through a dam and transforms a turbine into a generator. Industrialisation and the continuous increase in economic activities require energy for development, and electricity plays a pivotal role. The European Commission placed a high priority on accessing affordable, clean electricity from low-carbon sources to spur sustainable development and significantly lower the environmental risks posed by climate change (Goldemberg, 2006).

### 1.1.1 Types of Hydropower

(i) Run-of-the-river (no storage facility) is a system that channels fluid water from a river through a channel to spin a turbine. Run-of-the-river provides a continuous supply of electricity (baseload), with some operation flexibility for daily fluctuations in demand through water flow that the facility regulates.

(ii) A storage plant is an extensive system that uses a dam to store water in a reservoir. Electricity is produced by releasing water from the reservoir and passing it through a turbine, which activates a generator. Storage hydropower provides baseload and the ability to be shut down and started up at short notice according to the system's demands (peak load). It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks or even months.

(iii) Pumped storage allows for peak-load supply, connecting water between a lower and upper reservoir by pumps. It uses surplus energy from the system in low demand times and releases water back to the lower reservoir through turbines to produce electricity during high demand.

(iv) Offshore plants are underdeveloped technology that uses waves to generate electricity from seawater.

### 1.1.2 European river basins: allocation and management

Over the last two decades, the EU Water Framework Directive (WFD) has been affected by a gradual intellectual transition towards more holistic resource management, with stakeholder participation becoming a vital part of the implementation of river basin development (Molle, 2009). The EU WFD has achieved remarkable milestones since it was established in October 2000 (see Baranyai, 2019). It is generally recognized as the most ambitious and detailed EU legislation on water (Jager et al., 2016). The primary purpose of the WFD is to protect and reinstate the European water environment in the course of participatory and integrative river basin management (TAC, 2000). Reichert (2016) has said that the WFD is possibly the most complex supranational water protection instrument globally.

Rainfall, river flow, and storage are important factors for water availability, and these vary significantly throughout Europe and the member countries of the European Union. In the EU, the volumes of river flow in southern Spain and the Atlantic coast have fluctuated significantly between 50 and 1500 mm/year. However, the average annual precipitation level is between 400 and 1000 mm/year in the Mediterranean, Central Europe, and the Atlantic coast (European Environmental Agency-EEA, 2009). Also, the EU is home to the highest number of shared river basins in the world, whose voluntary joint management is increasingly under pressure given rapidly changing hydrological conditions (Wolf et al., 1999). Some EU member countries, such as Germany, Greece, Luxembourg, and Portugal, derive 40% of their surface waters from overseas, the Netherlands and Slovakia 80%, while Hungary receives 95% (Rieu-Clarke, 2006).

### 1.1.3 Contributions and benefits of the hydropower industry

The hydropower industry is a crucial catalyst for improving the EU National Renewable Energy Action Plans (NREAPs) and the mitigation of greenhouse gas (GHG) emissions, in line with the EU Renewable Energy Directive objectives (Kahraman et al., 2009**;** Ma et al., 2014). Hydropower has the second-lowest lifecycle of GHG emissions kilowatt-per hour (see Figure 1.1). Electricity generation from hydropower will save a million tonnes of particulates, a million tonnes of sulfur dioxide, and a million tonnes of nitrogen oxide (IHA, 2019).

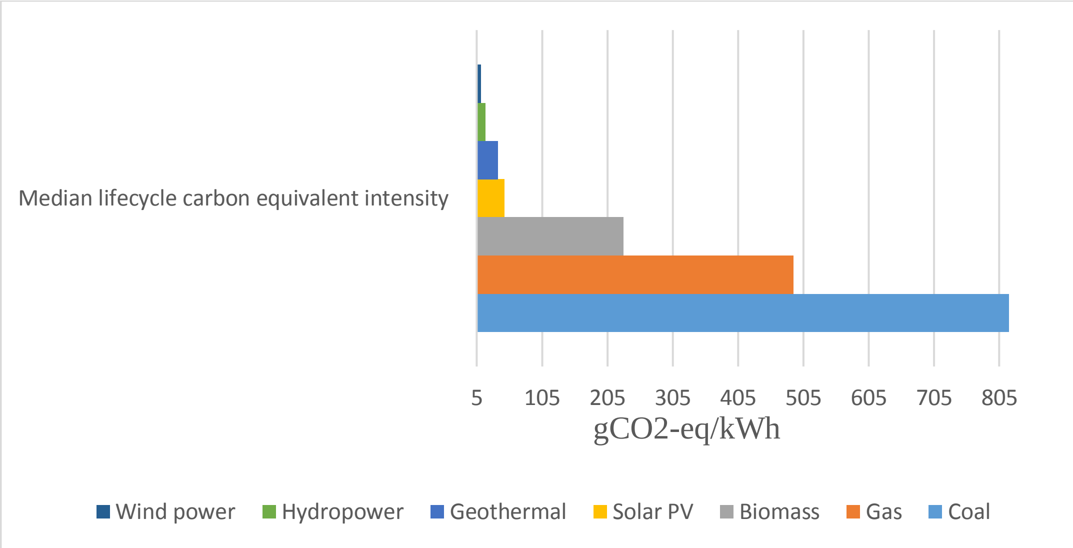



**Figure 1.1 : Chart of the Median Lifecycle Carbon Equivalent Intensity**
(Source : IHA 2019. International Hydropower Agency, Status Report 2019)

A significant inter-annual fluctuation in natural rainfall and prolonged dry seasons due to climate change is a global problem that has disrupted water availability in several local populations (Turral et al., 2011). However, Zhang et al. (2015) indicated that droughts worsen water shortages and negatively affect human health and productivity. Once again, the hydropower industry has successfully utilised dams and reservoirs to collect, sustain and regulate clean water supply, food-producing irrigation projects, rural development initiatives, leisure facilities and eco-tourism (Kaygusuz, 2004; EIA, 2007; Mäkinen & Khan, 2010; Yüksel, 2010; Lehner et al., 2011**;** Berga, 2016). Between 2013 and 2017, the hydropower industry employed an estimated 1.8 million people where operation and management (O&M) was responsible for 63%. Construction and installation accounted for 30%, while manufacturing remained a distant third due to its lower labour intensity (IRENA, 2019).

In 2015, International Hydropower Agency (IHA) reported the European hydropower industry has saved about EUR 24 billion from fossil fuel use in the European Union region and more than 180 metric tons of comparable CO2 pollution in the energy market. Despite the relatively high competition from wind and solar industries, the EU hydropower industry can increase electricity production further, given favourable economic and regulatory policies and significant expenditure to boost growth for the next two decades.

### 1.1.4 General background of the EU region

The European Union (EU), initially known as the European Economic Community (EEC), came into being in 1958 and now consists of 28 European countries as displayed in Figure 1.2. The primary purpose of the union was to bring to an end economic competition among neighbours. The Union started with six economies: Belgium, France, Germany, Italy, Luxembourg and the Netherlands. Acceleration of economic growth through investment, innovation, human capital, and significant trade policies made the EU the biggest economy globally with the gross domestic product (GDP) of 15.3 trillion Euro as of 2017 (Europa, 2017). The EU has the third-largest population globally (after China and India), with 508 million, and covers 4 million square kilometres of land. Most of the 'developed' countries in the EU had already experienced economic growth in the 19th century, while so-called 'developing' countries, such as Poland, Hungary, and Malta, have benefitted from the economic integration of EU membership. However, the EU, recognising the adverse effect that climate change might have on ecosystems and economic growth, has established a pollution-free campaign (with built-in reviews) to achieve sustainable development in the region by 2050.

