Research Article

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Diffusion of Innovation of RET's Renewable Energy Technsologies in Transition Economies Using Diffusion Models. (Case for Germany and Western Balkan countries)

Erlet Shaqe*

mpWatt Company, 14 Rue de Treves, 2631 Luxembourg, LU

Corresponding Author: Erlet Shaqe, mpWatt Company, 14 Rue de Treves, 2631 Luxembourg, LU.

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Abstract

The purpose of this thesis is to highlight how the diffusion of innovative new RET's renewable energy technologies, such as solar and wind, in Western Balkan countries as transition economies, could have a significant impact on reaching the EU Green Deal energy transition targets of "no net emissions of greenhouse gases by 2050" and the Paris Agreement to cut greenhouse gas emissions (GHG) and transition of these economies to low-carbon development paths [1]. The purpose of this analysis is to present sufficient evidence regarding the reliability and viability of the adapted renewable energy technologies, specifically solar PV and wind technologies. Additionally, it aims to assess the diffusion of innovation in these technologies and predict the extent to which the growth of these innovative technologies is contributing to the achievement of national energy transition objectives for Western Balkan countries.

This thesis will utilize diffusion models dual phase logistic (bi-logistic) and Gompertz for the objective of analysing the adoption and forecasting RET's wind and solar PV, since it has been shown to be effective in previous research studies [2]. The proposed methodology will be utilized to examine the cumulative capacity (measured in megawatts MW) of renewable energy technologies (RETs) wind and solar PV throughout the previous ten-year period for WB6 and from 1990 for Germany. The utilization diffusion models simulation scenarios will enable the projection of solar PV and wind technologies penetration up until the year 2035 and 2050.

Keywords

Innovation, Diffusion Models, Adoption Rates, Renewable Energy Technologies (RETs), Wind, Solar PV, Western Balkan Energy, S-Curve

Introduction

The worldwide climate threat is characterized by its extensive, swift, and accelerating nature [3]. Recent analysis of IPCC presents a concerning outlook about the imminent global warming crisis and urges the prompt implementation of climate mitigation and adaptation strategies. According to [4], the electricity generation sector as the main source of worldwide CO2 emissions, generating around 73% of overall emissions. To achieve the Paris Agreement's 1.5°C warming target it is vital for the global energy sector to swiftly transition from fossil fuel-based energy generation, encompassing oil, gas, and coal, to renewable energies [3].

Energy experts in the Western Balkans (WB) agree that the European Union's (EU) current energy transition policies, support programs, and established mechanisms are not likely to deliver the expected results and will not ensure the successful implementation of the green energy transition in the WB [5] [6]. Experts assert that without significant modifications to EU policies and support mechanisms for the WB-6 (Western Balkan countries), the ongoing trend of unintentional decarbonization will persist, with WB-6 governments only making superficial commitments to decarbonization objectives [7].

Renewable energy technologies (RETs) can help accelerate the energy transition by delivering cleaner, economically viable, and environmentally friendly alternatives. Renewable technologies have the potential to improve, among other things, energy efficiency and security, sustainable growth, efficient use of local resources, self-sufficiency from energy imports, and cost competitiveness. However, renewables' proportion in global energy mixes remains rather small, and not sufficient for Western Balkan countries.

The Western Balkans, being the least developed region in Europe, heavily depends on coal and lignite for electricity generation. Therefore, it is imperative to examine the effects of the spread of green energy technologies. This analysis is crucial for the European Union to support the decarbonization of the region's electric power sectors by offering the required technical, financial, and policy support for adoption.

Overview and Motivation

The Western Balkans are now in the early stages of their green transition, as shown by prominent evaluations conducted by the EC, the Energy Community Secretariat, and the World Bank [8-10]. The WB-6 nations have committed to attaining carbon neutrality by 2050, while reducing emissions of greenhouse gases by 55% by 2030, in accordance with the Paris Agreement. WB-6 countries have pledged to actively pursue the shift to renewable energy [11].

In the year 2022, the Western Balkan countries produced 69.5 TWh of electricity, with coal-fired thermal power plants (TPPs) accounting for 63% of the total. Kosovo had the highest percentage of coal TPPs (92%), followed by North Macedonia (72%), and Serbia (70%). In the WB region, 36 coal TPP units were operational, with cumulative installed capacity of 8,255 MW. TPPs and related coal mines directly employed approximately 46,000 people, while they indirectly employed 80,000 to 100,000 people. Hydropower plants produced 23.5 TWh (34%), while renewable energy sources like solar photovoltaic plants (PVPs) and wind power plants (WPPs) accounted for an insignificant 3.5% of the generating mix.

As a result, in 2022, 1,130 MW of total RES installed capacity equivalent to 0.0645 kW/person were available for the 17.5 million WB-6 population. The installed capacity of RES per person in the EU in 2022 was 1 kW. As a result, the EU has 15.5 times more installed RES kW per person than the WB region [6].

The problem surrounding the formulation of this thesis arises from the observation that the Western Balkan nations are not making significant progress in adopting renewable energy per capita, despite experiencing fast economic development and growing energy demands. The sector experiences early adopter's disadvantages in both the commercialization and market expansion stages of renewable energy technologies. Additionally, the absence of effective and well-defined laws and regulations poses challenges in scaling up renewable energy technologies.

This thesis research intends to use the diffusion models like Gompertz and Bi-Logistic, to conduct an analysis of the development and adaptation of RET's for solar photovoltaic (PV) and wind energy in the Western Balkan (WB-6) region. This region is characterized by early-stage development in these RET's; the research will also compare this diffusion process with another EU country which has advanced more in adapting these technologies like Germany.

Global and European Renewable Energy Market Overview

Global Energy Overview

In 2023, the global production of electricity was primarily fuelled by fossil fuels, which accounted for 61% of the total output. More specifically, coal was responsible for 35% (equivalent to 10,434 TWh) and gas contributed 23% (equivalent to 6,634 TWh) of the global electricity generation. Despite the prevailing dominance of fossil fuels, a significant transition towards renewable energy sources has been observed. In 2023, renewable energy sources achieved a landmark by generating 30% of the global electricity for the first time. This growth trajectory was predominantly propelled by substantial increments in solar and wind power, which collectively contributed 13.4% (amounting to 3,935 TWh) to the global electricity mix.

Solar energy, in particular, witnessed a growth of 23%, adding 1,631 TWh to the global electricity production. Concurrently, wind energy experienced a growth rate of 9.8%, contributing an additional 2,304 TWh. These figures underscore the increasing significance and potential of RES in global power generation market [12].

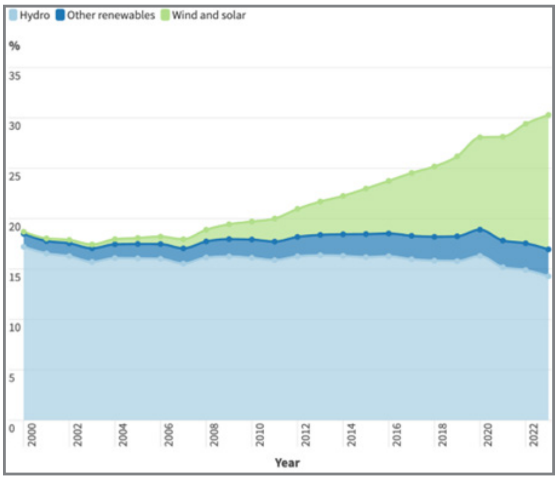

Figure 1.1: Level of electricity produced worldwide from renewable sources (%). Adapted by author, data [12].

The growth of renewable energy, mostly propelled by solar and wind energy, has significantly mitigated the growth rate of fossil fuels by approximately two-thirds over the past decade. The annual growth rate of fossil fuel generation, which was previously at an average of 3.5% from 2004 to 2013, decelerated to 1.3% from 2014 to 2023.

In 2023, the generation of electricity from fossil fuels was 22% less than the projected amount had the development of solar and wind energy infrastructure not taken place. From 2005 to 2023, the implementation of wind and solar energy systems has prevented the emission of 19 gigatonnes of CO2, which constitutes more than half of the total global CO2 emissions in 2023. This underscores the substantial contribution of RES in combating climate change and energy transition [12].

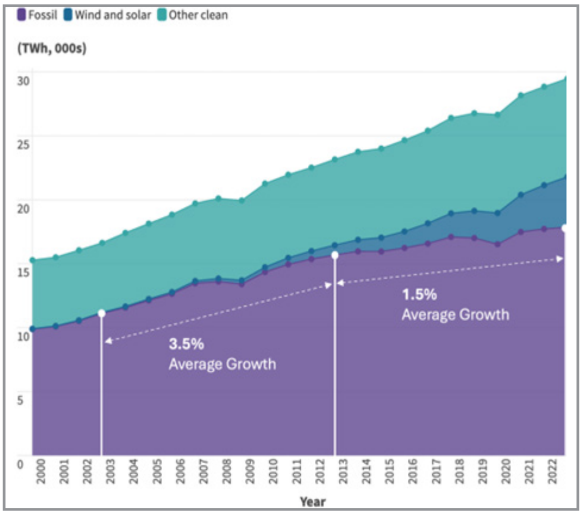

Figure 1-2: Level of power electricity produced globally from RES (TWh). Adapted by author data, [13].

More than fifty per cent of the globe's economies have grown back from their heights after more than five years since the peak of fossil fuel-based power production. The previous ten years have seen an approximate 25% decrease in emissions for these 118 power sectors. Together, they cover 43% of the global demand for electricity.

The pinnacle of many major economies occurred more than ten years ago. The biggest reductions in fossil fuel generation have occurred in European countries: the UK has had a 63% drop since 2008, Greece has seen a 57% drop (peaking in 2007), Spain has seen a 59% drop (2005), and Germany has seen a 42% fall (2007). The largest decreases have occurred most recently, at the same time when solar and wind power have become more widely used.

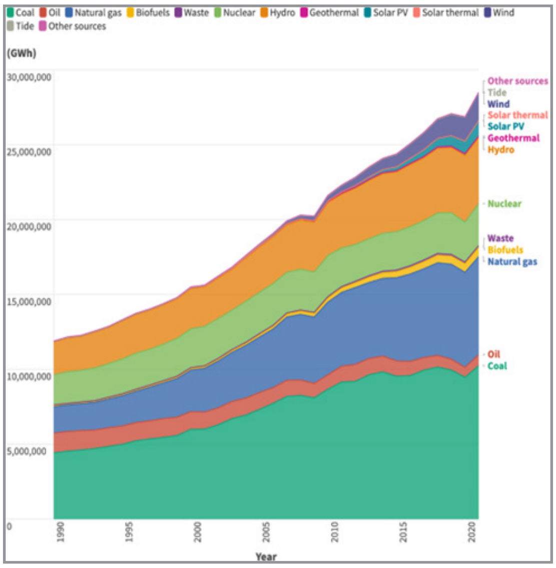

Figure 1.3: Global electricity generation by source, 1990–2021. Adopted by author [14].

In 2022, 30% of the world's power was generated by RES, projected to rise to nearly 50% by 2030 in the IEA scenarios analysis. While hydropower is currently the largest low-emission electricity source, contributing 15% of generation, its growth is constrained by high initial capital costs and site development limitations. Other renewables, including bioenergy, geothermal, concentrating solar, and marine power, also contribute, but wind and solar PV are the primary RET's to rollout for faster energy supply decarbonisation. Coal, currently the world's largest electricity source, accounting for 36% of the total, is surpassed by renewables by 2025 in all IEA scenarios.

The diffusion of new Renewable Energy Technologies (RETs) demands significantly fewer aggregate extractive resources than the current energy system. In the NZE Scenario, the energy system uses two-thirds less materials, fossil fuels, and essential minerals per unit of energy provided in 2050 than it does now. However, this doesn't eliminate energy and mineral security concerns, which may even intensify as the global energy sector undergoes transformation. Recent increases in clean energy expenditure have been focused on areas associated with clean electrification, particularly solar PV and other renewable power forms, and end-use electrification.

European Energy Overview

After falling by 3.6% in 2022, Europe's demand for electricity fell by 2.4% year over year in 2023. Due to the weak manufacturing and industrial activity as well as the slow macroeconomic climate, the majority of EU nations saw a decline in the demand for power. Nonetheless, diverse patterns of electricity demand were observed throughout the EU.

It is projected that throughout the 2024–2026 forecast period, Europe's power consumption would increase by 2.4% annually on average. This growth will be fueled by a slow but steady come back of industrial activity, more electrification of the transportation and heating sectors, and the growth of the data centre industry [12].

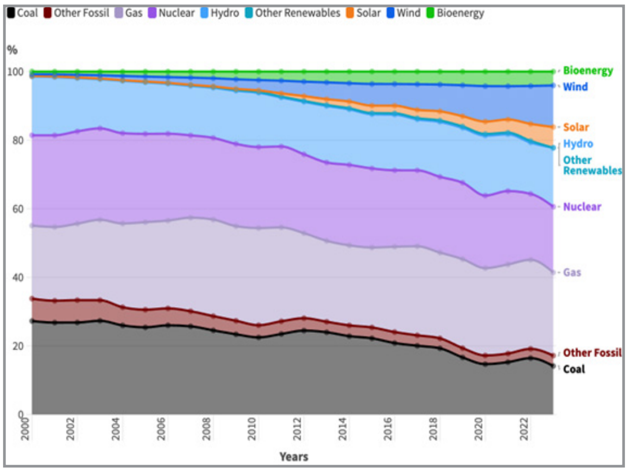

Figure 1.4: European power generation in % 2000–2023. Adopted by author [12].

The economic consequences are still being felt by consumers and companies, but the climate problem is becoming worse, in 2023 will be the second-hottest year on record in Europe. In light of this, switching to cost-effective renewable energy will be beneficial in several ways. While there are some indications that Europe is increasing its ambition and speed, delivery still needs to catch up with the EU's energy targets or its commitments to the global climate [15].

Targets established by the EU and its Member States have started to change in line with the prospect of an energy future dominated by RES as wind and solar PV hit new highs across Europe. According to the REPowerEU plan, by 2030, renewable energy will account for 72% of electricity generation, up from 44% in 2023 [5]. Wind and solar PV are the main drivers of this; they will increase from 27% in 2023 to 55% in 2030.

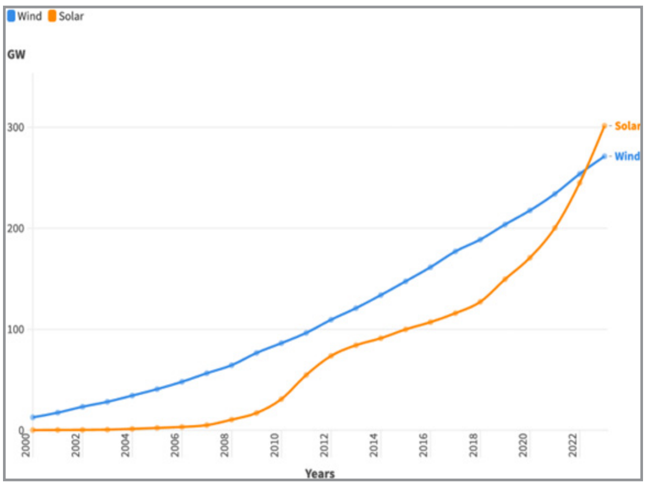

Figure 1-5: European installed capacity GW of wind and solar 2000–2023. Adopted by author [15].

