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Description automatically generated**University of the West of England**

Department of Computer Science and Creative Technologies

**MSc Data Science**

**Dissertation**

**Title**: Energy Consumption Analysis and Visualization for Sustainability

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Abstract: Exploration into strategies for optimizing energy usage and enhancing energy efficiency across various sectors are necessary for the future. By analysing energy consumption data, the study identifies key behaviours, peak demand periods, and factors influencing consumption. These insights empower stakeholders to make informed, data-driven decisions and implement targeted interventions aimed at improving energy efficiency. By visualizing energy usage and pinpointing inefficiencies, the project contributes to reducing greenhouse gas emissions and conserving natural resources, ultimately fostering environmental sustainability. Additionally, the study demonstrates how energy efficiency improvements can lead to significant cost savings for communities by minimizing energy expenditures and affecting consumption. The research also advocates for the adoption of renewable energy sources, such as solar, wind, and hydropower, by highlighting their benefits and identifying integration opportunities country-wise. Finally, the dissertation underscores the importance of facilitating informed decision-making and catalysing behavioural change to promote energy conservation and sustainability. Through this comprehensive approach, the project aims to drive a shift toward more sustainable energy practices and promote a better future.

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1 Introduction and Objectives

In the contemporary world, the rising demand for energy, coupled with the environmental impacts of its production and consumption, has brought sustainability to the forefront of global concerns. Energy consumption is intricately linked with economic growth, societal development, and environmental preservation, making it a critical area of focus for governments, businesses, and communities alike. However, the path to achieving sustainable energy practices is fraught with challenges, including inefficient energy use, reliance on non-renewable resources, and the significant carbon footprint associated with traditional energy production.

The rapid advancements in technology and data analytics offer unprecedented opportunities to address these challenges. By leveraging data-driven insights into energy consumption patterns, stakeholders can identify inefficiencies, optimize resource allocation, and make informed decisions that align with sustainability goals.

The target is to set the stage for a comprehensive exploration of how energy consumption analysis and visualization can contribute to sustainability efforts. The focus is on not only understanding energy usage but also on taking actionable steps toward improving efficiency, reducing environmental impact, and promoting renewable energy.

1.1 Introduction

Energy consumption analysis and visualization play a pivotal role in this context, providing a clear, actionable understanding of how energy is used and where improvements can be made.

Focusing to explore and enhance the understanding of energy consumption behaviour through comprehensive analysis and visualization techniques provides the stakeholders with the tools and knowledge needed to drive energy efficiency, reduce environmental impact, and foster the adoption of renewable energy sources. By focusing on real-world data and practical applications, this research contributes to the global efforts towards a more sustainable energy future. setting the stage for a comprehensive exploration of how energy consumption analysis and visualization can contribute to sustainability efforts. The focus is on not only understanding energy usage but also on taking actionable steps toward improving efficiency, reducing environmental impact, and promoting renewable energy.

Diagram of a diagram of a diagram

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1.2 Objectives

Analyse Energy Consumption Patterns: Investigating the key factors influencing energy consumption across different sectors. Identify peak demand periods and usage trends to understand the drivers of energy consumption.

Enhance Energy Efficiency: Develop strategies to optimize energy use in the system. Identifying and promoting energy-saving measures and technologies that can be implemented to reduce overall consumption.

Mitigate Environmental Impact: Assessing the environmental implications of current energy consumption patterns, with a focus on greenhouse gas emissions and resource depletion. To align with environmental sustainability goals, including the reduction of carbon footprints through improved efficiency.

Promote Renewable Energy Adoption: Advocate for the integration of renewable energy sources, such as solar, wind, and hydropower, into existing energy systems. Identify opportunities for increasing the share of renewables in the energy mix.

Facilitate Informed Decision-Making: Provide stakeholders with data-driven insights to support effective energy management, infrastructure investment, and policy development. Enhance decision-making capabilities through the use of advanced data visualization tools that clearly communicate energy usage patterns and trends.