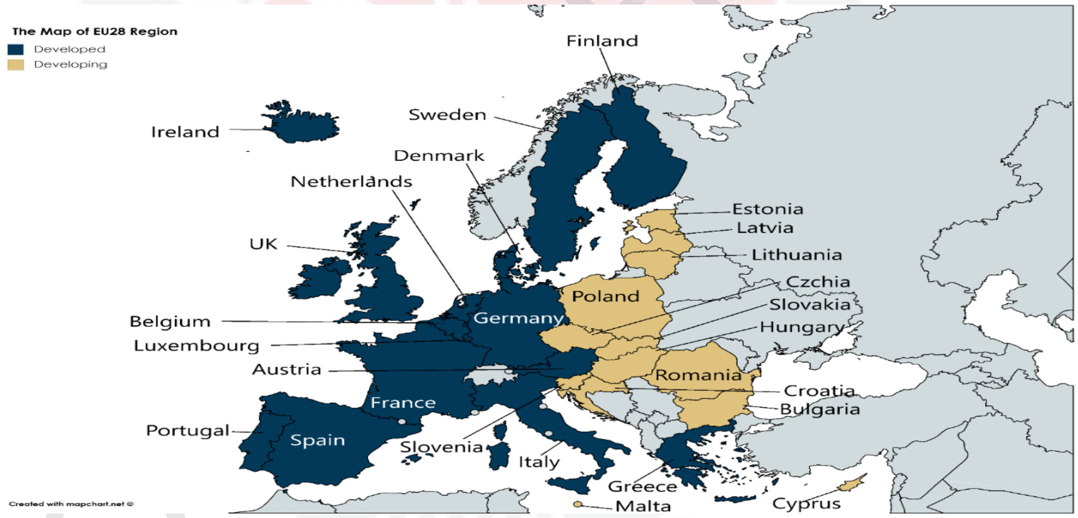



**Figure 1.2 : Map of the EU28 Region**

### 1.1.5 Efficiency and market profile of the hydropower industry in the EU region

The EU member countries are frequently compared with each other. Still, it is difficult to compare a small member country like Lithuania with Germany, the most populous EU member country. However, the EU15 developed countries were described by European statistics as to where GDP per population was more than 90 % of the EU average and EU11 developing countries as to where GDP per population was less than 75 % of the EU average.

Merriam-Webster dictionary defines efficiency as the ratio of the useful energy delivered by a dynamic system to its power. Moreover, Farrell (1957) proposed that the efficiency of an industry or firm includes two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which echoes the ability of a firm to use the input in optimal proportions, given their respective prices.

Energy efficiency has gained increasing attention from policymakers, consumers, and researchers, and the EU has been one of the prime movers in this regard (Oberthür & Roche Kelly, 2008). Figure 1.3 shows a five-year interval for renewable electricity generation by technology in European Union member countries from 1990-2016.

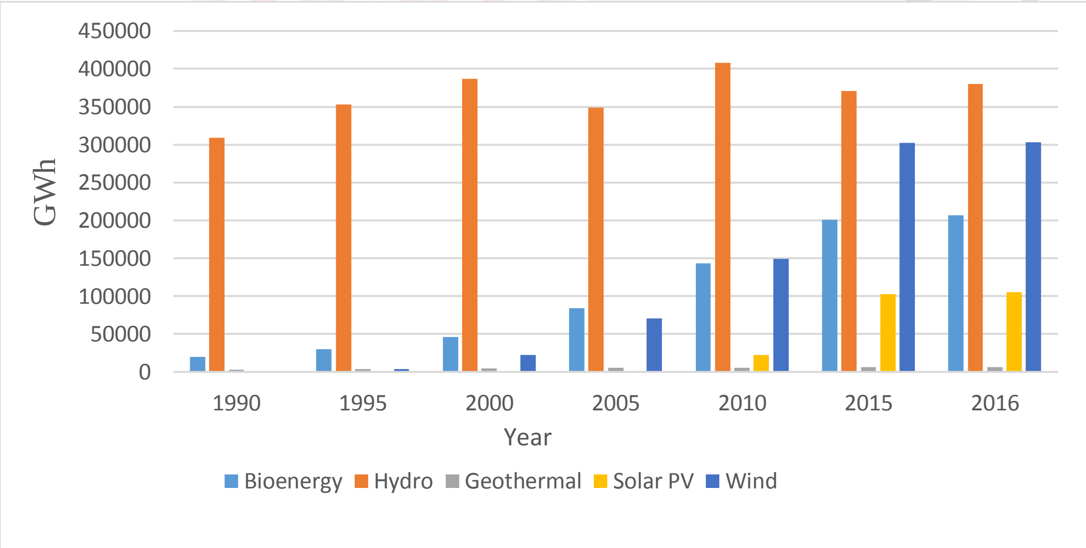



**Figure 1.3 : Chart of Renewable Electricity Generation by Technology in EU region**
(Sources : IEA 2018. Electricity Information 2018)

It shows that the hydropower industry remains the largest renewable electricity source powering industrial development in the EU. In 2010, the sector generated 408,006 GW/year of electricity; there was a slight decrease in 2015, and output decreased further to 380,180 GW in 2016. This deficiency can be linked to other European renewable industries' recent development, such as wind, bioenergy, and solar. In 2010, the bioenergy industry generated 143,119 GW of electricity, with a slight increase of 63,222 GW in 2016. Between 1990 and 2016, the growth of the European bioenergy industry points to diversification away from hydropower. The solar power industry experienced an increase of 82,715 GW of electricity generated between 2010 and 2016.

The wind power industry witnessed relatively higher growth in the period 2000-2016. In 2000, 22,225 GW of electricity was generated and by the end of 2016, the industry produced 302,294 GW. This amounts to an increase of 289,069 GW of electricity generated. Other European renewable energy sectors' rapid growth may be due to policy support and several developmental packages. Besides, the production life-cycle of hydro technologies in the EU is mature compared with other renewable energy sources, possibly resulting in technical inefficiency. Storage capacity is as important as production capacity since storage can bridge the gap between demand and supply and support the integration of variable renewable energy sources (v-RES) such as hydropower plants.

Some countries in the EU lack natural conditions and therefore have little or no hydropower production or capacity (Cyprus, Malta, Denmark, Belgium, and the Netherlands). This means that the hydropower position variation depends on geographical conditions, environment, rainfall patterns, institutional capacity, and technical skills within the various national system for electricity generation.

The installed hydropower capacity by country can be shown in Figure 1.4. Countries such as Cyprus, Malta, Estonia, Denmark, the Netherlands, Lithuania, Luxembourg, and Hungary, do not have sufficient hydro-enhancing power and only provide 376 MW of 2018. Therefore, the hydropower installed capacities of these countries are not displayed in Figure 1.4.

Some Balkan countries are recently-joined members of the EU, and the enormous potential of hydropower is yet to be harnessed in these countries. For example, in Bulgaria, hydropower accounted for 56.4% of total renewable feasibility, Croatia 64.8%, Latvia 87.1%, Romania 56.8%, Slovakia 62.7% and Slovenia 78.3% (IEA, 2018). Moreover, many EU member countries, e.g. Cyprus, Malta, and Estonia, still depend heavily on fossil fuels for their electricity outputs (European Commission, 2016). Increasing the capacity for hydropower plants in the EU region, particularly those with low installed capacity, would significantly impact the amount of hydro in the EU energy market.