In the meantime, the EU intensified its transition away from fossil fuels in 2023, setting records for emissions, petrol, and coal use. Less than one-third of the power generated in the EU comes from fossil fuels, which saw a historic 19% decline to their lowest point ever. For the first time, renewables surpassed 40% to reach a record 44% share. The expansion of RES was mostly driven by onshore and offshore wind and solar PV, which in 2023 produced a record 27% of the electricity in the EU and achieved their largest-ever annual capacity increases. In addition, wind power achieved a significant milestone by overtaking gas for the first time. Record of 90 TWh with more energy was generated by wind and solar PV combined, and 73 GW more capacity was constructed. With 56 GW of added capacity in 2023, solar continued its reliable rise, up from 41 GW in 2022 (+37%) [15].

European clean electricity future and with the states strong policy scenarios and regulatory support are crucial for driving the energy transition. Enhanced proposals in the RE Power EU plan and the European Wind Charter aim to strengthen targets, national plans, and auction designs to overcome barriers in the wind sector. These initiatives reflect the political will needed to achieve the ambitious clean energy goals.

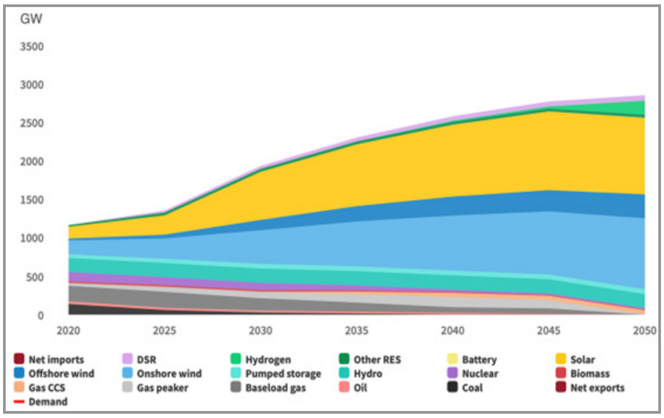

Figure 1-6: European future clean electricity installed capacity GW, based on stated strong policy scenario 2020 - 2050. Data source [15].

The "Pathway Based on Current Stated Policies by European Countries" graph from Ember's European Clean Power Pathways Explorer provides a detailed projection of the installed capacity of various energy sources from 2020 to 2050 under the current national policies of European countries. This projection highlights significant growth in renewable energy capacities, particularly in solar and wind power. Solar capacity is set to increase dramatically, reflecting robust policy support and technological advancements that reduce costs. Onshore and offshore wind capacities are also projected to rise substantially, driven by enhanced policy frameworks and investment commitments such as those outlined in the REPowerEU plan.

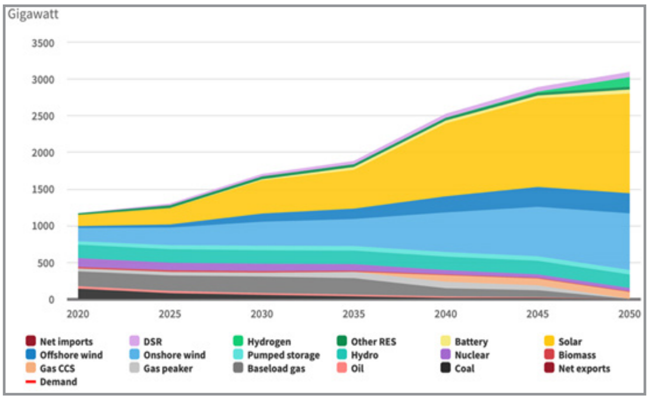

Figure 1-7: European future clean electricity installed capacity GW, based on technology driven scenario 2020 - 2050. Data source [15].

The diffusion of renewable energy technologies by European countries could influence their transition to clean power systems. As illustrated in the "Technology Driven scenario" graph Fig. 1-7, is significantly shaping the clean power pathways in Europe if this scenario is chosen. The graph shows a significant increase in solar and wind capacities over time. By 2050, these renewable energy technologies are expected to constitute a major portion of Europe's energy mix. This indicates that the diffusion of solar and wind technologies is playing a crucial role in shaping Europe's clean power pathways. This transition is driven by technological advancements, in mix with supportive policies, and the overarching goal of achieving climate neutrality.

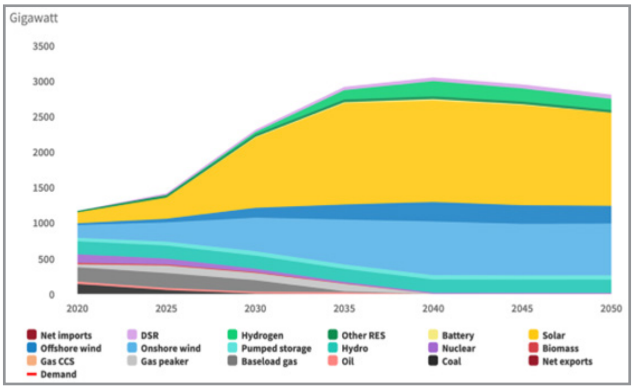

Figure 1-8: European future clean electricity installed capacity GW, based on system change scenario 2020 - 2050. Data source [15].

Change scenario is the route that complies with the baselines of CAN Europe's Paris Agreement Compatibility scenario (1.5C). It is compatible with a net-zero energy sector by 2040 and has the greatest energy-saving and electrification goal.

The "System Change" scenario depicted in the Ember analysis, with data shown in Figure 1-8 projects a substantial transformation in Europe's energy landscape from 2020 to 2050, emphasizing a shift towards renewable energy sources quicker towards neutral zero in 2040. The scenario illustrates a marked increase in the installed capacity of onshore and offshore wind, as well as solar energy, underscoring the pivotal role these technologies will play in achieving carbon neutrality. Concurrently, there is a decline in the capacity of fossil as coal, oil, and gas plants, reflecting a strategic move away from carbon-intensive energy sources. The scenario also highlights the stabilization of nuclear energy capacity, suggesting its limited expansion in the future energy mix. Additionally, the increasing capacities for hydrogen and battery storage indicate the rising importance of these technologies in ensuring grid stability and accommodating the intermittent nature of renewable energy.

This transition is further supported by a decrease in net imports, pointing towards enhanced energy self-sufficiency, and the implementation of demand-side response measures to manage consumption peaks. The scenario emphasizes the necessity of substantial investments in energy storage solutions and grid infrastructure to facilitate the integration of renewable energy. Moreover, the emergence of hydrogen as a significant component of the energy system signals its potential to decarbonize sectors that are difficult to electrify.

Research Objectives & Questions

The problem surrounding the formulation of this thesis arises from the observation that the Western Balkan nations are not making significant progress in adopting renewable energy per capita, despite experiencing fast economic development and growing energy demands. The sector experiences early adopter's disadvantages in both the commercialization and market expansion stages of renewable energy technologies. Additionally, the absence of effective and well-defined laws and regulations poses challenges in scaling up renewable energy technologies.

This research intends to use the diffusion innovation models to conduct an analysis of the development and adaptation of RET's for solar photovoltaic (PV) and wind energy in the Western Balkan (WB-6) region. This region is characterized by early-stage development in these technologies; the research will also compare this diffusion process with another EU country which has advanced more in adapting these technologies like Germany.

Several scholars have identified a country's innovation performance as a key driver for economic development [17]. However, much of the existing research adopts a broad perspective, examining how policies, for instance, influence national innovative performance in general terms, or how this diffusion of innovation helps in creating new enterprises in the sector. This methodology emphasises the necessity of doing a more comprehensive examination of an entire country's innovation system. As [18] points out, Technology-based systems have a big influence on how innovations are developed, shared, and used in an economy. Quantitative question remains to be answered: to what extent have renewable energy technologies (RET's), solar PV and wind diffused throughout the WB6 region?

To solve this Question, Research Objectives were Created

- **Quantitative:** The objective of this study is to utilize the diffusion models to determine the specific stage or phases of the diffusion of the innovation process in which RET's are situated on the S-curve. Additionally, the aim is to project the rate of adoption of both of these technologies in the WB6 area over the course of the next ten years and compare the results with other countries Germany.
- **Qualitative:** To ascertain the various categories of initiatives, technology, innovative companies created, and challenges associated with renewable energy policy barriers. This study aims to examine a qualitative analysis of the barriers of the current market and the impact of policy and regulation on the rapid development of RET's in Western Balkan countries, specifically focusing on photovoltaic (PV) solar and wind technologies.

The results will be helpful for many parties in understanding potential elements that lead to system dropout. Western Balkan economies may use this data to create and implement initiatives aimed at reducing these barriers and accelerating the adoption of renewable energy technologies.

Significance of the Research

According to (WBIF), the energy economy in the Western Balkans is experiencing a split change never seen before. It includes a transition from previously state-dominated, centralised systems to ones that are free and competitive in the market. Simultaneously, there is a crucial shift towards decarbonisation, signifying a major paradigm shift in the industry [19].

EU institutions have been supporting the gas development in the Western Balkans opposing the EU's intentions to reduce the European emissions to net zero by 2050 [16], replacing imports of gas with renewable energy, and welcoming the Western Balkans within the union [20].

Building additional fossil fuel-fueled thermal power plants and gas infrastructure would be moving backwards for the Western Balkan economies, who are already struggling with power deficits, net-zero objectives, and EU membership expectations. This region offers great possibilities for renewable energy sources including solar and wind energy, as well as chances with the region's three times higher energy intensity than the EU [21]. In addition to easing the region's energy transition, an increased investment in renewable energy from various sources combined with energy-saving measures would help safeguard the Western Balkans against two major risks: fluctuations in global energy markets and the collapse of regional energy enterprises.

The diffusion of RET's in the Western Balkans is of paramount importance due to several interrelated factors. Primarily, it mitigates the region's significant reliance on coal, which contributes to severe environmental degradation and public health concerns through high pollution levels in order to reduce greenhouse gas emissions and improve air quality, adopting renewable energy sources like wind and solar power is crucial. This will support regional and global decarbonisation initiatives, especially those set forward by the EU. This transition not only enhances energy security and economic stability by diversifying energy sources but also attracts investment from both domestic and international actors. Furthermore, the strategic support provided by the EU through various funding mechanisms and policy frameworks underscores the critical geopolitical and environmental imperatives of advancing renewable energy adoption in the Western Balkans.

Scope and Limitations

This thesis aims to examine initial diffusion of renewable energy technologies (RETs), specifically wind and solar PV, within the Western Balkans countries (WB6). It will draw a comparative analysis with nations such as Germany, where the diffusion of these RETs has reached a point of saturation will provide a benchmark for assessing the WB-6 region's progress. This analysis will be conducted by employing diffusion models with outputs of the S-curve, predicated on the installed capacity of RETs in megawatts (MW), the prevailing energy policies, pertinent to solar photovoltaics (PV) and wind energy.

This research is subject to several limitations, like data availability: the analysis is contingent upon the availability and reliability of data regarding the installed capacity of RETs, energy policies, in the WB-6 region, in which some of the data will be updated by data of TSO (Transmission System Operators) with the purpose of this thesis as many official data of installed RET's capacities are until 2022.

- **Other limitation will be model constraints:** the bi-logistic and Gompertz diffusion models will be used, while robust, may not capture all nuances of the diffusion process, particularly in regions with complex socio-economic dynamics like the WB6.
- **Limitation regarding comparative analysis:** where the comparison with Germany may be limited by the differing stages of economic development and energy infrastructure between the two regions one as the leading European economy and WB6 the last European emerging economy to follow.
- **Policy and Regulatory Framework Limitations:** as the study assumes that current policies and regulations will remain relatively stable over the next decade, which may not account for potential shifts in the political or geopolitical and economic landscape that will barrier more the energy green transition towards application of RET's.
- **Limitations in scope of innovation:** the focus on solar PV and wind energy excludes other forms of RETs, which may be important in the region's energy transition, such as hydropower, hydropower pump storage, battery storage, biomass, etc.
- **Economic and Market Factors limitation:** this research does not extensively cover the economic viability and market forces that could influence the adoption and diffusion of RETs in the WB-6, even though we will touch some energy economics which has influenced the adoption of this new technologies.
- **Geopolitical Considerations:** While the study acknowledges the EU's influence, it does not fully explore the geopolitical implications of energy transitions in the WB6 which are very sensitive.

Literature Review

Solar and wind technologies

Solar PV Technology

PV technologies have become widely accepted and technologically mature, with the market growing at an impressive rate of 34% annually from 2010 to 2020. The efficiency of PV cells has significantly improved over the years, with monocrystalline cells being the most efficient, followed by polycrystalline cells. Laboratory-scale cells can achieve efficiencies up to 46% under ideal conditions [22].

- **Monocrystalline and Polycrystalline PV Systems:** These are the first-generation PV cells, suitable for various applications and sizes, including large grid-connected installations, and are widely accepted globally due to their efficiency and reliability.
- **Thin-Film PV Systems:** These second-generation PV technologies, such as CdTe and CIGS, require further research and development to achieve commercial and technical acceptance, with challenges including raw material availability and environmental issues.
- **Perovskite PV Systems:** These are among the promising third-generation technologies, with laboratory-scale efficiencies reaching 23.3%, but they still need significant advancements to reach commercial viability [22].

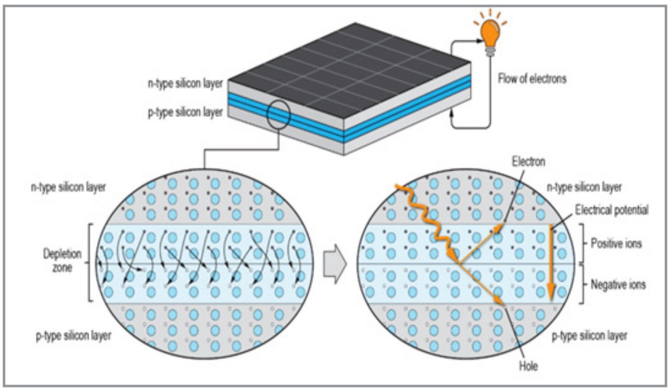

Figure 2-1: A solar cell n-p-type layers [23].

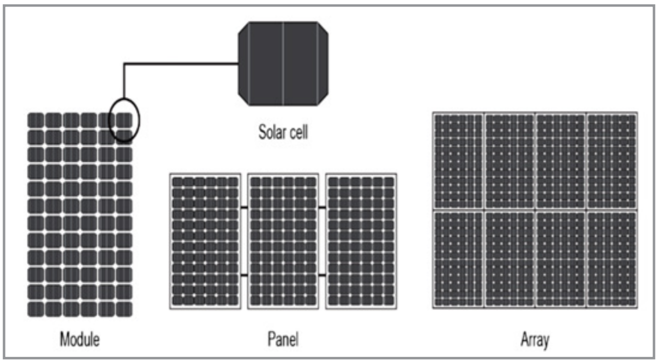

Figure 2-2: Schematic of solar cell, module, panel, and array systems [23].

Solar panels utilize the photovoltaic effect to convert sunlight into DC electricity, which is then optimized by a DC-DC converter for efficient power transfer. This DC is transformed into AC electricity by the inverter, aligning with the standard electrical systems in national transmission and distribution grid. The AC can be used immediately, stored in batteries for later use, or even fed back into the power grid, potentially earning income and improving energy efficiency. This system ensures a reliable power supply, regardless of sunlight availability [24].

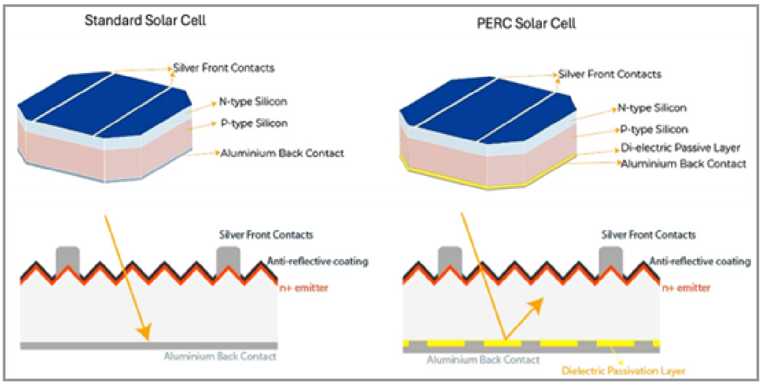

Figure 2-3: Example of PERC solar cells, are known for their higher efficiency, typically achieving around 20-22% efficiency [25].

The future of photovoltaic (PV) technology is characterized by significant advancements aimed at enhancing efficiency, reducing costs, and expanding the applicability of solar cells. Crystalline silicon solar cells, particularly those utilizing advanced techniques such as disrupted emitter back cell technology and PERC, continue to dominate the market due to their high energy conversion efficiencies and robustness in various climates.

Concurrently other photovoltaic cells innovation like thin film technologies, leveraging materials like CdTe, CIGS, and quantum dots, promise reductions in material usage and production costs while enabling the creation of flexible and lightweight solar cells. Perovskite solar cells, with efficiencies surpassing 25%, and III-V multijunction solar cells, known for their high efficiency in specific applications such as space and concentrated solar power, represent significant breakthroughs poised to further elevate the performance and economical feasibility of PV systems.

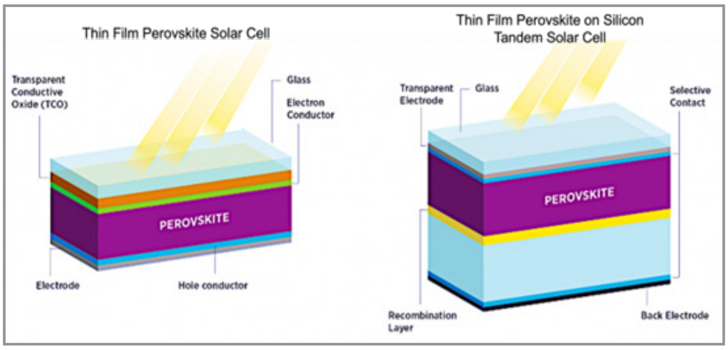

Figure 2-4: Example of Perovskite solar cells, [26].

In addition to these technological innovation, the trend towards flexible and lightweight solar cells is expanding the potential applications of PV technology, including in wearable electronics and portable systems. Market dynamics reflect a dramatic decrease in the cost of silicon photovoltaics, fostering wider adoption of PV solar energy. Furthermore, future PV technologies are prioritizing sustainability by aiming to minimize material use and lifecycle emissions, thus mitigating environmental impact. These continuous improvements and innovations underscore the increasingly pivotal role of solar energy in the global energy landscape [27].

The total cumulative PV installations amounted to about 1,581 GWp according to IEA-PVPS at the end of year 2023; IRENA reports 1,412 GWp. In Figure 2-3 (a), are shown in percentages global installed PV capacity, including off-grid systems. The innovation efficiency of crystalline Silicon(c-Si) wafer-based modules is 21.6% in Q4-2023 Figure 2-3 (b), where many global companies are investing in R&D to develop next technology in PV cells with the highest efficiency and economic feasibility [28].

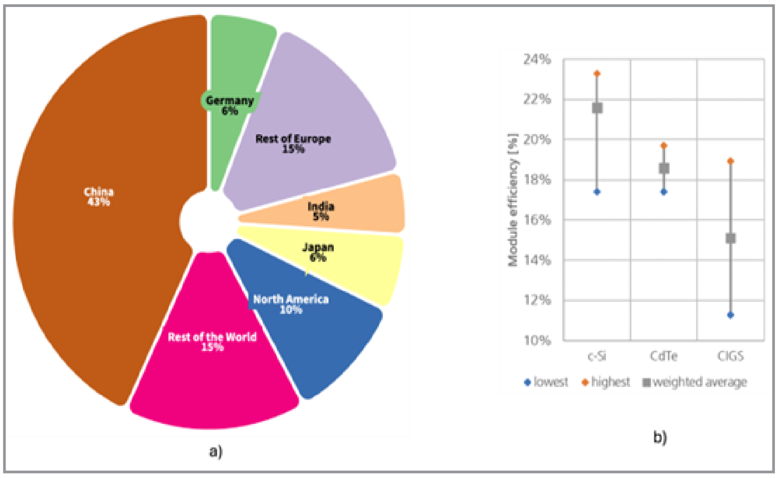

Figure 2-5: a) Global Cumulative PV Installation by Region 2023 in %, b) Efficiency of PV Commercial Modules. Adapted by author, data by [28].

Photovoltaic (PV) systems have seen remarkable advancements in efficiency and technology over the years. The performance ratio of PV systems has significantly increased from around 70% before the year 2000 to a robust 80-90% today, reflecting the substantial improvements in performance. Up to date, laboratory records have documented record efficiencies for various PV technologies: mono-crystalline silicon cells have reached 26.8%, multi-crystalline silicon cells at 24.4%, Copper Indium Gallium Selenide (CIGS) at 23.4%, Cadmium Telluride (CdTe) at 21.0%, and Perovskite at 25.2%. In the commercial sphere, the average efficiency of crystalline silicon modules stood at 21.6% in the fourth quarter of 2023, with the highest module efficiency recorded at 23.3% [28].

In terms of technological innovation, mono-crystalline silicon technology has taken the lead, becoming the dominant form of PV technology, while multi-crystalline technology is gradually being phased out. This shift is indicative of the ongoing technological evolution within the PV industry. Moreover, the Energy Payback Time (EPBT) for a PV system for example located in Sicily using silicon modules is approximately one year. This means that such a system is capable of producing twenty times the energy required for its manufacture over its projected 20-year lifespan, underscoring the sustainability and long-term benefits of investing in PV technology.

Wind Technology Offshore and Onshore

The development of wind energy technology is evidence of human creativeness and the continuous search for environmentally friendly energy sources. Over years, wind power has transitioned from a supplementary energy source to a cornerstone of renewable energy portfolios worldwide. [29] elucidates the rapid advancements in wind power, highlighting the global installation of 77.6 GW of new power capacity in 2022 alone. This surge has propelled the total installed wind capacity to an impressive 906 GW. Europe's reliance on wind energy is particularly noteworthy, with wind power accounting for 17% of the continent's electricity consumption in 2022, and an astonishing 55% in Denmark. The article underscores the decreasing levelized cost of energy (LCOE) for wind power, asserting its growing competitiveness as an energy technology.

The development on wind technology further extends to the domain of onshore wind farms, as explored by Haces-Fernandez [30] provides a holistic perspective on the multifaceted factors influencing wind energy development, ranging from technological advancements to financial viability, environmental concerns, and government incentives. The authors advocate for a comprehensive approach that considers all critical factors to ensure the continued growth of wind energy. This growth is supported by stakeholders' holistic considerations, as evaluated in the review, which posits that wind energy may continue to expand globally as long as these factors are meticulously addressed.

The academic community is working together to more effectively and sustainably harness wind power, which will pave the way for a day when wind and other RES are essential to supplying the world's energy needs..

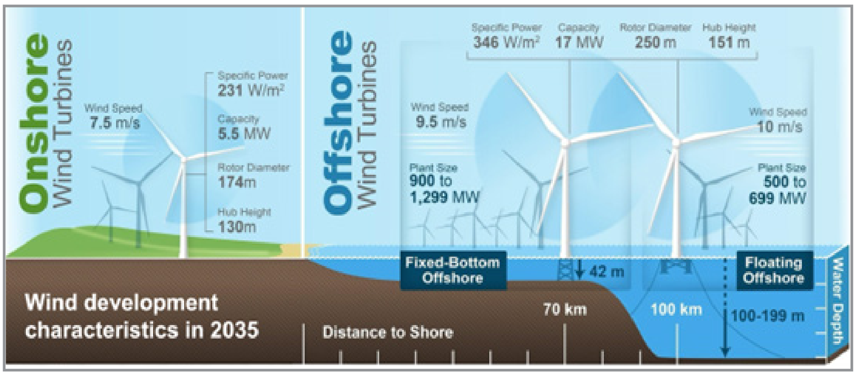

Figure 2-6: Main characteristics of the wind plants of the future [31].

The contemporary landscape of wind technology is characterized by a suite of innovations aimed at enhancing turbine performance and expanding operational terrains. These advancements include the creation of larger, more efficient blades, the utilization of advanced materials, and the implementation of sophisticated control systems to maximize energy capture, even in low wind conditions. The shift towards offshore wind farms exploits the more potent and consistent winds at sea, yielding greater energy production. Floating wind turbines represent a novel solution for deep-water areas beyond the reach of traditional turbines, thus increasing the potential locales for harnessing wind energy. The anticipated integration of wind power with smart grids heralds a future of improved energy management and grid stability. Concurrently, research is dedicated to reducing the environmental and visual impact of wind farms, addressing noise concerns, and safeguarding wildlife, thereby enhancing social acceptance and ecological harmony. Collectively, these efforts reflect a holistic approach to advancing wind energy technology while being cognizant of environmental and societal implications [31].

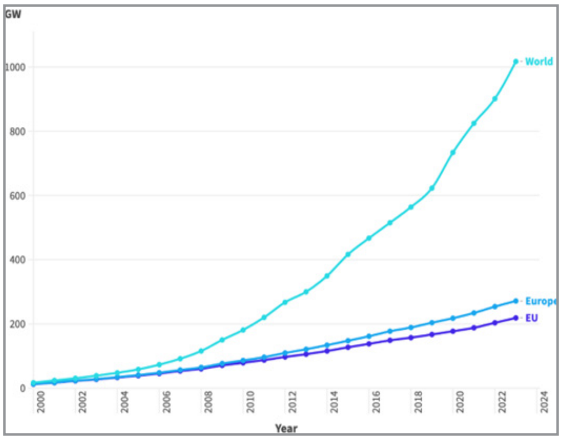

Figure 2-7: Wind installed capacity in GW for EU-27, Europe and World to year 2023. Adapted by author, data [15].

In the report [32] shows that in 2022 the European wind industry, with an annual turnover of €69 billion, significantly contributed to the EU economy, with nearly 60% of this revenue fostering internal economic growth. The sector's direct impact on the EU

GDP was €41.8 billion, with €26.3 billion originating from wind energy developers and manufacturers, and an additional €15.5 billion generated through indirect economic activities. The installation of wind energy capacity proved economically beneficial, with each GW of onshore and offshore wind contributing €2.2 billion and €2.5 billion to the EU economy, respectively. Furthermore, the industry maintained a stable employment rate, supporting 300,000 jobs in the EU, and exhibited a productivity level that surpassed the EU average.

Despite a decrease in research and innovation investment from 5% to 3.12% in 2022, the wind industry's expenditure remained above the EU's target of 2.3% of GDP. However, the number of patents filed in Europe for wind energy technology plummeted to a historic low, with only 83 patents registered in 2021. On an environmental note, wind energy generation in 2022 prevented the release of 138 million tons of CO2, equivalent to €11.5 billion based on EU emission allowance prices. During the energy crisis, wind energy also mitigated the need for fossil fuel imports, saving the EU approximately €71 billion. Under the REPowerEU plan, the wind industry is expected to contribute €104.2 billion to the EU GDP by 2030 and employ 936,000 people, underscoring its escalating importance in the EU's economic and environmental framework. Also the [33] analysis that EU funding for wind energy Research and innovation is recovering but remains low. The EU Joint Research Centre reports that the EU's financing for wind energy has only recently increased from less than €30 million, the lowest level in the previous five years. Wind energy was awarded around €70 million in 2022.

Diffusion of Innovations

Everett M. Rogers' diffusion of the innovation theory offers an approach to comprehending how novel concepts and cutting-edge technology grow throughout social economies. This theory has been also applied to renewable energy technologies, in some extend particularly wind and solar, as these technologies represent critical innovations for addressing climate change and achieving sustainable energy systems worldwide.

The spread of renewable energy technologies in emerging markets is a complex process influenced by various factors, including economic, social, cultural, geopolitical and countries internal political dynamics. The diffusion of innovations within the realm of (renewable energy technologies, ideas, products), in our case particularly wind and solar technologic products, is a complex process that individuals of a social system go through, affected by a variety of events and expressed through a variety of channels throughout time [34].

Rogers [34] discussed many diffusion components:

- **Innovation:** A concept, item, or method that a person or other unit of adoption social system perceives as novel is called an innovation. For an invention to be embraced by members of a social system, it must provide some sort of perceived benefit or enhancement over current possibilities. In our case novel idea is introduction of RET's (solar PV and wind) that stakeholders (social systems) perceive as novel. These technologies must demonstrate a clear comparative advantage and superior performance relative to the current nuclear, fossil fuel or other energy solutions to achieve widespread acceptance within a societal framework.
- **Communication:** These are the channels via which members of the social system are informed about the invention (renewable energy innovations). Mass media, face-to-face interactions, and digital platforms are examples of effective communication channels that aid in raising awareness and educating people about innovations.
- **Time:** The length of time it takes for innovations (RETs) to become integrated in a social system is the subject of the time factor. This comprises the time it takes for an invention to achieve critical mass in society or developing economies, the innovation-decision process, and the relative growing at which adoption happens.
- **Social System:** The social system is the community or group of individuals among whom the innovation is diffused. The structure, norms, policies of the social system, including social networks and opinion leaders, policy makers, external players have a crucial role in influencing the adoption process.

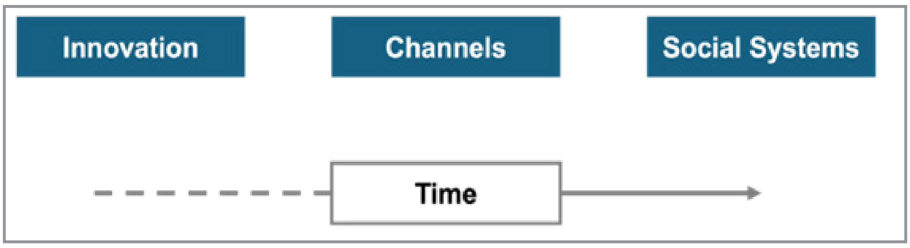

Figure 2-8: Rogers graph of four elements of diffusion of innovations.

In [35] further said that the process of new goods and services spreading throughout a market due to customer interactions and impact on society is known as diffusion of innovation. These social influences include all the ways consumers affect each other, whether they are aware of it or not, such as through word-of-mouth, network externalities, and social influences. The diffusion process has become more complex over time due to the variety of influences consumers are exposed to, including online social networks and global market trends. Understanding how consumers interact and influence each other is crucial for modelling the spread of innovations and predicting their market growth.

To enhance the diffusion of renewable energy technologies [36] who analyzed the acceptance of wind energy, identifying main trends, causal factors, and lessons learnt from 20 years, address the complex factors influencing social acceptance and to more successfully include communities in the process of making decisions.

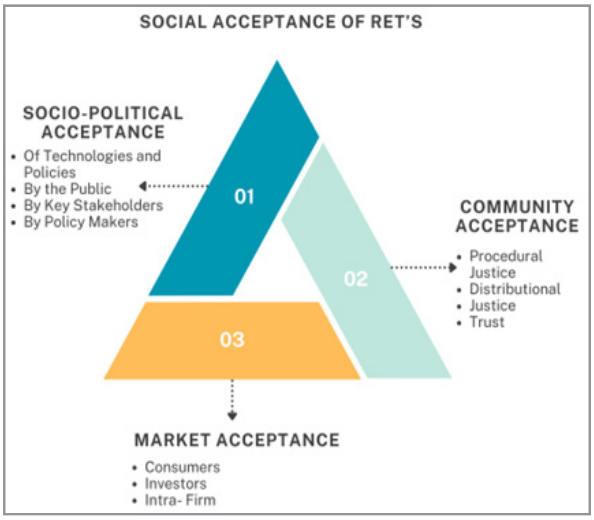

Figure 2-9: Triangle of social acceptance of RET's innovation adapted after [37].