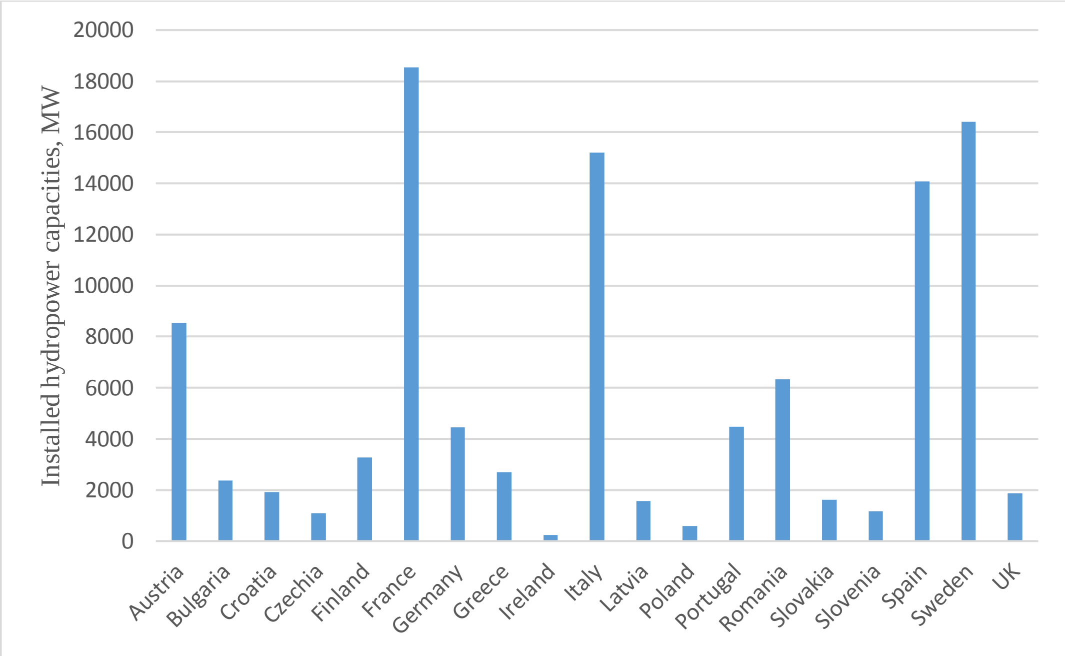
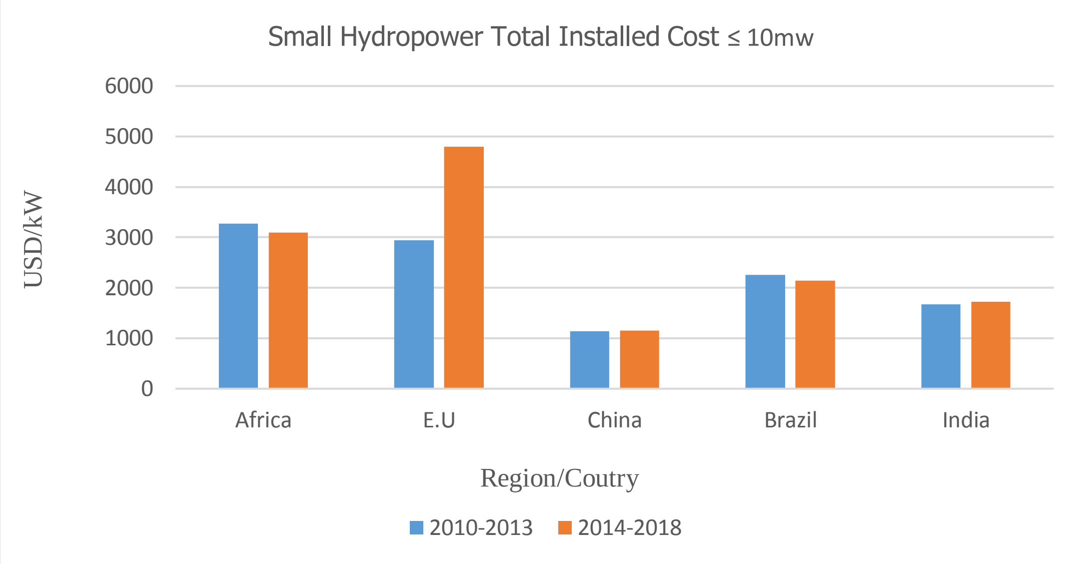



**Figure 1.4 : Installed Hydropower Capacities for the EU in 2018**
(Source : IEA statistics 2018)

Figure 1.5 compares (by region/country) the Levelized cost of electricity (LCOE) generated from small and large hydropower plants from 2010-2013 and 2014-2018. IRENA (2019) describes an LCOE in electrical energy production as the present value of the price of electrical power generated (usually measured in cents per kilowatt-hour), taking into account the plant's economic existence and the costs of construction, service, repair and fuel.



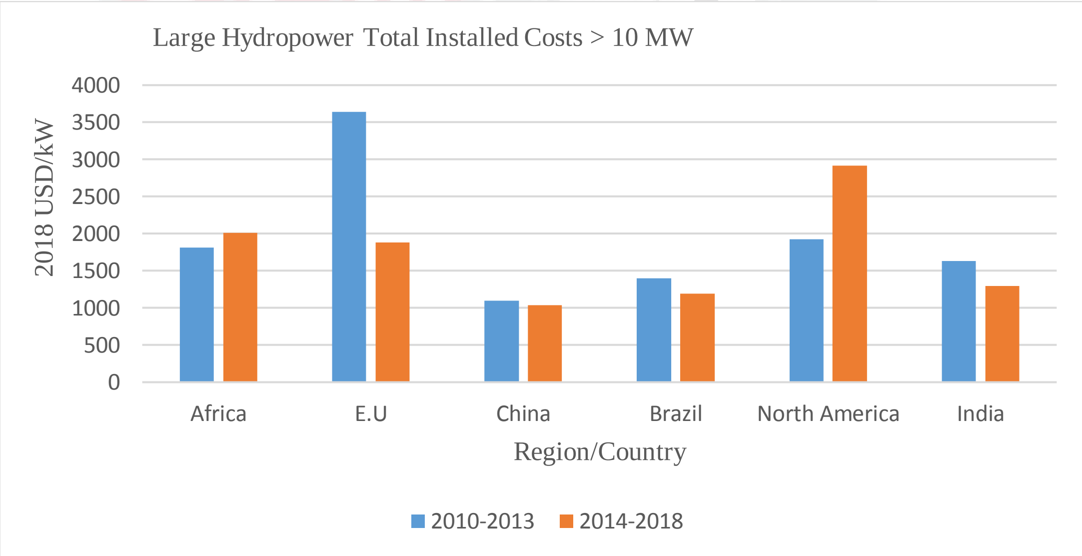




**Figure 1.5 : Chart of Levelised Cost of Installed Hydropower Capacity**
(Source : International Renewable Energy Agency 2019)

Small hydropower is described as a plant with less than or equal to 10 megawatts capacity. Figure 1.5 compares the LCOE in Africa, the EU, China, Brazil, and India. From 2010-2013, Africa had the highest installed capacity cost (USD 3,268) for generating kilowatts of electricity. In the same period, the EU incurred (USD 2,938), China (USD 1,137), Brazil (USD 2,258), and India (USD 1,699). In the period 2014-2018, the EU had the highest LCOE (USD 4,802), Africa (USD 3,088), Brazil (USD 2,147), India (USD 1,718), and China (USD 1,149) per kilowatts.

Figure 1.5 shows LCOE for large hydropower units, and here, particularly from 2010-2013, the EU hydropower industry shows high LCOE compared with Africa, North America, China, Brazil, and India. However, the EU's LCOE was lower than North America's and Africa's in 2014-2018. Assessing the cost efficiency level of the European hydropower industry is of importance for efficiency and market development. These statistics imply that the European hydropower industry incurred more significant input cost than every other region to generate electricity from small hydro between 2014 and 2018 and large hydro from 2010-2013. Theoretically, higher input costs can harm supply and give other countries with relatively lower input cost a competitive advantage in the renewable energy market.

As mentioned earlier, the EU region's geographical proximity (excluding Cyprus and Malta) lends itself to the intensive usage of untapped hydropower resources in the Balkan area. Therefore, expanding the technological, economic and environmental contribution of hydroelectric power could use a trade-off for high capital cost and also make a significant addition to the potential energy mix of the EU. This research seeks to promote a strategy that will increase hydroelectricity production in line with the EU RED and NREAP developed for 2030.

### 1.1.6 Hydropower Profile in the World

Based on World Energy Outlook 2012 (IEA, 2012) statistics, electricity demand will rise at a rate of 2.5% per year up to 2030, with approximately 16% of electricity currently generated by the hydropower industry. The growth of hydropower involves social and economic advantages such as trade between countries which can further contribute to jobs, expand global access to renewable and sustainable energy. It will also allow efficient use of fixed assets, enhance water resources productivity, and minimise climate effects on the environment.

Many countries, including China, the USA, Norway, France, Switzerland, Sweden, Italy, Canada, Brazil, India, and a few other countries, are using hydropower to neutralise their electricity markets (IHA, 2015). The worldwide potential for conventional hydropower is around 9770 terawatts (TW), with 3700 TW of electricity generated as of 2012 from an installed capacity of 990 GW. These are expected to reach 7000 TW by 2050.

As per Figure 1.6, the global hydropower industry makes some significant progress, with forty-eight countries adding new installed capacity in 2018. According to IHA 2019, the countries with the highest individual increases in installed capacity of hydropower were China (8,500 GW), Brazil (3,700 GW), Pakistan (2,500 GW), Turkey (1,100 GW) and Angola (700 GW).

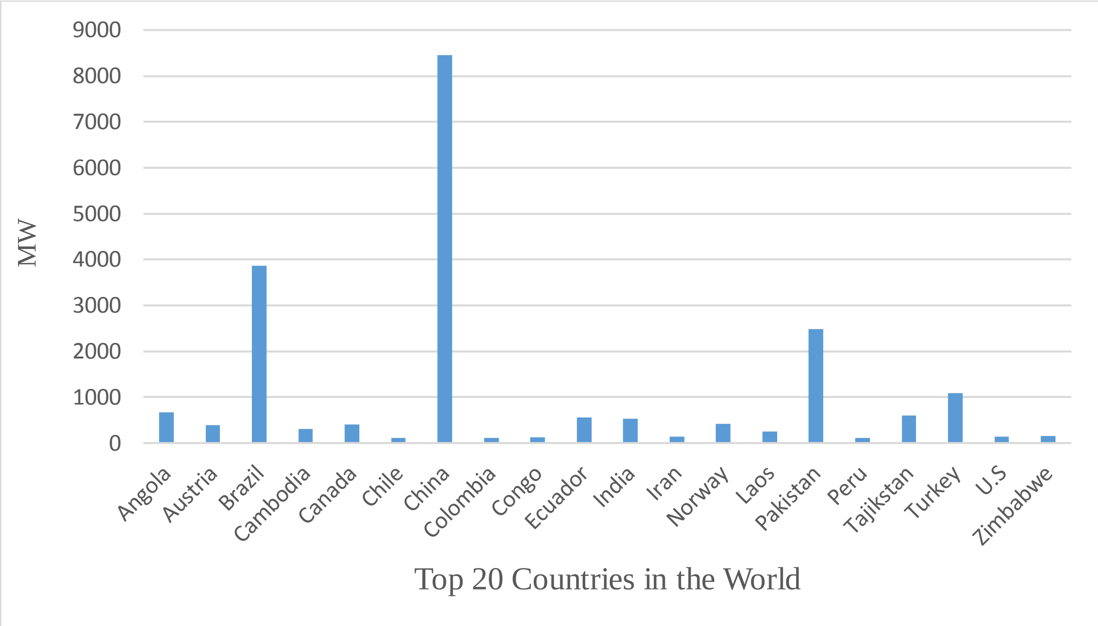



**Figure 1.6 : Chart of Added Installed Hydropower Capacity**
(Source : International hydropower agency, the 2019 Hydropower Status Report)

Pumped hydropower storage has proven to be a key component of current and potential clean energy systems. The significant improvement in intermittent renewable sources of electricity, such as wind and solar power, has replaced traditional generators, placing increased pressure on power grids and emphasising the need for pumped hydro efficiency.

The Eastasia remained the engine of the world's hydropower sector, where China accounted for most of the capacity additions and pumped storage (IHA, 2019). China's hydropower industry has expanded 20-fold to a combined output of 352 GW, accounting for more than a quarter of the world's installed capacity (Appavou et al., 2017). A variety of traditional hydropower schemes have been built with the world's largest hydropower project currently under development, the China Three Gorges (CTG), 16,000 MW Baihetan Project (Yan et al., 2006; Fu et al., 2010). The Chinese government has supported green finance to produce renewable energy while introducing standard green bonds to help large-scale hydropower. The CTG raised USD 2.25 billion to fund Jinsha River cascade projects, including the Baihetan and Wudongde hydroelectric projects, between 2017 and 2018. (IHA, 2019). Recently, the Chinese government released an Action Plan on Sustainable Energy Use 2018-2020 to reduce renewables' depletion, including hydropower. The strategy stressed the value of changing China's electricity sector, enhancing regional interconnections, growing energy storage, and increasing the power grid's versatility.

South America was the second-fastest-growing hydropower industry (Kirchherr and Matthews, 2018). Brazil contributed much of the added installed capacity in 2018, being the second fastest-growing country with abundant hydropower in the world after China. In Brazil, a coalition of hydropower companies and developers founded the Brazilian Platform for the Construction of Small Hydropower Plants to strengthen private sector investment in hydropower. This was triggered by the government's decision to stop concession auctions for new hydropower projects of more than 30 MW, which influences the increase in installed capacity. According to EIA (2013), Brazil's rising population required considerable improvements in electricity and transmission lines; therefore, the government invested in adding hydroelectric infrastructure to prevent power shortages and support its economic growth. For example, the 14,000-megawatt Belo Monte Dam, which is expected to be built in 2016, will become the second-largest dam in Brazil and the third largest dam in the world at an approximate cost of about S$13 billion.