In [36] according to their analysis, societal approval has a critical role in determining the success and rate of adoption of renewable energy technologies, such as wind energy. This depends on a number of variables, such as the project's features, how the expenses and benefits are seen, and how much the public participates.

In [38] evaluated the link between technological innovation and renewable energy in the G10 countries, as well as the relationship between innovation and economic growth. They found that technology innovation significantly impacts renewable energy in countries with a strong innovative base and substantial R&D spending. However, the causation from technology innovation to renewable energy development is not uniform across all countries.

In [22] the paper examines the arguments for and against demand-pull and technology-push strategies in the renewable energy sector. In order to increase the efficacy of clean energy policies, they contend that a variety of policy tools are required. Their conclusions point to different effects on the generation and spread of innovation for public R&D expenditures, renewable energy guidance policies, and per capita income.

The diffusion of wind and solar technologies is a dynamic process driven by a combination of technology-push and demand-pull elements. While innovation and economic growth play critical roles, overcoming barriers to diffusion is essential for the widespread adoption of these technologies. The communication of these innovations through various channels over time facilitates their acceptance and integration into the social system, ultimately contributing to the transition towards sustainable energy.

In [39] examines the impact of technological innovation, energy consumption, and financial development in BRICS countries from 1990 to 2018. According to the study, long-term environmental quality declines due to the diffusion of technology and non-renewable energy use, while environmental sustainability is greatly enhanced by renewable energy and technological innovation. The Environmental Kuznets Curve (EKC) theory, which assumes that environmental degradation rises with economic expansion initially but eventually decreases after reaching a certain level of income. It provides policy recommendations, suggesting that governments should promote technological innovation and renewable energy consumption to enhance environmental quality and achieve sustainable development goals (SDGs).

Models of Technological Diffusion

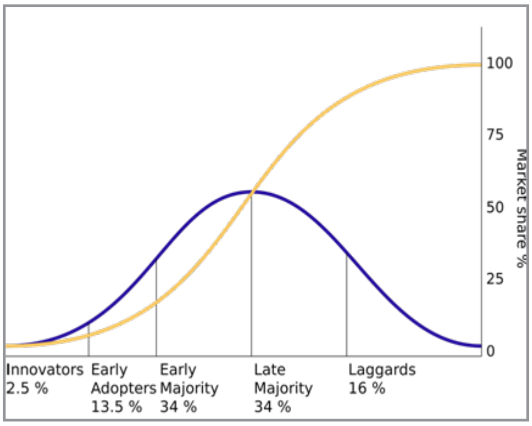

Figure 2-10: The spread of innovations Rogers Graph.

Diffusion models forecast the rate and extent to which members of a social system will accept new concepts or technologies, considering factors like communication channels and social influence [34]. These models identify the different stages that individuals go through when deciding whether to adopt an innovation, such as becoming aware of it, showing interest, evaluating it, trying it out, and finally adopting it.

Diffusion models also predict how social networks and relationships influence the adoption process, highlighting the role of opinion leaders and the concept of critical mass in speeding up the spread of innovations. They explain why some people or groups adopt new ideas earlier than others, taking into account individual differences and the specific characteristics of the innovation.

In [34] noted that when the total number of adopters is charted over time, the cumulative diffusion time path of an invention is frequently represented by an S-shaped curve, showing a slow start initially, only a few people (early adopters) take up the innovation, but as more people see its benefits will result in a rapid growth, and then a levelling off as most potential adopters have adopted the innovation, after which it slows down as fewer people are left to adopt it.

Diffusion of innovations, models can be classified into discrete and continuous types, each offering unique insights into the adoption process. Discrete diffusion models, unlike continuous ones, analyze the adoption at specific intervals, thereby emphasizing the distinct stages of the diffusion process. Researchers have considered discrete models are particularly adept at capturing the granularity of the adoption process, because they are able to clearly follow the development through a number of phases, including awareness, curiosity, assessments, trials, and adoption [34]. Continuous diffusion models, on the other hand, assume that adoption happens smoothly and steadily over time without distinct stages or breaks in the process. Discrete models look at adoption as happening in chunks or steps, while continuous models see it as a flowing process without clear stages [40].

The basic diffusion model makes the assumption that there is a set total number of prospective adopters in a social system, indicating that the population size does not fluctuate over time [41]. The fundamental diffusion model, which provides a mathematical framework for comprehending how novel concepts, ideas, or behaviours move within a social system, is a cornerstone in the study of innovation diffusion. This model is central to diffusion theory and has been extensively studied and applied across various disciplines, including sociology, marketing, and technology management.

In diffusion models, the process is described as discrete rather than continuous, reflecting a lack of concern for the many stages of the diffusion. The primary diffusion model makes the assumption that the maximum number of adapters in the social system is represented by a set carry capability (N). This capacity is seen as both obvious and unchangeable, leaving the model static; the social system's size is assumed to remain constant during the diffusion process, as highlighted by [41]. Furthermore, the model only allows for one adoption event per invention, ignoring the possibility that an adopter would subsequently abandon the innovation, the model does not accept changes to the invention along the course of the diffuse.

The systematic utilisation and analysis of diffusion model findings require a thorough comprehension of both the conceptual framework and the mathematical foundations, which are often embodied in a differential equation:

$$\frac{dN(t)}{d(t)} = g(t)[m - N(t)], \quad N_{t=t_0} = N_0 \quad \text{Equation (2-1)}$$

Where:
m = total prospective adopters in the social system at a given moment (t)
N(*t*) = total adopters at time (t) cumulatively
N(*t*)=∫_(t_0)^t▒n(t)dt,n(t)
N_0=" cumulative adopters at time " t_0

$\frac{dN(t)}{dt}$ = diffusion rate at time " t

N_0="number of cumulative adopters at time " t_0
g(*t*) = represents the rate of adoption
N̅ =total prospective adopters in the social system at a given moment t

Cumulative Adoption N(t) denotes the total number of people who, as of time t, accepted the invention. It is a function of time and typically follows an S-shaped curve, characteristic of many diffusion processes.

Rate of Adoption g(t) represents the adoption rate, which can vary over time. This function is crucial as it captures the changing dynamics of the adoption process. In many models, g(t) might be influenced by factors such as advertising, word-of-mouth, and the innovation's perceived utility.

Market Potential (m): is the saturation level or the total market potential. It represents the greatest number of adopters that the population can have. This parameter is critical as it sets an upper limit to the cumulative number of adopters.

Unadopted Population m-N(t)is a representation of the untapped market or the amount of people who have not yet embraced the invention. This residual market potential diminishes over time as more individuals adopt the innovation.

Equation 2-1 demonstrates the gap between the number of individuals who might still endorse an invention and the number of people who are currently using it impacts how quickly an innovation propagates at any given time (t) [N¯- N(t)].

Growth Rate: According to the equation, this is the rate at which the number of adopters is growing (dN(t))/dt is a function of the residuals market potential m-N(t) and the diffusion rate, g(t). This reflects the idea that the adoption rate is higher when there are more potential adopters left in the market and decreases as the market becomes saturated.

Dynamic Nature: The function g(t) can vary, capturing the dynamic nature of the adoption process. For example, g(t) might start low, increase as the innovation gains popularity, and then decrease as the market approaches saturation.

To represent g(t), two distinct methods have been used. g(t) has been represented as a function of time in one method, and as a function of the number of previous adopters in another. This case uses the latter strategy as it is significantly more frequent. In particular, g(t) can be expressed as an cofficent of N(t):
g(t)=a+b N(t)+c N(t)^2+…
g(t) can be represented for simplified purpose as:
External Model: g(t)=p
Internal Model: g(t)=qN(t)
Mixed Model: g(t)=p+qN(t)

Here a and b are the coefficients of the model or parameters. Adding *g*(*t*) to the equations above provides various diffusion models.

For g(t)=a ; basic diffusion model can be expressed:

$$\frac{dN(t)}{dt} = p[m - N(t)]$$ Equation (2-2)

this version is external-influence diffusion model.

The explanation of the external-influence diffusion model's coefficient (a) is provided by [42] represents the rate of adoption due to external factors. Regardless of how many prior adopters there are in the social system, these outside forces have an equal and consistent impact on prospective adopters. The main outside factors that impact the invention include advertising, mass media campaigns, and other external communication channels. In [42] model emphasizes the importance of mass media and other external communication in the early stages of diffusion.

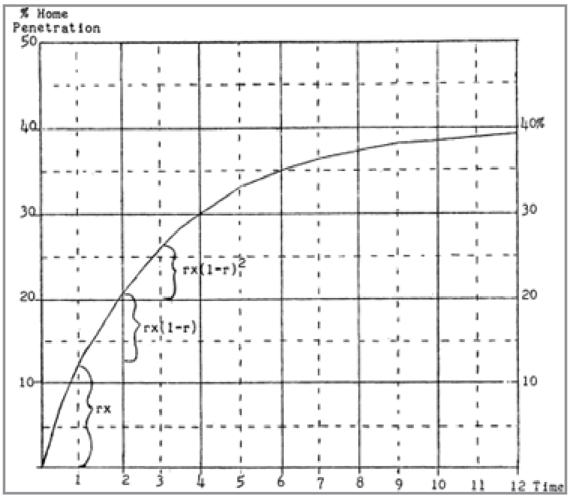

Figure 2-11: Sale curve forecast. Source: (Fourt and Woodlock, 1960)

In [42] forecasted the sales, where the saturation threshold is 40% in Figure 2-11, shows that while the cumulative number of adopters grows over time at a constantly falling pace, the curve does not have an inflection point.

Secondly, g(t)=bN(t) the basic diffusion model is represented by:

$$\frac{dN(t)}{dt} = q(N(t))[m - N(t)]$$ Equation (3-2)

Known as the internal diffusion model, with the most known model the Gompertz model.

Thirdly, *g*(*t*)=(a+*bN*(*t*)) the basic diffusion model is represented by:

$$\frac{dN(t)}{dt} = (p + qN(t))[m - N(t)]$$ Equation (4-2)

The reason this model is called the mixed-influence diffusion model is that it simulate equations 2-2 and 3-2, and uses internal and external influences in one model. The best model that uses this approach is Bass Model [41].

Within the field of diffusion research, the internal-influence model suggests that social system interactions are the primary driver of innovation spread; yet, it may not account for the significant impact of external factors like the media and outside actors. Conversely, the mixed-influence model takes into account both internal and external variables, but it has difficulty accurately measuring and balancing these influences. This is especially limited in real-world scenarios where there is a lot of variation in the relative impact of internal and external factors. This complication emphasises how challenging it is to apply a generic model to the multifaceted process of invention diffusion. It might be due to this lack of adaptability that certain models work well in some situations but not others. Researchers studying the spread of innovation have proposed variable diffusion models (Figure 2-12) as a solution to the identified shortcomings.

Model	Model Equation ($\frac{dF}{dt}$ =)	Model Solution (F =)	Point of Inflection (F*)	Symmetry[a]	Coefficient of Internal Influence	Illustrated Reported Applications
1. Bass (1969)[b]	$(p + qF)(1 - F)$	$\frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}}$	.0–.5	NS	Constant	Consumer durable goods; retail service, agricultural, education, and industrial innovations; electronics, photographic products, industrial processes
2. Gompertz curve[c] (see Hendry 1972; Dixon 1980)	$qF \ln\left(\frac{1}{F}\right)$	$e^{-e^{-(c+qt)}}$	.37	NS	Constant	Consumer durable goods, agricultural innovations
3. Mansfield (1961)	$qF(1 - F)$	$\frac{1}{1 + e^{-(c+qt)}}$	.5	S	Constant	Industrial, high technology, and administrative innovations
4. Floyd (1962)	$qF(1 - F)^2$	*	.33	NS	Decreasing to zero	Industrial innovations
5. Sharif and Kabir (1976)[d]	$\frac{qF(1 - F)^2}{1 - F(1 - \sigma)}$	*	.33–.5	S or NS	Constant or decreasing to zero	Industrial innovations
6. Jeuland (1981)[e]	$(p + qF)(1 - F)^{1+\gamma}$	*	.0–.5	S or NS	Constant or decreasing to zero	Consumer durable goods
7. Nonuniform influence (NUI) (Easingwood, Mahajan, and Muller 1983)	$(p + qF^{\delta})(1 - F)$	*	.0–1.0	S or NS	Increasing, decreasing, or constant	Consumer durable, retail service, and education innovations
Nonsymmetric responding logistic (NSRL, p = 0 in NUI) (Easingwood, Mahajan, and Muller 1981)	$qF^{\delta}(1 - F)$	*	.0–1.0	S or NS	Increasing, decreasing, or constant	Medical innovations
8. Nelder[f,g] (1962; see McGowan 1986)	$qF(1 - F^{\phi})$	$\frac{1}{[1 + \phi e^{-(c+qt)}]^{1/\phi}}$	.0–1.0	S or NS	Decreasing to a constant	Agricultural innovations
Von Bertalanffy[h] (1957; see Richards 1959)	$\frac{q}{1 - \theta} F^{\theta}(1 - F^{1-\theta})$	$[1 - e^{-(c+qt)}]^{1/1-\theta}$	.0–1.0	S or NS	Decreasing to a constant	
9. Stanford Research[i] Institute (e.g., Teotia and Raju 1986)	$\frac{q}{t} F(1 - F)$	$\frac{1}{1 + \left(\frac{T^*}{t}\right)^q}$	.0–.5	NS	Decreasing to zero	Energy-efficient innovations
10. Flexible logistic[j] growth (FLOG; (Bewley and Fiebig 1988)	$q[(1 + kt)^{1/k}]^{\mu-k}$	$\frac{1}{1 + e^{-(c+qf(\mu,k))}}$	.0–1.0	S or NS	Increasing, decreasing, or constant	Telecommunication innovations

Figure 2-12: Flexible Diffusion Models [43].

Western Balkans Renewable Energy, Policy and Innovation Index

Large coal-fired power plants (THPs), which supply most of the electricity in the Western Balkans (WB) and contribute more than 50% of the region's carbon dioxide (CO2) emissions, were constructed more than 40 years ago. The THP fleet of WB poses a significant threat to human and wildlife habitats, as well as nationally specified contributions to the reduction objectives to ameliorate global warming as set forth in the Paris Agreement, because to their poor technical condition and lack of modernization. The WB's great potential for developing its whole energy transition based on renewable energy (RE) is outlined by strong regional ambitions for EU membership.

The majority of the energy supply in the Western Balkan countries comes from wood, coal, and oil. More over half of the power production in Kosovo, Serbia, and Bosnia and Herzegovina comes from coal; in North Macedonia, this percentage is a little lower. With the exception of Albania which is producing its electricity 98% from hydropower, every Western Balkan nation uses coal as their primary energy source [7].

Table 2-1: WB6 energy mix 2020 [11].

Economy	Coal	Oil and oil products	Natural gas	Renewable energy
Albania	6.8%	49.5%	1.7%	33.1%
Bosnia and Herzegovina	56.4%	21.7%	2.4%	24.4%
Kosovo	57.9%	28.0%	0%	15.1%
Montenegro	37.5%	32.5%	0%	29.4%
North Macedonia	29.2%	38.4%	10.7%	14.0%
Serbia	49.6%	22.5%	12.5%	15.7%
WB6 average	39.6%	32.1%	4.6%	21.9%
EU average	10.2%	34.5%	23.7%	17.4%

In 2020, the Western Balkans 6 (WB6) witnessed a substantial incorporation of renewable energy into their energy portfolio, ranging from 14% in North Macedonia to 33.1% in Albania. However, this was predominantly attributed to hydroelectric generation a longstanding energy resource within the WB6 despite the region's significant untapped potential for wind and solar power generation. While alternative renewable energy sources to hydroelectric power are still in the early stages of development, the past four years have seen a positive trajectory in the WB6, marked by a transformative renewable energy policy shift that has catalyzed increased investments in wind and solar energy projects overpassing 2GWp installed capacity in 2023.