Pakistan is a country well equipped with significant water resources (IHA, 2017). According to the Water and Power Development Authority (WAPDA), there are approximately 60,000 MW of hydropower-installed capacity in Pakistan, of which only 7,320 MW has been utilized. Moreover, the Pakistan government remains under tremendous pressure to resolve the annual average power deficit of 4,000 MW due to over-reliance on imported thermal-generated fuels and price volatility. In order to resolve this power shortfall, the hydropower sector in Pakistan is expected to raise overall electricity production to 40% by 2030 (IHA, 2017). The Private Power & Infrastructure Commission is constructing several power plants such as Karot (720 MW), Suki (870 MW) and Kohala (1,124 MW). These projects are part of the China-Pakistan Economic Corridor (CPEC) – an initiative funded by the Chinese government to improve Pakistan's economic well-being (IHA, 2017). However, challenges of many emerging countries is raising capital to build and sustain hydropower projects while ensuring that national institutions have sufficient capacity and projects are delivered in line with acceptable environmental and social performance practices.

### 1.1.7 Some potential socio-economic drivers for the efficiency of the hydropower industry in the EU region

In May 1992, at the Earth Summit in Rio de Janeiro, Brazil, the United Nations Framework Convention on Climate Change (UNFCCC), developed a legal mechanism to regulate ambient greenhouse gas (GHG) concentrations to prevent harmful anthropogenic conflict with the climate system (Berga**,** 2016). The UNFCCC, including the EU, decided on 12 December 2015 in its 21st Conference of the Parties (COP21) that climate change impacts on biodiversity should be held below 2°C to ease global warming to improve natural resource efficiency and economic growth, especially in emerging economies (Năstase et al., 2017).

Figure 1.7 shows the average temperature change in EU member countries from 1990-2019. In large part, the EU countries maintained an average temperature change well below 1.5°C from 1990-2006, with a sharp rise in 2007. A dip below 0.5°C occurred in 2010 but increased significantly in 2014, going above 2°C, indicating that the EU had, for the first time, breaking the Paris (COP21) agreement on environmental sustainability. Meanwhile, according to Berga (2016), unprecedented temperature increases are likely to change the water-levels in rivers, affecting water availability, water regularity, and electricity generation in the EU region.

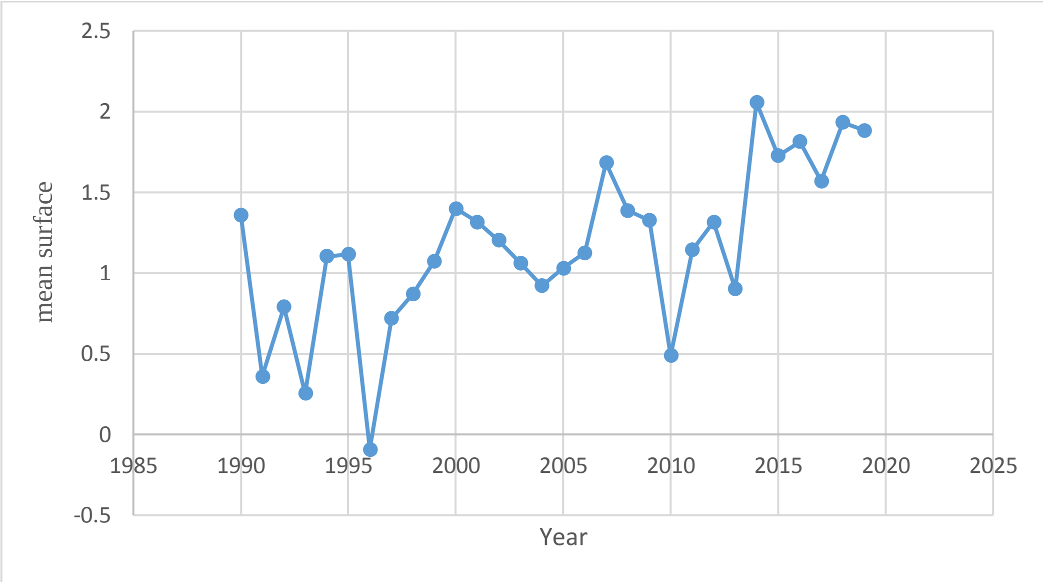



**Figure 1.7 : Chart of Temperature change in European Union Region**
(Source : Food and Agriculture Organization of the United Nations FAO)

Research & Development (R&D) is a catalyst for continued growth in a knowledge-based and innovative economy (Savova, 2012; Chung, 2015). The EU share of R&D expenditure as a percentage of GDP from 2009-2020 is shown in Figure 1.8. It shows that R&D remained between 1.9% and 2% over the period 2009 to 2012. Between 2013 and 2018, it increased slightly from 2.01% to 2.12%, and the 3% EU 2020 target is still a long way off. The European Union would have to increase R&D expenditure by at least 0.88% to meet the EU 2020 target. Ragwitz & Miola (2005) suggested that awareness and rationalisation of R&D expenditure is the starting point for a simplified approach to strengthening the industry in power generation.

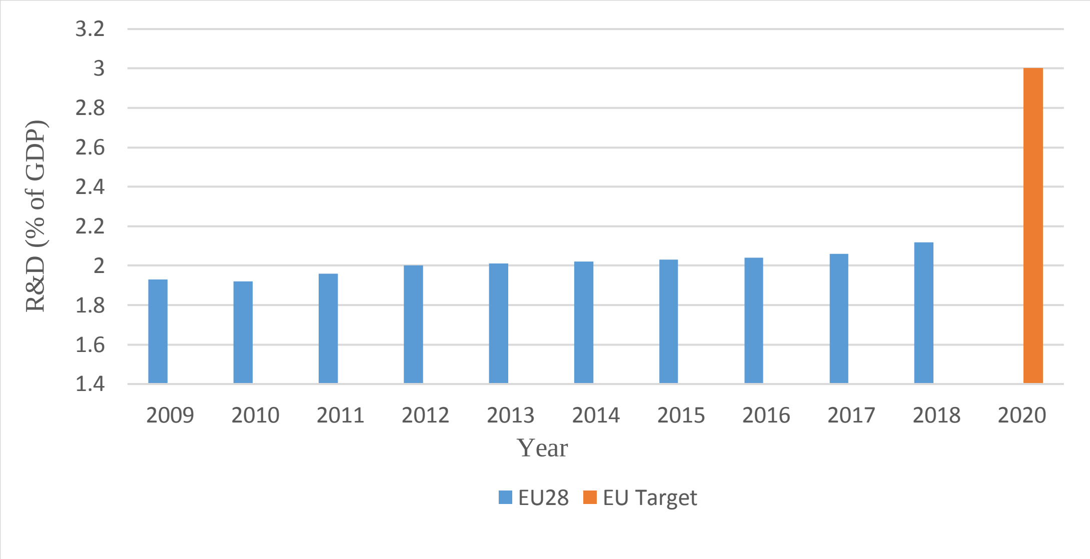



**Figure 1.8 : Research and development expenditure, percentage of GDP in the EU region**
(Source : Eurostat 2020)

The EU drafted a development path in Lisbon strategy in 2000, and after several adjustments to the plan, the European Commission defined the objective of 3% of GDP allotted to R&D spending in 2005 (Albu, 2011). The follow-up is known as the European strategy for smart, sustainable and broad growth 2020 (Athina et al., 2018). However, Figures 1.9 and 1.10 describes the position of R&D percentage of GDP in both EU developed and developing countries from 2009-2018.