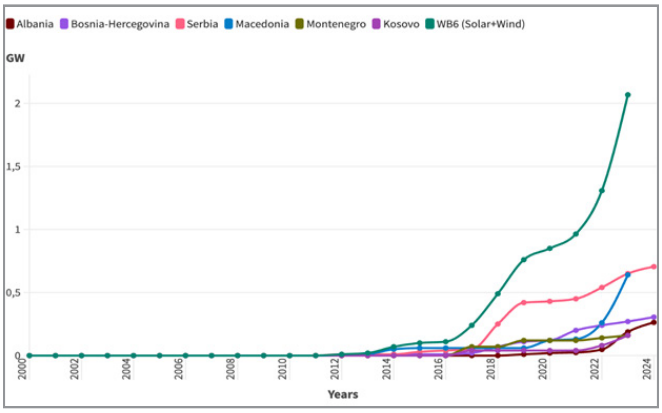

Figure 2-13: Cumulative installed wind and solar capacities in WB6 for each country. Adapted by author, [12, 15].

Table 2-2: Western Balkans' Policies on Energy and Climate [7].

	Energy Strategy	Low-carbon Development Strategy	Climate-change Law	Energy Efficiency Strategy	Renewables Development Strategy
Albania	National Energy Strategy 2018-2030	National Climate Change Strategy (endorsed in 2019)	Law on Climate Change (adopted in December 2020)	National Energy Efficiency Action Plan expired in 2020	National Action Plan for Renewable Energy Resources in Albania 2021-2025
Bosnia and Herzegovina	Framework Energy Strategy 2035	Climate Change Adaptation and Low Emissions Growth Strategy 2025	–	Action Plan for Energy Efficiency of Bosnia and Herzegovina 2019-2021 (NEEAP BiH) (final draft)	National Renewable Energy Action Plan 2020
Kosovo	Energy Strategy 2017-2028	Climate Change Strategy 2019-2028 and Action Plan on Climate Change 2019-2021 (approved)	–	National Energy Efficiency Action Plan (NEEAP) 2019-2021	National Renewable Energy Action Plan (NREAP 2011-2020)
North Macedonia	Energy Development Strategy 2030	Long-term Strategy on Climate Action and National Action Plan on Climate Change	Law on Climate Action	Fourth National Energy Efficiency Action Plan (NEEAP) (adopted)	Renewable Energy Action Plan Until 2025

Serbia	Energy Sector Development Strategy for the Period until 2025; Energy Development Strategy 2040 Strategy 2040	Draft low-carbon development strategy	Law on Climate Change (adopted in 2021)	Fourth National Energy Efficiency Action Plan (NEEAP) (until 2021) (adopted)	National Renewable Energy Action Plan 2020 (adopted in 2013)

The Western Balkan governments face a complicated and contentious agenda in the form of the Green Agenda, which has significant goals that are evidently interconnected. While most nations have drafted and enacted the legislative framework covering the most essential concerns, the required changes are still not in force. As per the prevalent evaluations conducted by many organisations such as the European Commission, Energy Community Secretariat, EBRD, OECD, and World Bank, the WB6 are now in the first stages of their environmentally conscious shift [7].

Governments have passed specific laws that establish the legal and regulatory frameworks associated with energy and climate change, although some of the legislation is out-of-date and the frameworks are insufficient (Table 1-2). Furthermore, a large number of these laws are either partially or not at all enforced.

Table 2-3: Western Balkan Innovation Index. Adapted by [44], [45].

Country	Total score	2023 rank	R&D rank	Industry rank
Albania	0.46	83	109	99
Bosnia and Hercegovina	0.51	77	89	78
Serbia	0.64	53	58	43
Kosovo	0.54	79	102	78
Montenegro	0.58	75	113	81
North Macedonia	0.53	54	94	61

A thorough assessment of the innovation performance of different economies is provided by the Global Innovation Index (GII) 2023, which focuses especially on the Western Balkans. Out of the 39 European economies included in this edition, three economies from the Western Balkans have made significant advancement in their rankings. Two of the leading economies are Serbia and North Macedonia, which are placed 53rd and 54th, respectively, out of the 132 economies in the GII 20231. Compared to its GDP2, North Macedonia's economy is outperforming all others in the Western Balkans. This development demonstrates the region's increasing capacity for innovation and promise for economic growth shown in (Table 2-3).

The analysis does, however, also highlight a discrepancy between the amount of money invested in innovation and the actual amount of innovation produced by Western Balkan countries. These economies produce less innovation than their investments in this field, notwithstanding their development.

Summary

Research review underscores the pivotal role of renewable energy technologies (RETs) in energy transition, fortifying energy security, and fostering sustainable development within the Western Balkans. This region is predominantly reliant on coal and lignite for its electricity production. The theoretical framework employs Everett M. Rogers' diffusion of innovations theory to elucidate the diffusion of RET's technologies, such as solar and wind energy, across societies. This dissemination is shaped by a confluence of economic, social, cultural, and political determinants.

Confronted with substantial impediments to the escalation of RETs, the Western Balkans grapple with antiquated coal-powered facilities, necessitating modernization to align with the global warming mitigation targets stipulated by the Paris Agreement.

The research invokes diffusion innovation paradigms, inclusive of the Bass Model, to scrutinize the evolution and assimilation of solar photovoltaic (PV) and wind energy within the Western Balkans. This analysis is juxtaposed against the backdrop of more technologically advanced European Union nations, such as Germany, to draw comparative insights.

The literature's implications point to the necessity for a variety of policy tools to improve clean energy policies by indicating that public RD investments, renewable energy support laws, and per capita income have various effects on the creation and adoption of innovations. The WB6 governments have enacted legislative frameworks for environmental concerns, but the required changes are still not in force, indicating a need for stronger implementation of policies to support the green agenda.

Conceptual and substantive assumptions assumes that the diffusion of RETs follows the S-curve model, where adoption starts slowly, accelerates, and then levels off as the market becomes saturated. It also assumes that policy and regulatory support are crucial for overcoming barriers to the adoption of RETs.

The diffusion of innovations theory, which describes how new technologies spread across societies and the elements that impact this process, serves as the foundation for the theoretical framework. The study will examine the relationships among variables such as economic incentives, policy support, and social acceptance to understand their impact on the diffusion of RETs in the Western Balkans.

Methodology, Data Analysis and Results

We present the method that was used in this chapter to answer our research questions. To help researchers in the understanding of the advancements in solar and wind energy photovoltaic (PV) technologies used in electricity generation projects, the WB6 has been chosen as a growing transitional economy within Europe. Germany was selected as a leading European nation in the commercial diffusion of these technologies. The simplicity of data collection and Germany's status as a pioneer in the wind and solar PV industries—two industries with impressive development trajectories that are instructive—also played a role in this decision.

Germany and WB6 Western Balkan Countries Datasets

Based on cumulative wind and solar PV capacity figures developed datasets by the [46] for Germany and for WB6 from [12].

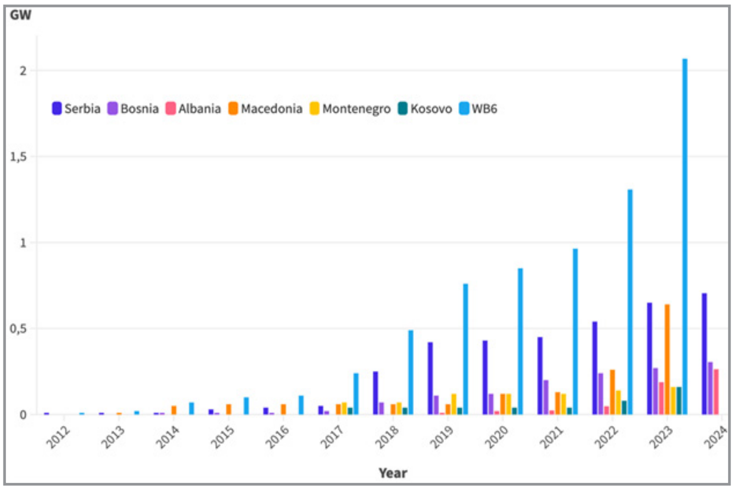

Figure 3-1: Data for WB6 of wind and solar PV installed cumulative capacity from 2010-2024 [12].

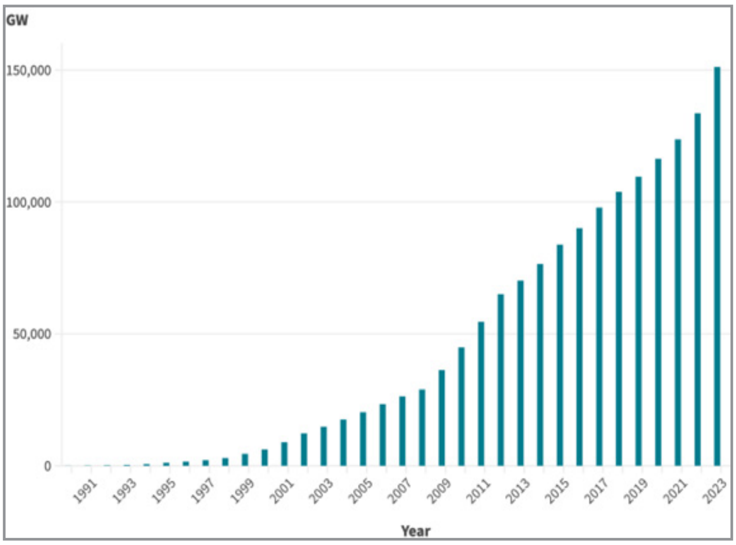

Figure 3-2: Data for Germany of wind and solar PV installed cumulative capacity from 1990-2023 [46].

Methodology and Models Used

Gompertz Model

A mathematical model called the Gompertz model is used to explain how an innovation spreads over time or how a population grows. When modelling scenarios where development begins slowly, picks up speed, and then slows down as it gets closer to a maximum limit, it is very helpful in different diffusion analysis. The Gompertz model's as Internal Influence Model component, examines how the number of existing users affects adoption rates, i.e., the more individuals use a product, the more probable it is that others will do the same [43].

Because of its adaptability and ability to suit different kinds of growth data, the model is a useful tool for academics and marketers to precisely analyse and anticipate market behaviour. The Gompertz model is sometimes contrasted with other diffusion models, such as the Bass model, which offers a thorough explanation of the adoption process by taking into account outside factors like word-of-mouth and advertising.

Gompertz function can be written from main formula of internal influence as:

$\frac{dN(t)}{dt} = bN(t)[\ln N - \ln N(t)]$ or $y(t) = ae^{bct}$ or $\frac{dN(t)}{dt} = \overline{N} \cdot e^{-a \cdot e^{-bt}}$

where "b" stands for the imitation index (internal influence) which comes from interactions between new adopters and previous adopters.

Where:

- $\frac{dN(t)}{dt}$ is the growth at which the number of adapters at the time t is changing.
- $\overline{N}$ represents maximum possible growth rate, carrying capacity or the upper limit of adopters.
- *e* base of natural logarithm.
- *a* and b are parameters of the model, where a relates to the initial adoption level and b relates with growth rate of adaption.
- t is time.

An S-curve graph representing the total number of adopters over time is presented in Figure 3-3(a), which also provides the findings of a point of convergence at 50% of the total capacity for future adopters.

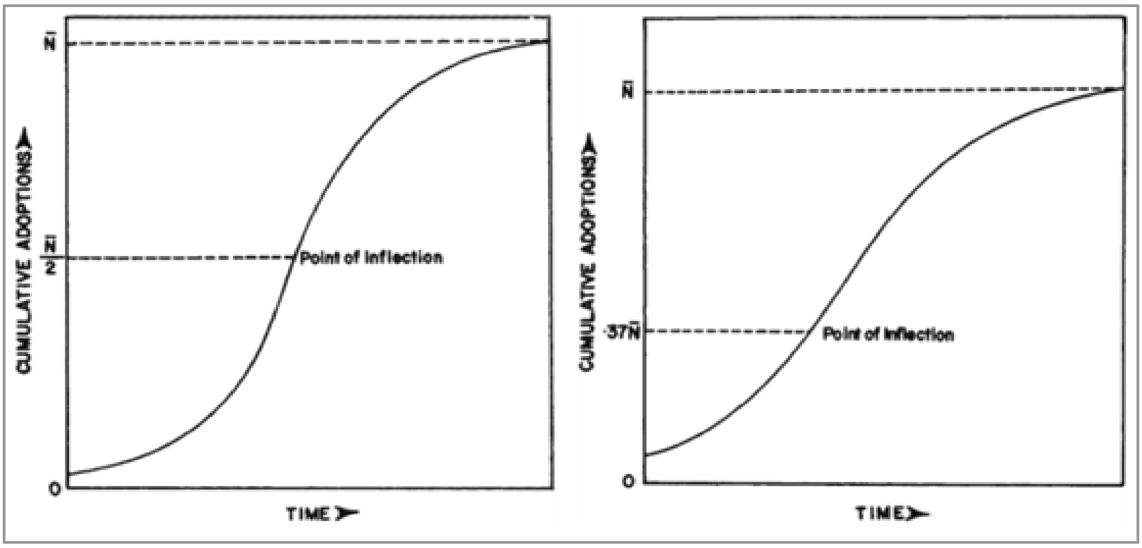

Figure 3-3: (a) 50% inflection S-Curve and (b) S-Curve Gompertz model with 37% inflection [41].

As diffusion reaches approximately 37% of the saturation threshold, as seen in Figure 3-3(b), its highest growth rate is reached $\frac{\overline{N} \cdot b}{e}$,this signifies how quick the adopters is changing at any time t. In the context of diffusion, it represents how fast a new technology, product, or behaviour is being adopted by the population. ¯N is often interpreted as the carrying capacity or the upper limit of adopters. It shows the maximum number of individuals who could potentially adopt the innovation.

Dual Phase Logistic Model

Meyer created the bi-logistic growth model, an extension of the basic logistic growth model, to better fit real-world data that indicates two distinct stages of growth. Meyer's model is especially helpful in situations when a slower, secondary phase of development occurs after an initial period of fast expansion, maybe as a result of evolving barriers or variations in the dynamics of the system.

Mayer analysed the logistic growth model which describes the early fast increase of a population, which slows down as it approaches a maximum threshold and takes the form of an S-shaped graph. According to this model, although the population grows exponentially at first, the rate of expansion slows down as it approaches the carrying capacity represented as (K), which is caused by a lack of resources or more intense competition. The carrying capacity is the maximum sustainable population size for the ecosystem and the point at which population growth may be achieved. The population's rate of growth significantly slows down and stabilises close to the carrying capacity at the saturation point, creating the upper plateau of the S-curve. Because the logistic model is inherently symmetrical about the midpoint ((t_m)), its growth rate mirrors itself both before and after this nexus, making it a sophisticated but powerful tool for simulating real growth scenarios [47].

Classical Logistic Growth Model

According to the logistic growth model, a population increases quickly at first before slowing down as it gets closer to its carrying capacity. The model is provided by equation [48]:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) \quad \text{Equation 3-1}$$

where:
N population at time t
r growth rate
K carrying capacity
t_0 inflection point at which the growth rate starts to slow down.
This equation derives the classical logistic growth model is represented by the equation [48]:

$$N(t) = \frac{K}{1 + e^{-r(t-t_0)}} \quad \text{Equation 3-2}$$

Although helpful, the logistic model is frequently oversimplified for systems with complicated development patterns. Multiple development stages are commonly observed in real-world data that have a variety of causes, including resource availability, technology improvements, and governmental policy changes.

In order to overcome these barriers, Perrin Meyer developed the dual-phase model (bi-logistic model). In order to represent two stages of growth inside a single system, the bi-logistic growth model integrates two logistic growth functions. The consolidated model is shown as follow equation:

$$N(t) = \frac{K_1}{1 + e^{-r_1(t-t_1)}} + \frac{K_2}{1 + e^{-r_2(t-t_2)}} \quad \text{Equation 3-3}$$

where:
K_1 and K_2 are the carrying capacities of the first and second growth phases.
r_1 and r_2 are the growth rates of the first and second phases.
t_1 and t_2 are the inflection points of the first and second phases.

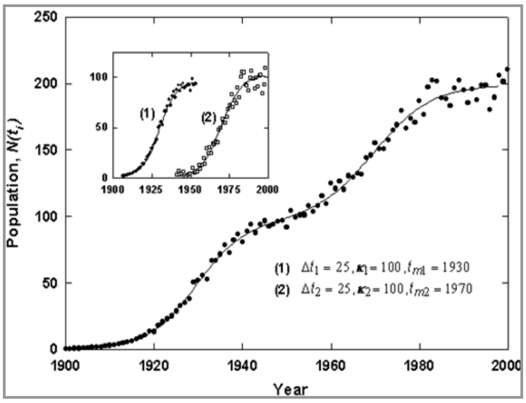

Figure 3-4: Example of a Bi-Logistic growth curve, [48].

Nonlinear regression techniques (Non-Linear Least Square estimation (NLS)) IIASA-LSM II application is used for calculating the parameters of the bi-logistic model and LogletLab to validate them [49]. By fitting the combined logistic model to our datasets we collected, in our case wind and solar PV cumulative installed capacity for Germany and WB6, these method aim to reduce the variation between the expected and observed values. Meyer's bi-logistic model requires fitting the six parameters ($K_1, K_2, r_1, r_2, t_1, t_2$) to the observed dataset using NLS Non-Linear Least Square technique. We will evaluate the quality of fit by employing statistical metrics like the coefficient of determination (R^2).

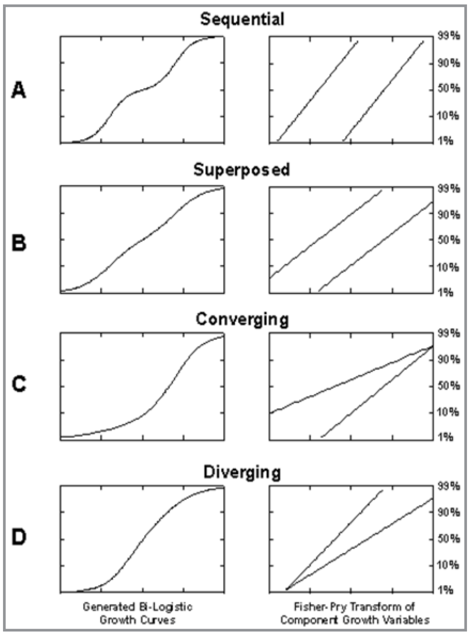

Figure 3-5: Bi-logistic growth model type of plotted curves.

Based on scientific literature, the Bi-logistic model can generate a variety of growth curves, each reflecting different scenarios of technological or biological evolution [48], Figure 3-5.

- **A-Sequential Curves:** These curves show situations in which there are two independent logistic growth processes that follow one another. Two distinct phases of fast expansion followed by stabilisation are represented by the composite S-shaped curve, which occurs when the first growth phase exceeds its carrying capacity before the second phase starts.

- **B-Superposed Curves:** Two logistic growth processes, each having a carrying capacity of its own, we have overlap in this situation. The resultant curve is a more complicated S-shaped curve with a notable middle part where the influences of both growth stages are visible. It is the combination of the two growth phases.
- **C-Converging Curves:** These curves show situations in which two growth processes begin at distinct points in time and progress at different rates until coming together to reach a shared carrying capacity. The growth curve narrows off as the processes converge after initially rising sharply, indicating fast growth.
- **D-Diverging Curves:** In contrast to converging curves, begin together but eventually split as a result of varying carrying capacities or growth rates. The curve displays a shared growth phase at first, which is followed by a divergence when two processes expand at different rates, resulting in independent S-shaped trajectories [48].

Data Analysis and Results

The parameters for the Gompertz and Logistic growth models, as applied to both the Western Balkans Six (WB6) and Germany, have been quantitatively determined as delineated in the accompanying table. This estimation was conducted utilizing the IIASA-LSM II, which incorporates data on the annual installations and the cumulative total of installed capacities for solar and wind energy generation, extending from the year 1990 through 2023, as reported by the International Energy Agency (IEA) in 2024. It is noteworthy that the initiation of solar and wind capacity installations across the WB6 nations commenced subsequent to the year 2011, before to this juncture, such installations were non-existent.

Table 3-1: Logistic and Gompertz models parameter estimates for WB6 and Germany for wind and solar capacity in GW. Calculated with IIASA-LSM II.

	Gompertz Model				Logistic Model			
	K	Tm	Delta T (ΔT)	R2	K	Tm	Delta T (ΔT)	R2
Germany	282.373	2018	40.904	0.997	171.368	2015	22.535	0.995
Scenario	360.000	2021	48.5	0.996	360.000	2025	33.546	0.986
WB6	121.406	2044	46.73	0.98	12.056	2027	12.26	0.979
Scenario	13.500	2029	26.05	0.979	13.500	2028	12.38	0.979

Gompertz Model

In the context of Germany's renewable energy capacity, when scenario constraints are not applied to the IIASA-LSM II model for specific saturation levels, with the exception of the Green Scenario 360.000 GW, the Gompertz model forecasts a saturation point at 282.373 gigawatts (GW), while the Logistic model posits a saturation at 171.368 GW. According to this range, Germany's total installed capacity for solar and wind power is expected to be between 171.368 GW and 282.373 GW.

Figure 2-11, as delineated by the Gompertz model, exhibits the projected trends up to the year 2075 for Germany's cumulative installed wind and solar power capacity, with an expected saturation level of 282.373 GW by 2040, and an aspirational governmental policy target of 360.000 GW by 2030, as outlined in the Scenario. The analysis is predicated on the estimations provided by the IIASA-LSM II model, with subsequent analyses expected to primarily utilize Gompertz model at saturation of 360.000 GW for wind and solar PV installed capacity.

The equation: $\frac{dN(t)}{dt} = \overline{N} \cdot e^{-a \cdot e^{-bt}}$ where $\frac{dN(t)}{dt}$ in our case is the cumulative installed wind and solar capacity at period of time t.

$\frac{dN(t)}{dt} = \overline{282.373} \cdot e^{-40.904 \cdot e^{-0.371t}}$ where t is 1 for 1990, …60 for 2050.

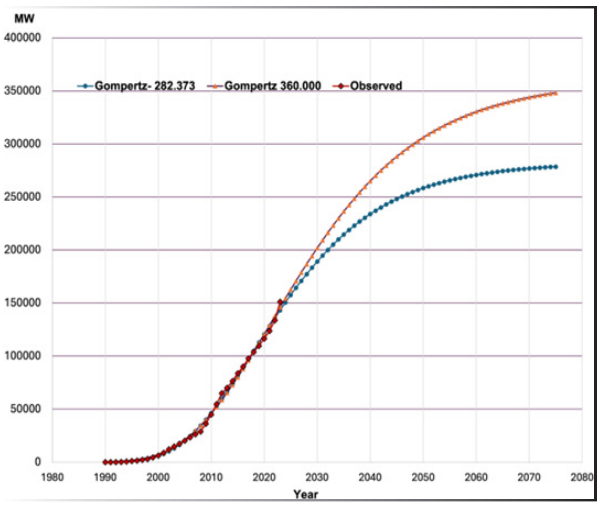

Figure 3-6: The Gompertz model's installed Wind and Solar for Germany in MW per year (1990-2075).

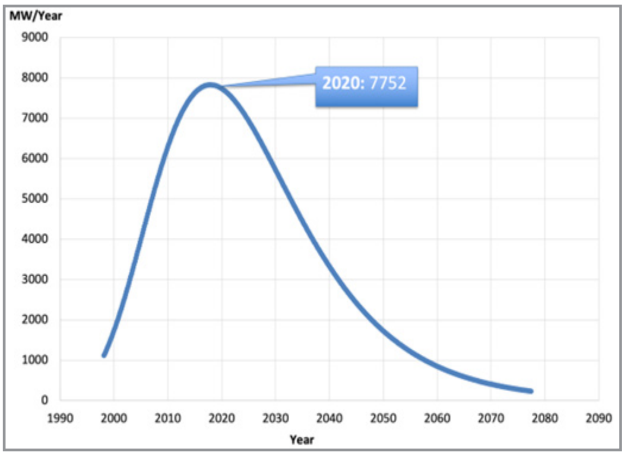

Figure 3-7: Gompertz rate of installation of wind and solar change in MW for Germany per year.

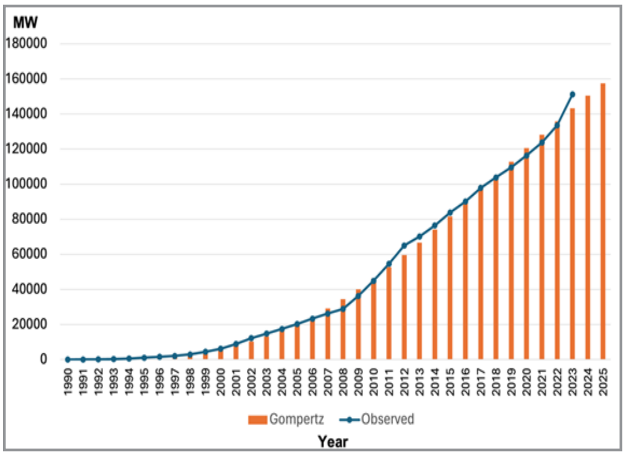

Figure 3-8: Gompertz cumulative Germany wind and solar installation in MW for scenario with K=360GW for years (1990- 2025).

The results of this investigation demonstrate that the diffusion curve's inflection point (Tm=2023) occurred between 2023 and 2024, as shown in Figure 3-6. This tipping point indicates that Germany's installed wind and solar capacity increased until 2024. The projections presented in Figure 3-8 show that Germany's installed capacity for solar and wind power will continue to rise, reaching 162.5 gigawatts (GW) by 2025.

Analyzing the case of WB6 presents challenges due to the slow diffusion of Renewable Energy Technologies (RET) since 2011, with significant large-scale projects only emerging in the past four years. For our analysis, we will utilize the cumulative data of wind and solar installed capacity. Additionally, we will not limit the IIASA-LSM II model for saturation levels. According to the Gompertz prediction a maximum adaption upper level of saturation with 121.406 GW, which is notably high; this is reasonable given the limited number of years during which RETs have been operational and actual observed datasets in WB6 (see Tables 3-1). Conversely, the Logistic model estimates for a non-restricted saturation level of 12.056 GW, which aligns closely with the realistic scenario of WB6's National Energy Action Plans of energy transition (without taking in consideration the electricity demand increase, and long term amortizations of RE power plants) from installed fossil fuel power plant with total actual capacity of around 13.5 GW. When we limit the adoption level of the upper saturation to 13.5 GW, the Gompertz model react more realistically in the prediction of the saturation in the future for WB6 in the graph Figure 3-9.

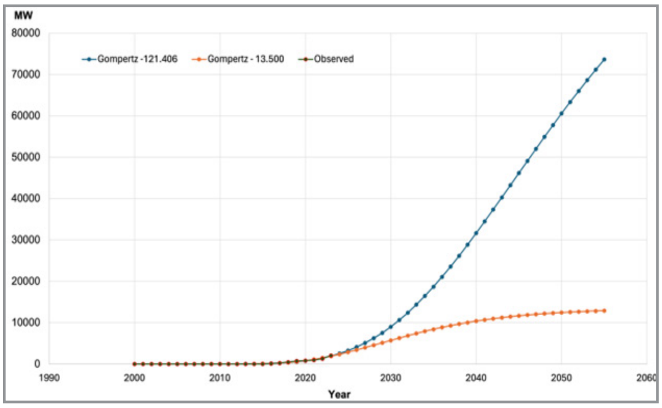

Figure 3- 9: The Gompertz model's installed Wind and Solar in MW for WB6 for scenarios K=121.460 GW and K=13.500 GW for years (1990-2055).

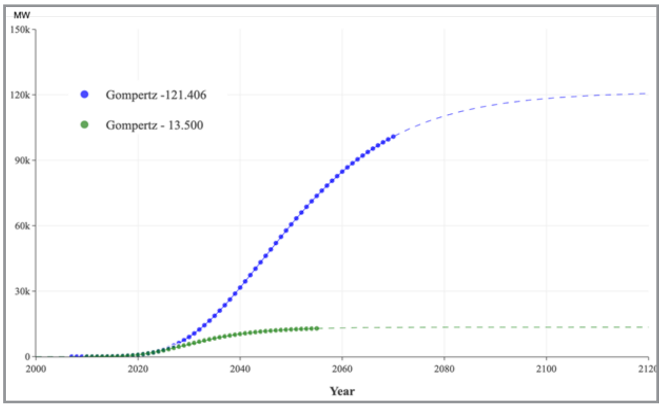

Figure 3-10: The Gompertz model's installed Wind and Solar capacities for WB6 and scenario saturation, for saturation K=121.406GW and saturation for K=13.5GW. for years (1990-2055).

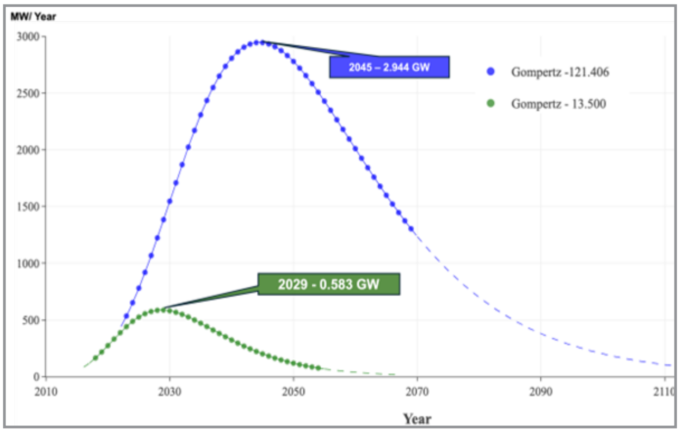

Figure 3-11: Gompertz rate of growth for wind and solar installation for WB6 with scenarios, with saturation of K=121.406GW and saturation level of K=13.5GW per year up to 2070 in MW.

The rate of growth of installed wind and solar for observed 121.406GW scenario will increase till 2045 with peak 2.944 GW a year installed capacity, and decrease after, this scenario is not realistic, as the model was allowed to estimate the saturation based on only few data.

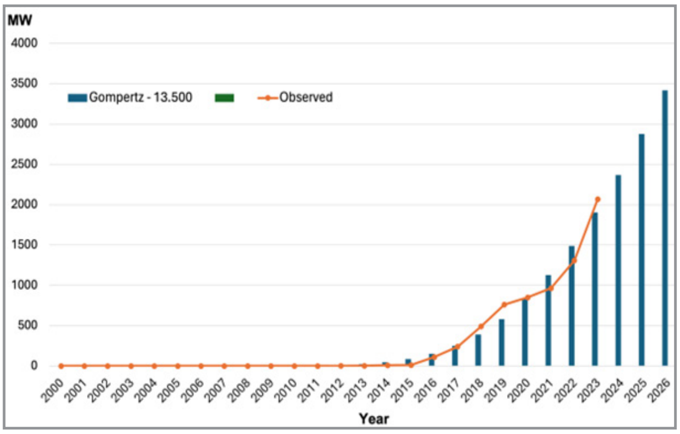

Figure 3-12: Gompertz Scenario K=13.500GW fits with observed cumulative wind and solar PV installation for years (2000 - 2026) for Western Balkan countries, WB6 in MW.