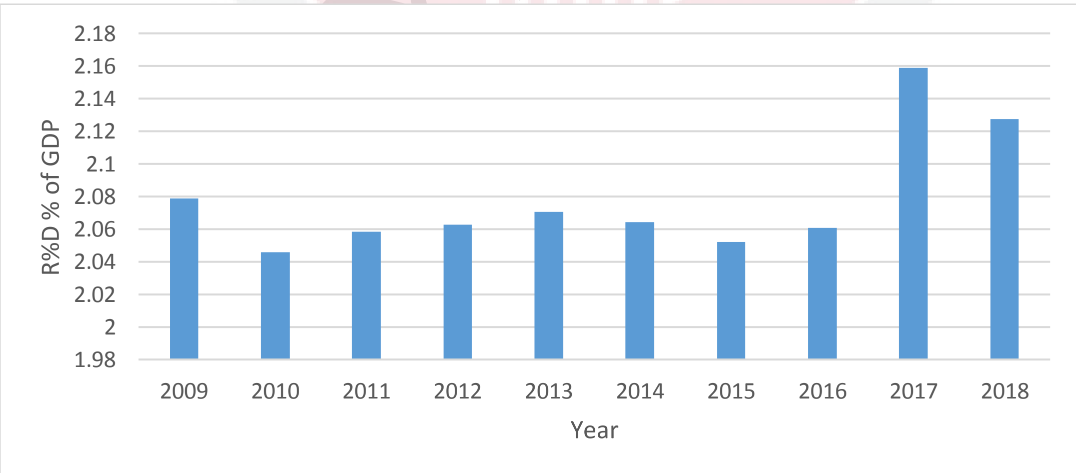



**Figure 1.9 : Research and development expenditure, percentage of GDP in EU developed countries**
(Source : World Development Indicators 2020)

Figure 1.10 shows the actual R&D spending of the EU developing countries is below 1.5%, on average, thus requires improvement, as the proscribing 3% spending 2020 strategy is far from reaching. The less than 1.5% of R&D spending in the EU developing countries indicates insufficient investment, alongside the uncertainty about the long-term prospect in research and development.

Moreover, the difference between the EU15 and EU11 countries show an improvement of R&D efforts within the EU developed zone. Nonetheless, there was a decrease in R&D spending of the EU15 in 2018. The amount of R&D expenditure has a catalytic role in creating innovation in sectors, particularly the hydropower industry, which requires extensive research before constructing a Dam.

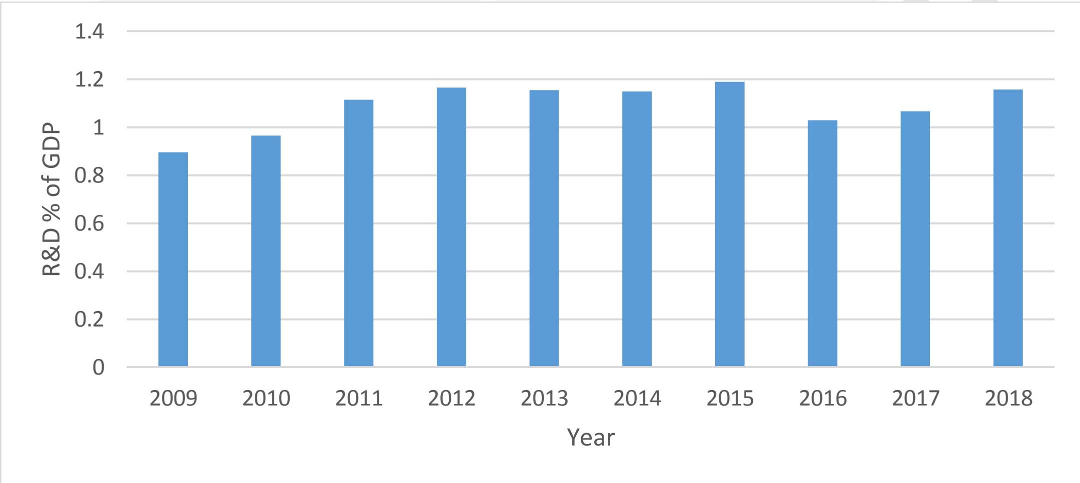



**Figure 1.10 : Research and development expenditure, percentage of GDP in EU developing countries**
(Source : World Development Indicators 2020)

The production of renewable electricity in the EU has evolved, highlighting, in particular, a general shift from fossil fuels to renewable energy sources, mainly hydropower, solar, wind, and bioenergy. The European Commission set a net transfer capacity target of 10% of all installed capacity by 2020 and 15% by 2030, implying that electricity trading through interconnectors will be an essential component of the ongoing transformation of the UK's power supply and EU member states by 2030. Recent research by Özcan et al. (2019) describes a Turkish hydropower industry project as capital-intensive in infrastructure with a holistic goal of delivering sustainable energy. The project's long-term aim is to produce simultaneously uninterrupted, secure, effective, and economically and environmentally sensitive electricity.

Based on the latest available data, Figure 1.11 explains the renewable electricity output as a percentage of total electricity in European Union member countries in 2015. This percentage varied widely among member states. Austria (76.5 per cent), Croatia (73.9%), Denmark (65.9%), and Sweden (63.3%) are the countries with relatively high renewable energy outputs. Other countries - such as Belgium, Bulgaria, Cyprus, and Czech - need to improve renewable power production, mainly by increasing installed capacity, research, development and investment.

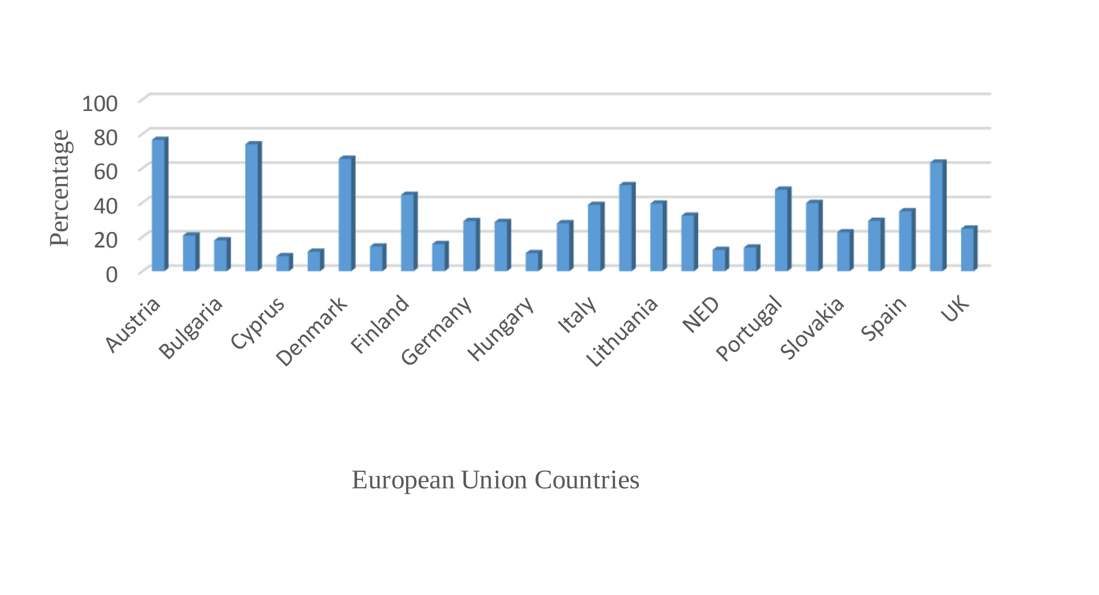



**Figure 1.11: Renewable electricity output (% of total electricity output)**
(Source : World Development Indicators 2018)

In some nations, regulatory is enforced following clean energy targets, leading to legislative conflicts over costs between industries. Market leaders, in particular, are often worried that new or stricter legislation could damage them by inflating prices and reducing competitiveness. The high number of industrial exemptions and special rules in the EU's tradable carbon allowance system, for example, decreases market efficiency (Fuss et al., 2009). The EU transition from high-carbon to carbon-neutral electricity generation in rising regulatory uncertainty (RU) could be challenging for renewable energy sources, including the hydropower industry. A potential increase in RU would hinder investors' willingness to research better pathways for integrating the renewable electricity market.