For the Gompertz - 13.5GW scenario, the rate of growth of installed wind and solar for observed scenario will increase till 2029 with 0.583GW a year and thereafter slowly decrease till 2050, this is more realistic scenario without taking in consideration the increase of electricity demand for the region of WB6 as another influencer.

The Gompertz model naturally anticipated the saturation for WB6 121.406 GW (Tables 3-1) when the IIASA-LSM II was not restricted to saturation levels, and the Logistic model showed a saturation of 12.056 GW, a more reasonable estimation. This saturation of cumulative installed wind and solar PV capacity in WB6 can be between 12.056 GW and 121.406 GW.

Figure 3-9 shows the projected patterns of installed wind and solar PV in WB6 until 2055 as per results from modeling of Gompertz, without restricting saturation, resulting in K=121.406 GW upper level of saturation and a restricted saturated scenario of K=13.5 GW.

The research emphasises that the diffusion curve's inflection point (Tm=2029) is anticipated to occur between 2028 and 2029 period with 5GW, as illustrated in Figure 3-10, under Gompertz model with an anticipated installed capacity of K=13.5GW. It is observed that the growth rate of installed wind and solar photovoltaic (PV) capacity augmented until 2029, subsequently entering a phase of decline. Projections for the WB6 region indicate that by the year 2030, a minimum of 6.018 GW of solar PV capacity will be installed, as depicted in Figure 3-11. Moreover, the trend analysis suggests a continued deceleration in the growth rate of installed capacity extending up to the year 2055.

According to Table 3-1's calculations, WB6 will require 26 years (delta T=26.05) for a shift from 10% to 90% of the 13.5 GW saturation scenario for wind and solar PV for the Gompertz model with ratio of determination of R2 = 0.979.

Table 3-2: Years and percentage of wind and solar installation saturation for WB6 with Gompertz model scenarios K= 13.500GW, K=121.406GW

Percentage Saturation	1%	10%	37%	75%	90%	99%
Year of Saturation K=13.500GW	2016	2022	2029	2039	2048	2067
Year of Saturation K=121.406GW	2022	2032	2044	2063	2079	2113

Table 3-3: Years and percentage of wind and solar installation saturation level for Germany Gompertz model, K= 282.373GW, and K=360.000GW scenarios.

Percentage Saturation	1%	10%	37%	75%	90%	99%
Year of Saturation K=282.373GW	1998	2007	2018	2034	2048	2078
Year of Saturation K=360.000GW	1998	2008	2021	2041	2057	2092

Table 3-3 indicates that, under the Gompertz model with R2 = 0.995 Germany will require about 41 years (ΔT=40.904) transition starting 1% (1998) to 90% (2048) for the 282.373GW non restricted saturation scenario.

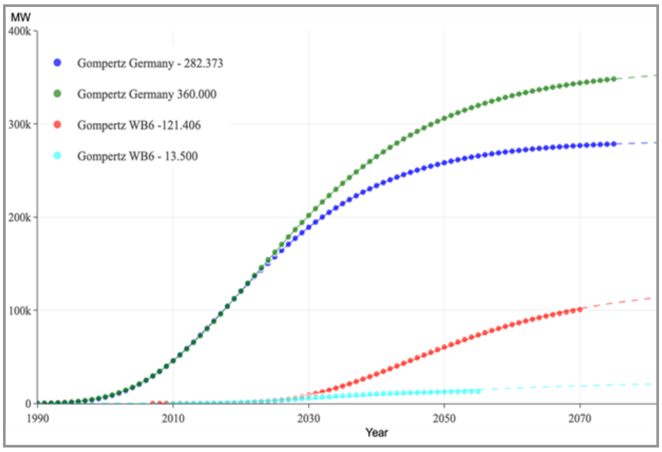

Figure 3-13: The Gompertz Germany and WB6 model's for cumulative installation for wind and solar PV for years (1990-2075).

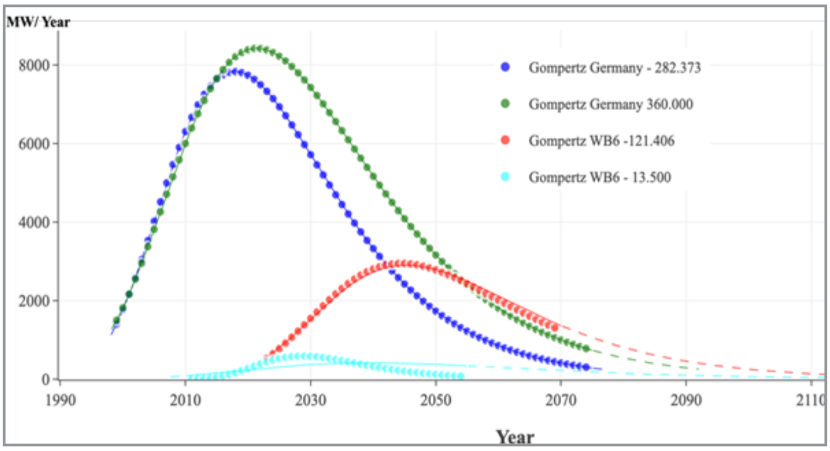

Figure 3- 14: Gompertz rate of wind and solar installation growth models for Germany and WB6 scenarios, where WB6 K=13.5GW scenario is estimated more realistically.

From the Figure 2-19 is seen that the Germany has reached its saturation much more quicker than WB6.

Logistic Model

According to the logistic growth model, Figure 2-20 shows how Germany's cumulative wind and solar photovoltaic (PV) capacity is expected to change by 2050. Two different scenarios are depicted in the figure: the first predicts a saturation level of 171.368 GW for the IIASA-LSM II model without any limitations, while the second suggests a saturation level of 360.00 GW. Based on the parameter estimates from the IIASA-LSM II model, this study will primarily concentrate on these two logistic model cases. Its purpose is to clarify the predicted saturation point (K = 360.00 GW) of comulative installed wind and solar PV power that Germany hopes to reach by 2030.

The equation: $N(t) = \frac{K}{1+e^{-r(t-t_0)}}$ where; $N(T)$ shows the total amount of installed solar and wind during a certain time period (t = 1,..., and 60 for 2050).

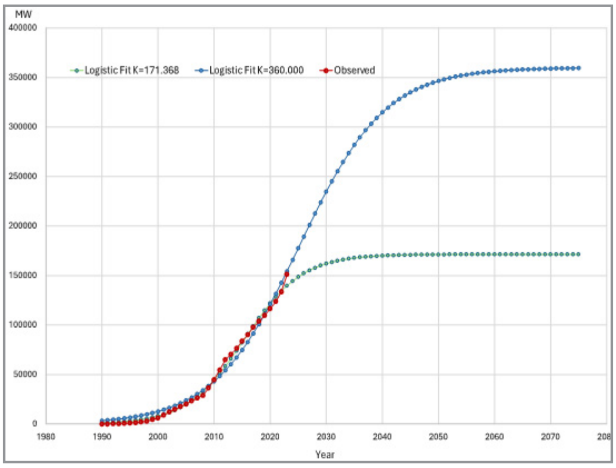

Figure 3- 15: Germany - Logistic models S-Curve for cumulative wind and solar PV installed power (1990-2050).

Figure 3-15 depicts the moment of transition, inflection point at (Tm=2022) of the diffusing curve which transpired during the years 2021-2022 for K=360GW. This inflection point indicates that the saturation level of 50% of installed wind and solar photovoltaic (PV) capacity reaching it in 2022. Projections for Germany's installed flexibility suggest that by 2026, there will be an installation of 189.393 GW of wind and solar PV capacity (as depicted in Figure 3-17), aligned with a saturation for the level K=360.000 GW. The growth rate of wind and solar PV installed capacity is expected to continue its downward trajectory post-2024, ultimately halting after 2050, as shown in Figure 3-16 for K=360GW.

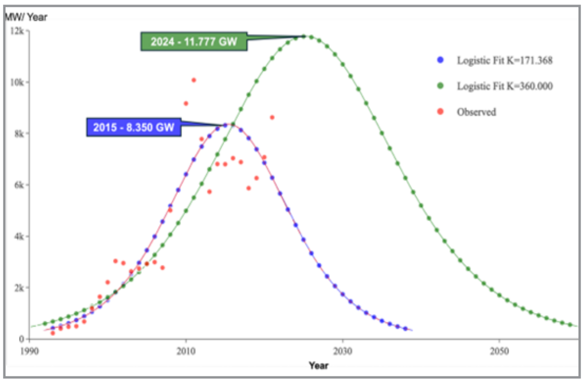

Figure 3-16: Logistic rate of growth models for Germany wind and solar installations for both scenarios of K= 171.368GW and K=360.000GW up to year 2050.

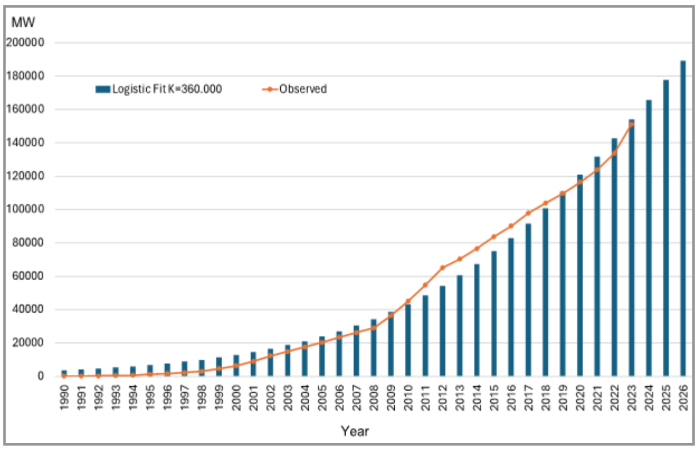

Figure 3-17: Logistic Scenario for Germany K=360.000GW fits better with observed cumulative wind and solar installed power for years (2000- 2026).

Table 3-4: Years and percentage of wind and solar PV installation saturation for Germany with Logistic model for K= 360.000, and K=171.368 scenarios

Percentage Saturation	1%	10%	50%	90%	99%
Year of Saturation K=171.368	1992	2004	2015	2027	2039
Year of Saturation K= 360.000	1990	2008	2025	2043	2060

Table 3-4 reveals that under the scenario where (K = 360) GW, Germany is projected to achieve 90% of the saturation level dating from 1990 by the year 2043. This trajectory is incongruent with the targets set forth in the German Green Policy, which stipulates the attainment of 360 GW of wind and solar photovoltaic (PV) installed capacity by the year 2030.

WB6 Logistic Model

Figure 2-23 depicts moment of transition of inflection point (Tm=2028) of the S-curve, which transpired during the years 2028-2029 even though with many data missing, as the WB6 has very late development of RET's installed capacities. This inflection point indicates that the growth rate of installed wind and solar photovoltaic (PV) will reach 50% of capacity around 2028-29 for K=13.500GW restricted upper level of saturation scenario and in the 2027-28 for the K=12.056 non restricted upper level of saturation scenario. Projections for WB6 installed flexibility suggest that by 2028, there will be an installation of 6.819 GW of wind and solar PV capacity (as depicted in Figure 3-18), aligned with a saturation for the level K=13.500 GW. The growth rate of wind and solar PV installed capacity is expected to continue its downward trajectory post-2028, ultimately halting after 2040, as shown in Figure 3-19.

Table 3-5: Years and percentage of level of wind and solar PV installation saturation for WB6 for Logistic for K=12.056GW, K= 13.500GW scenarios

Percentage Saturation	1%	10%	50%	90%	99%
Year of Saturation K=12.056 GW	2015	2021	2028	2034	2040
Year of Saturation K= 13.500 GW	2015	2021	2028	2034	2041

Table 3-5 reveals that under the scenario where (K = 13.500) GW, WB6 is projected to achieve 90% of the saturation level dating from 2015 by the year 2034. Both of the trajectory saturations are realistic, which stipulates the attainment of 13.5 GW of wind and solar photovoltaic (PV) installed capacity by the year 2034 shifting the WB6 region towards 90% green transition of the existed fossils fuels power plants will take around 10 years to reach it.

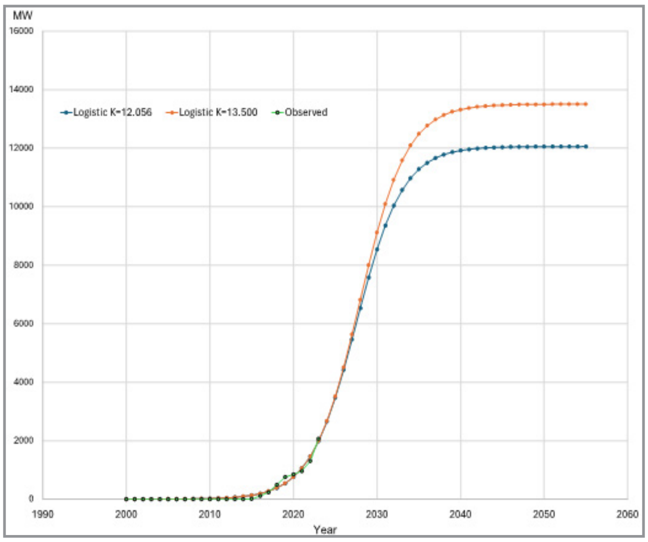

Figure 3-18: WB6 - Logistic models cumulative wind and solar PV installed power for years (1990-2050) in MW.

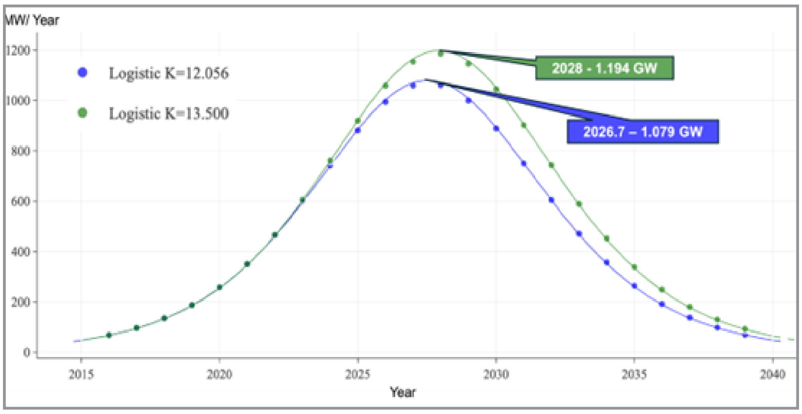

Figure 3-19: Logistic rate of wind and solar PV growth models for WB6 for both scenarios K=12.056GW, K= 13.500GW.

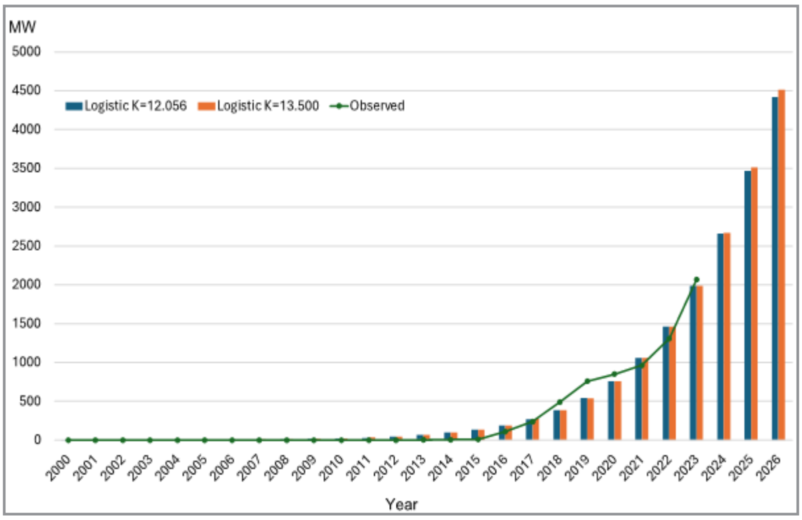

Figure 3-20: Logistic Scenario for WB6 fits with observed cumulative wind and solar PV installation for years (2000- 2026) in MW.