## 1.2 Statement of the research problems

One of the challenges facing the European Union hydropower industry is the lack of cost efficiency benchmarking mechanisms to enable economic operators to allocate resources where they are most required. High input costs are not adaptable to changing market situations and could convince customers to consume a product with a higher price in a competitive market. Additionally, dams can stretch to hundreds or even thousands of square kilometres, requiring detailed hydrology, geology, topography and general environment research costs. This means that, in addition to high installation costs, social and environmental impact assessments must be carried out and be addressed in the project plan if there are negative impacts on local populations, ecosystems and biodiversity.

In conceptual definition, socio-economic is described as a matter involving the total household, employment, income, education, health and assets in a given community. Domac et al. (2005) opine that socio-economic is a central component of a specific industry or sector's development plans in an economy. However, in recent years, regulatory uncertainty has significantly increased. It affects numerous economic activities that may also play a negative role in investment cost and advance materials for hydropower output. In some nations, regulatory policy is enforced under clean energy targets, leading to legislative conflicts over costs between industries. Market leaders, in particular, are often worried that new or inconsistent regulations could damage them by inflating prices and reducing efficiency. European regulatory authorities must find a balance between creating a coherent institutional framework that provides security for investor planning, sufficient market flexibility, and effective technology choices for hydropower electricity innovation to avoid negative spill-overs.

It worth mentioning that dam construction requires research and development to guide the proper implementation of the hydropower project plan. However, in terms of R&D, the EU is some distance away from reaching the 2020 investment goal of 3% of GDP. This might translate into a lack of improvement in the efficiency of the hydropower industry in the region. The R&D spending in EU11 developing countries is below 1.5% on average, indicating that some member countries still need improvement in achieving the 3% spending target in 2020.

Moreover, the percentage of renewable electricity as a proportion of total electricity generation is below 20% in many EU member countries. This implies that the fossil fuel industry is playing a dominant role in electricity generated in the EU region and may improve hydropower's cost efficiency. Investigating the cost efficiency is necessary because we do not know which hydropower industry in EU countries are cost-efficient and inefficient and what might cause their inefficiency.

Another important reason for this research is the technical feasibility of the hydropower industry in European Union countries. The hydropower system relies on precipitation amounts, which can fluctuate from year to year and create an electricity output fluctuation. However, massive dams are easily susceptible to climate change, affecting rivers' flow and course. The key issues are the lack of robust implementation of water-usage optimisation, the use of advanced materials for electricity generation and the extent of management or policy support for hydropower could contribute to the technical inefficiency of hydropower in the EU region. Among many reasons, the most problematic one is that current hydropower technology has shown signs of stagnation compared with other renewable technologies, and the level of installed hydropower capacity is relatively lower in many EU countries.

It is worth to note that more than half of the hydro-potential has been utilized in the EU, and many facilities were constructed decades ago. However, using technologies that are deemed outdated to achieve hydropower's digitalisation may lead to low electricity output, resulting in scale inefficiency. Moreover, hydropower's lack of technological progress relies heavily on political support and management skills; therefore, it may be difficult for the industry to respond to markets' variability and climate change. More importantly, modern hydropower construction and the improvements and repairs of established installations must comply with stringent environmental requirements. Therefore, investigating the hydropower industry's technical efficiency is of particular interest in the EU context.

In order to provide clarity to the problem associated with technical efficiency, it is important to highlight the purpose of its decomposition, i.e., pure-technical and scale efficiencies. On the one hand, the pure-technical efficiency would permit us to reveal the extent to which management or policy is advancing technical efficiency. On the other hand, scale efficiency would point out the level at which the size of facilities shapes the hydropower industry's technical efficiency in the EU.

One of the main inputs of hydropower resources is the volume of precipitation in a calendar year. Meanwhile, the availability of water for hydropower largely depends on temperature change and the EU WFD regulations. The problem here is that, in multiple years, the temperature rises above 1.5°C and 2°C pre-industrial levels in the EU region. This would have a significant negative impact on the EU hydropower industry's technical efficiency, not only because of a lack of timely rainfall but also because of increased sediment yields and recurrent natural hazards.

In recent years, a wide-ranging analysis has been carried out on impact-oriented water footprints that evaluate the volume of water usage and the relationship between water and energy generation. Most impact-oriented studies were on randomly selected countries or specific country. Although few studies have considered analysing the hydropower market drivers, none have been done in the EU region, which is one of this research's focus.

The EU is one of the leading producers of hydropower globally. Still, market integration capacities are becoming more challenging due to several economic factors such as investment cost, regulations, price volatility and water-energy nexus. Nonetheless, despite ensuring that hydropower production matches demand securely in the real-time market, uncertainty about investment cost and concession rights continue to impede the goal's achievement. Sedimentation disturbs the stability of dams and limits electricity generation, storage and discharge capacity. It raises load on dams and turbines, destroys mechanical infrastructure, and produces various environmental impacts. These problems affect the reliability of water availability for power generations and increase hydropower operators' investment cost. In addition, hydropower projects are subject to stringent licensing procedures, which could hinder investment decisions for the development of new or extension of established hydropower plants. To integrate the EU hydropower market, regulators require policies that appropriately provide the certainty needed to attract investors and reduce various input cost and prices.

Solar and hydropower are widely regarded as alternatives in the EU for green resources. The main distinction between hydropower and solar is that hydro can generate more electricity at peak hours. However, solar's erratic production and its specific peak generation periods pose threats to the hydropower market in the EU. IRENA estimated that hydropower's price at current dams is between $0.01 and $0.10 per kilowatt-hour (kWh) while modern small hydropower is between $0.06 and $0.14 per kWh. However, the price of solar energy is estimated to be $0.20 per kWh. The primary problem here is that utilities face negative prices and hydroelectricity is exported when supply exceeds demand. Solar could be price competitive and use as a substitute for hydropower in the EU region, assuming further technological advances and holding constant current public policies.

It is typically the case that the aggregated panel data will generate a low time frequency while the disaggregated panel data produces a higher frequency. Fundamentally, aggregation of micro or macro-economic data is about managing a purposeful group of countries (for example, the EU region) that are significantly similar in economic activities. However, in this research's empirical applications, we have disaggregated the EU into sub-regions, i.e. developed and developing. This is because the sub-regions could be distinct in the degree to which they participated in the hydropower market. The use of disaggregated panel models would allow this research to resolve policy issues related to efficiency, socio-economic factors, and market analyses of the EU region's hydropower industry.