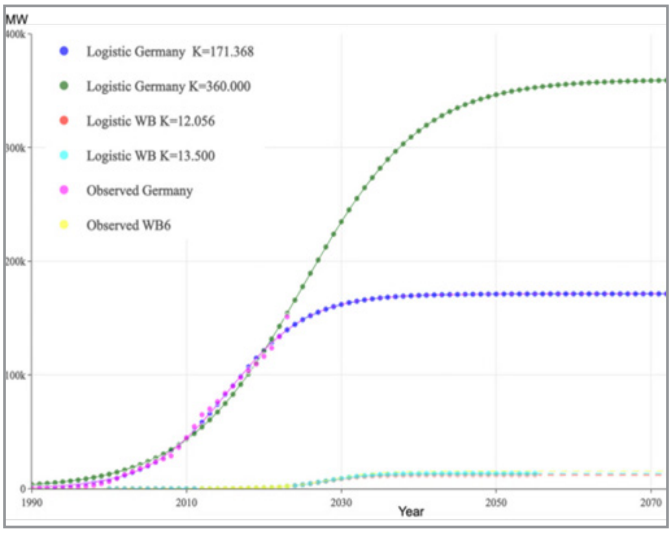

Figure 3-21: WB6 - Logistic models cumulative wind and solar PV installed power for Germany and WB6 for all scenarios and observed data (1990-2050) in MW.

The comparison of the German and WB6 saturation scenarios in a single figure, as shown in Figure 3-21, offers important information about how wind and solar photovoltaic (PV) development are developing in the WB6 region. This comparison sheds insight on the reasons for the WB6's delayed adoption of (RETs) with difficulties in achieving 2030 green energy transition objectives. Furthermore, Figure 3-22 provides an interesting perspective on the patterns in growth rates for each of the scenario scenarios. After 2030, there is expected to be a decline in the installed cumulative capacity of wind and solar power in Germany and the WB6, which is expected to last until after 2050. In order for Europe to become the first continent to be climate-neutral by 2050, the following period after 2030 is crucial.

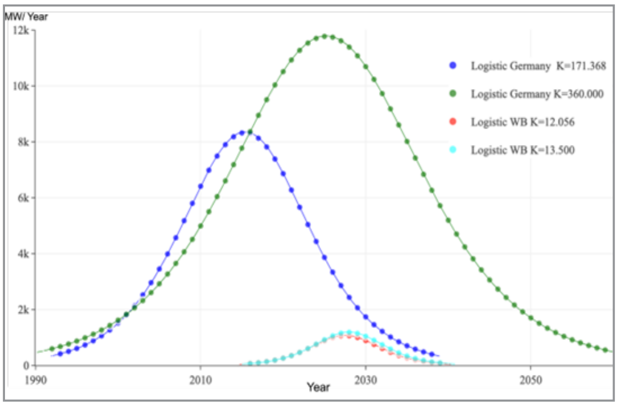

Figure 3-22: Logistic rate of growth models for wind and solar PV installation for WB6 and Germany for all scenarios, years (1990-2050) in MW.

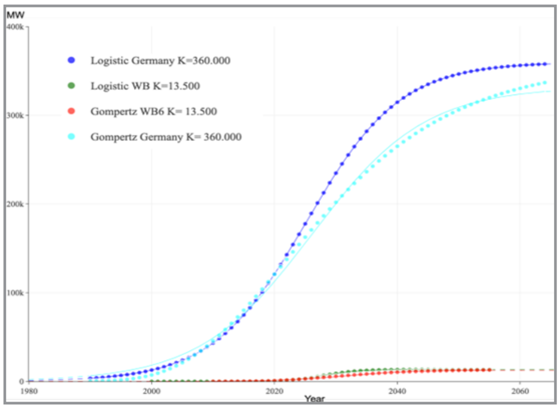

Figure 3-23: Gompertz vs Logistic models, cumulative wind and solar PV installed power for Germany and WB6 difference for years (1990-2050).

The investigation aimed at determining the most efficient diffusion analysis model for the trajectories in the WB6 and Germany involved comparing the predicted and actual values of cumulative installed capacity of wind and solar PV power, as well as for the future saturations of wind and solar photovoltaic (PV) technologies. The results show that, with a saturation level of 13.5 GW and an unconstrained estimation of (K = 12.056) GW, as seen by the coefficient R2, the logistic model (see Figure 3-21) is more precisely aligned with the data and the actual energy transitions green policies for both Germany and WB6 than the Gompertz model. As a result, when predicting the spread of renewable energy technologies (RETs), the logistic model is advised. While the Gompertz model at 360 GW of saturation fits the data well, the logistic model at the same saturation level fits the data much better also with the policy action plans, thus recommended for predicting the spread of solar and wind PV technologies.

Policy and Regulation

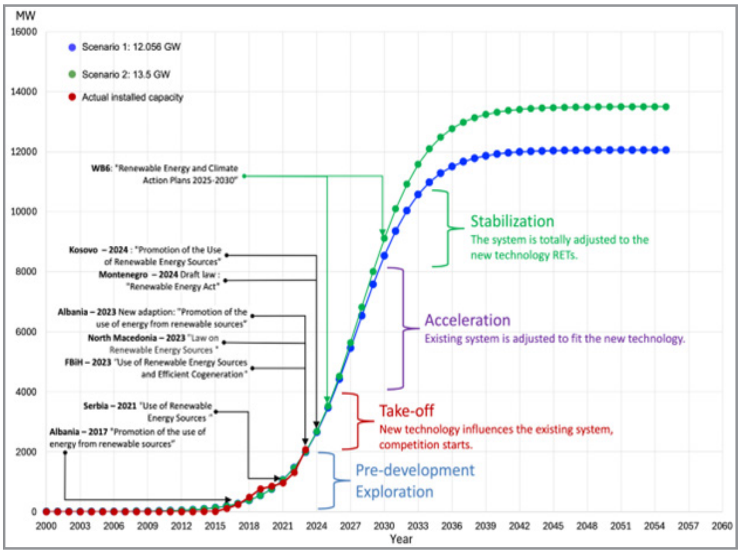

Figure 3- 24: WB6 Logistic models, and the years when “Use of Renewable Energy” laws are implemented for each WB6 countries.

Republic of Kosovo approved on May 2024 law No. 08/L-258, which provides a comprehensive legislative framework for promoting renewable energy. It aims to increase the use of renewable energy sources in the electrical power, heating, cooling, and transportation sectors. The law establishes financial incentives for investments, such as Contracts for Difference and Contracts for Premium, which are funded by the Renewable Energy Support Fund. It requires comprehensive definitions, roles, and duties for all stakeholders, providing clarity and effectiveness in execution. The Ministry and the Regulator monitor development and ensure compliance, while Renewable Energy Communities and public access to information promote openness and public involvement. The law also encourages strategic investments and public-private partnerships by recognising projects vital to national energy needs. Transitional rules guarantee that current contracts and secondary legislation are aligned within nine months after introduction. Law No. 08/L-258 intends to significantly boost renewable energy, promoting sustainable development, energy security, and environmental protection while aligning Kosovo with international renewable energy norms and obligations.

The Montenegro proposed legislation (draft law Renewable Energy Act 2024) addresses many elements of renewable energy use. It provides regulation on financial assistance measures for renewable-generated power and discusses prosumers' involvement in the energy market. Furthermore, the regulation emphasises the use of renewable energy in areas like as heating, cooling, and transportation, while protecting the certification of energy sources.

In addition, this legislation establishes sustainability guidelines and reduces emissions of greenhouse gases in biofuels, bioliquids, and biomass-derived fuels.

The Montenegrin government is developing a three-year incentive scheme for market premiums and feed-in tariffs. This will have an impact on the establishing of yearly quotas, technologies, and capabilities. The Energy and Water Regulatory Agency of Montenegro (REGAGEN) shall determine the price cap for auctions under the new law [50].

Albania adopted Law No. 24/2023 “Promotion of the use of renewable energy sources”, which is primarily focused with the promotion and long-term deployment of renewable energy sources. This law is part of a national policy aiming at diversifying energy sources and maintaining security of energy in the Republic of Albania. It defines the national renewable energy objectives and the steps that will be taken to accomplish them. By 2030, the law requires 54.4% of total gross energy consumption to come from renewable sources. Furthermore, it establishes a support mechanism for renewable energy generation in the form of an energy purchase agreement, a contract for difference, or a premium contract. The law also establishes a category of "self-producers of renewable energy," which can include any small and medium-sized firm (SME) or residential customer. These self-producers are authorised to install up to 500 kW of capacity for self-consumption, as well as inject and sell any excess energy generated into the distribution network. This regulation is partially aligned with the EU acquis, notably the Directive 2018/2001 (RED II). Law No. 24/2023 overrides the previous Law No. 7/2017, which had the same scope.

North Macedonia is aggressively aligning its renewable energy policy "Law on Renewable Energy Sources" with European Union guidelines, with the goal of increasing the use of renewable energy sources and significantly reducing carbon emissions. The Energy Law of 2018, together with "Law on Renewable Energy Sources" 2023, serves as the foundation for the country's renewable energy policy framework. Key aims include reducing greenhouse gas emissions by 82% by 2030 and increasing renewable energy consumption to 45% by 2040. The institutional structure includes the Ministry of Economy's Department for Energy and the Energy and Water Services Regulatory Commission, which regulate and subsidise renewable energy projects. Despite these advances, North Macedonia still confronts significant problems, including challenging administrative procedures, limited grid capacity, and monopolistic actions by leading energy companies. To address such obstacles, solutions include improving governance, increasing transparency, and streamlining regulatory processes to encourage the growth of renewable energy projects. Addressing these difficulties is critical for the government to achieve its ambitious renewable energy and decarbonisation targets.

The Federation of Bosnia and Herzegovina (FBiH) adopted the "Law on the Use of Renewable Energy Sources and Efficient Cogeneration" in 2023, which regulates the promotion of renewable energy sources (RES) and efficient cogeneration (EC), as well as defining binding objectives for RES share in the FBiH's gross final energy consumption. It also establishes required targets for RES share in power generation, heating and cooling energy, and RES usage in transportation. The legislation defines further technologies for the use of RES and EC, investigates the potential of RES, and creates incentives for the generation of electricity and heat energy from RES and EC. It also contributes to environmental preservation, lowers reliance on fossil fuel imports, and helps Bosnia and Herzegovina meet the commitments it assumed by signing international treaties.

In an attempt to increase the amount of power produced from renewable sources, Serbia passed the Law on the Use of Renewable Energy Sources. The law, which went into force in 2021, specified how renewable energy must be used, established goals for its usage, and described how Serbia's share of renewable energy should be calculated in relation to gross final energy consumption. Guarantees regarding the origin of electric power are also included, as are incentive programmes for producing electricity from renewable sources and the market integration of renewable energy. The law establishes feed-in tariffs and market premiums as means of implementing incentive programmes for the generation of energy from renewable sources. Renewable energy sources can be used in the development or redevelopment of power plants to qualify for these incentives. A power plant that is still under construction cannot be the target of incentives, although they can be obtained for all or a portion of the plant's capacity.

With the goal of easing the transition to sustainable energy systems by 2025–2030, the Western Balkans area has launched strategic measures to create National Renewable Energy and Climate Plans (NECPs). These plans include a range of objectives and actions to increase the deployment of renewable energy, boost energy efficiency, and lower greenhouse gas emissions. They also comply with EU legislation and the acceleration phase of our Logistic Models Scenarios for WB6. Interestingly, the purpose of these NECPs is to reduce the region's reliance on fossil fuels and to lessen the effects of energy crises, even those that are made more acute by geopolitical instability. To guarantee a sustainable and balanced energy transition, the NECPs include targets for the percentage of renewable energy, particular decarbonisation goals, and the integration of climate resilience initiatives.

Each Western Balkan nation has customised its NECP to fit its own energy environment and socioeconomic circumstances. As an instance, North Macedonia's NECP provides a thorough framework for raising the proportion of renewable energy in the country's energy mix. It is backed by governmental initiatives and legal changes that make renewable energy projects easier to implement. In a similar vein, Serbia's NECP places a strong emphasis on encouraging energy communities and streamlining administrative procedures. Together, these strategies seek to remove current obstacles including grid infrastructure constraints, investment risks, and inefficiencies in administration, creating a condition that will support the expansion of renewable energy sources in the region.

Conclusions

According to the study's findings, adoption of renewable energy technologies (RETs) like solar and wind in the Western Balkan nations (WB6) starts off slowly, gains up acceleration, and then levels out as the market gets saturated.

By 2035, the diffusion model significantly contributes to the national energy transition goals by anticipating the rise of these technologies in WB6. Diffusion models' limitations the use of Gompertz and logistic models may not fully reflect the complexity of the diffusion process, particularly in areas with intricate socioeconomic dynamics of the Western Balkan Countries (WB6). The analysis assumes that the laws and regulations in place will not change quickly as they already have been updated by the external influence of the EU and the Energy Community, which will account for the potential energy-green transition shift.

Policymakers in the Western Balkans 6 (WB6) must put in place a system of stable financial incentives and strong regulatory backing. These kinds of actions are necessary to negotiate and remove the existing obstacles that limit the broad implementation of Renewable Energy Technologies (RETs). In addition to enabling an easier transition to sustainable energy sources, the thoughtful use of these incentives and regulations will guarantee the region's long-term energy security and economic stability. Practical implication for the projected 13.5 GW of solar and wind PV installed capacity is reached by 2034, the WB6 area will have significantly accelerated its transition to a sustainable period, in keeping with the goals of the EU Green Deal for energy transition. This significant expansion of the region's renewable energy capacity is a key step in the larger European effort to slow down climate change and demonstrates the region's commitment to a more environmentally friendly future.

A full understanding of the diffusion patterns of renewable energy technologies (RETs) is necessary in order to strategically create and implement policies that have the potential to accelerate the uptake of these technologies in the WB6 region. Policymakers may modify their strategies to successfully encourage the integration of RETs and accelerate the region's shift to a more environmentally friendly and sustainable energy landscape by recognising and comprehending these patterns.

Finally, it is critical that future research to be conducted to expand the analytical framework, which should include future changes in the political and economic landscapes. By doing so, the predictions would become more robust and offer a more complete picture of the region's prospects in relation to the transition to renewable energy. Including these dynamic elements is essential to creating a flexible and robust framework for energy planning and policy.

Furthermore, performing comparison studies with other countries at different stages of economic growth might provide priceless insights, especially for the grid integration cross-border power exchange. These studies would provide a balanced viewpoint that is diligent to the region's particular status, shedding light on the various possibilities and problems that the WB6 region faces within the energy sector. By using these comparative findings, stakeholders may develop more targeted and efficient strategies to capitalise on the region's unique strengths and overcome its limitations, ultimately leading to the achievement of sustainable energy goals.

Use of AI Tools Declaration

The author declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of Interest

The author declares no conflicts of interest.

Author Contributions

Conceptualization, analysing methodology, software, validation of data, formal analysis, resources, writing—original and final draft preparation.

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