## 1.3 Research questions

This study seeks to answer the following research questions:

What is the cost efficiency level of the hydropower industry and the role of socio-economic factors on cost efficiency in the EU region?

What is the technical efficiency level of the hydropower industry and the role of socio-economic factors on technical efficiency in the EU region?

What is the market performance of the hydropower industry in the EU region?

## 1.4 Objectives of the study

This study's general objective is to analyse the efficiency, socio-economic factors, and market of the hydropower industry in the EU region.

The specific objectives of the study are:

I. To investigate the cost efficiency level of the hydropower industry and the role of socio-economic factors on cost efficiency in the EU region.

II. To investigate the technical efficiency level of the hydropower industry and the role of socio-economic factors on technical efficiency in the EU region.

III. To analyse the drivers and forecast the market of hydropower in the EU region.

## 1.5 Significance of the study

Efficiency is an essential element for an industry existence, and the market competence of European hydropower reputation has experienced low status over the last decade. This is because of the rapid development of other renewables and the high cost of hydro-installed capacity in the EU region. The investigation of the cost efficiency of hydropower and its decomposition, i.e., technical efficiency and allocative efficiency, would provide direction as to which aspect of the industry needs improvement. Also, the investigation of technical efficiency and its decomposition, i.e., pure-technical efficiency and scale efficiency, is essential for the EU hydropower industry to determine whether to improve managerial or facilities size. This research, therefore, identifies the best and poor practices in cost and technical efficiencies performances, respectively, in hydropower among EU member countries. The outcomes would be useful for benchmarking mechanism in which the inefficient hydropower members adopt the efficient member pathways to achieve higher cost and technical efficiencies.

Hydropower is, among other functions, the primary source of renewable energy in the EU. However, in this modern technological advancement and regulatory uncertainty, the hydropower industry faces high resource costs, comparatively low installed capacity and slow growth in the market, which implies a need to calculate its cost and technological efficiencies. However, socio-economic considerations may serve an essential function in linking socio-economic priorities to the hydropower industry's cost and technical performances in the EU region. This will add a significant level of knowledge that could create new opportunities for the EU region's hydropower industry. Additionally, the panel of evidence on the EU disaggregation into sub-panels, i.e. EU15 (developed countries) and EU11 (developing countries), on socio-economic factors in the cost and technical efficiencies of hydropower has not explicitly been discussed in existing studies. We estimated the aggregation of EU panel data in fixed and random effects models. In particular, we show how the aggregation model may not sufficiently represent the EU sub-panels.

The domestic hydropower market in the EU depends on many factors; the volume of precipitation, hydropower price, substitute price, cost of production, and level of income. One of the vital significance of this research is the possibility of using an econometric framework to estimate market models to establish relationships between quantity supply and demand and its drivers. However, the market drivers' response can be used to manage hydropower development and influence policy support. For instance, quantity supply and quantity demanded could vary between the EU15 developed and EU11 developing countries due to differences in the availability of hydropower resources, own price, substitute price and income. However, economic models can support experienced judgment and stimulate a creative interaction between the regulators and operators, based on inferences drawn from the hydropower market drivers. On the other hand, the market forecast would identify the extent to which new supplies are expected to be non-incremental, i.e., demand exceeds supply, or incremental, i.e., no shortage. This distinction is vital for the optimization, planning and investment in hydropower.

## 1.6 Scope of the study

Decarbonisation of the energy market and prevention of anthropogenic climate change, which proposes a plan to support the aims of the Paris Agreement, is the extensive explanations of why the EU is the area chosen for this study. Hydropower has a tremendous ability to enhance the transition to a decarbonised environment in Europe. However, sluggish technical development, concession rights, widespread criticism, adverse business dynamics and environmental-related components are still concerns. While considerable progress has been made in resolving these problems, there is still a low degree of public understanding of these accomplishments. However, investments in research and development (R&D) are necessary to meet technical developments, reducing production cost and dealing with competition. Furthermore, to handle environmental and socio-economic dimensions at the regional level, there is a need to develop relations between industry, R&D and policy institutions. The scope of this research provides a comprehensive analysis of efficiency, socio-economic factors, and market performance of the hydropower industry in the EU region.

The study analysed the hydropower industry's efficiency and market in the EU region from 1990-2018, excluding Cyprus and Malta. The study covers 26 EU member countries, where endogenous data such as production, consumption, and installed capacity for hydropower are available. For the empirical segment, we first analysed EU26 member countries, then separated these into EU15 (developed countries) and EU11 (developing countries) to compare results in the sub-regions.

The first objective comprised a two-stage analysis. According to Coelli et al. (2005), the cost-efficiency calculation could be a multi-stage process, in which cost-efficiency decomposed into technical efficiency and allocative efficiency. To do this, we examine steps of cost efficiency calculation in Farrell (1957) and used data envelopment analysis (computer) program (DEAP) software, introduced by Coelli et al. (2005). In the second stage, the thesis investigates the socio-economic role in the cost efficiency of the hydropower industry in the EU region, using a fixed-effect model.

Similarly, the second objective gauged the hydropower industry's technical efficiency and decomposition: pure-technical efficiency (PTE) and scale efficiency (SE). We have used the multi-stage technical efficiency of the DEA approach. In the second stage, we used the random-effects model to investigate the role of socio-economic factors on the technical efficiency of the hydropower industry in the EU region.

In the third objective, the study analysed the domestic market of the hydropower industry in the EU from economic theory for supply and demand functions. We also forecast the supply and demand of the hydropower industry from 2019-2030. To analyse the domestic market, we employed a two-stage least square (2SLS) method. Then, we used the autoregressive integration moving average (ARIMA) to select an appropriate model for the forecast.

## 1.7 The organisation of the study

The study comprises six chapters, and it is organised as follows:

Chapter 1 presents an introduction that includes background to the study, a statement of the research problems, research questions and objectives of the study, and its scope. Chapter 2 provides theoretical and empirical literature. Chapter 3 reflects on the methodology, results and discussions of cost efficiency level and the role of socio-economic factors on cost efficiency. Chapter 4 is about methods, results and discussions of the technical efficiency level and the role of socio-economic factors on cost efficiency. Chapter 5 provides methodology, results and discussion for the domestic market and forecasting analysis. Finally, chapter 6 summarises, discusses policy and provides recommendations.

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## BIODATA OF STUDENT

Zubair Azeem Oluwaseyi obtained his first degree (B.Sc. Business Administration) from Kuala Lumpur Metropolitan University (KLMU), Malaysia in 2015. He joined the Universiti Putra Malaysia and received his second degree (Master of Economics) in 2018. In the same year, he continued with Universiti Putra Malaysia for the pursuance of his PhD program, specializing in Development and Environmental Economics.

He is currently a research associate with iFintel Business Intelligence Sdn Bhd. Malaysia. His research interest includes but not limited to, development economics, environmental economics, energy economics, and economic efficiency.

He has published a sizable number of articles in international journals and attended conferences. These journals include *Sustainable Development, Jurnal Ekonomi Malaysia*, *Business Strategy and Development, International Journal of Energy Economics and Policy, Current Research in Environmental Sustainability*, *Environmental Science and Pollution Research, International Journal of Energy Sector Management, Environment, Development and Sustainability, and Elsevier's Book Module for Earth Systems and Environmental Sciences.*

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