A diagram of energy efficiency

Description automatically generated1.3 Scope and Aim

Analysing and visualizing energy consumption data is crucial for identifying sustainability problems and finding solutions. Here's a step-by-step approach to tackle this: First, gather data on energy consumption from various, clean and preprocess the data to handle missing values, outliers, and inconsistencies through techniques like data imputation and normalization.

Conducting exploratory data analysis to gain insights into consumption patterns, exploring trends, seasonality, correlations, and anomalies. Create relevant features such as time of day, weather conditions, etc to provide context for analysis

Visualize data using techniques like time series plots, heatmaps, and histograms to communicate insights effectively.

- Time series plots: Show trends and patterns in energy consumption over time.

- Histograms and box plots: Analyses distribution and variability of energy consumption.

-Pie/donut chart**:** To represents the total energy consumption and production in gigawatt-hours (GWh) for various countries, the contribution of various types of renewable energy (Hydro, Wind, Solar, and Other Renewable Energy) to the total renewable energy production; and showing the sum of different types of renewable energy (likely including Solar, Hydro, and Other Renewable Energy) by country.

**-**The line graph overlays the stacked bars, representing the sum of total renewable energy production each year.

Comparing consumption patterns across different time periods, regions for benchmarking and optimization purposes. Use of optimization techniques to minimize consumption while maintaining operational requirements. Continuously monitor data, gather feedback, and iterate on the process to ensure alignment with evolving needs and priorities. Through these steps, organizations can implement targeted interventions to address sustainability challenges depending on their requirements.

1.4 Ethical, Legal and Professional Considerations

There are no ethical, legal, or professional restrictions on the use of the datasets that will be used in this study. This work contains no personal data of any sort. Research Data under the license of Attribution 4.0 International (CC BY 4.0) and the license of Creative Commons Corporation  (CC0 1.0 Universal). The datasets in these website is used for academic and research purposes only. Therefore, it doesn’t oppose any ethical, legal, or professional restrictions on its use.

1.5 Code, Data model and visualisation Availability (Repository)

Available at the GitHub repository.[( https://github.com/Sayen95/CST-dissertation.git)]

A diagram of a solar power system

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2 Literature Review

The  environmental impact of universities, focusing on calculating the carbon footprint of the University of Castilla-La Mancha (UCLM) using a hybrid environmentally extended input-output model in a multiregional framework. This novel approach allows for a more accurate assessment of both direct and indirect emissions. It highlights the significant contributions of indirect emissions, particularly from energy consumption, underscoring the need for comprehensive carbon management strategies. The review supports the necessity of universities to adopt holistic approaches encompassing all aspects of their operations to lead effectively in sustainability, emphasizing the potential for educational institutions to influence broader societal change towards environmental responsibility.

University of Edinburgh Sustainability Data Portal provides access to a wide range of sustainability data for the University of Edinburgh, including data on energy consumption, waste generation, and transportation. The data can be downloaded and used to create custom visualizations.

Sustainability at Australian Universities, the renewable energy transition technique is taken from the case study of Australian universities which suggest the perspective of solar and wind power can reduce the carbon emission. Comparative analysis is used to demonstrate the future carbon sustainability to reach the United Nations Sustainable Development Goals.

A magnifying glass and papers

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3 Methodology

**Data cleaning and preparation:** Using python scripts the dataset was cleaned to remove discrepancies and rows with missing data; also ensuring all the columns with relationship with other dataset used the same title.

**Data Integration and Modelling:** Using Power BI to combine data from different sources for comprehensive analysis, modelling and visualisation.

4 Results, Findings and Discussion:

4.1 Energy consumption trend(2000-2022)

A graph with blue lines

Description automatically generated

**Findings:**

**Fluctuations in Energy Consumption:** The graph reflects significant fluctuations in energy consumption from year to year. For example, there is a noticeable dip around 2009 and 2012, followed by peaks around 2010 and 2018.

**Periods of Decline:** The data shows distinct periods where energy consumption decreased, such as between 2009 and 2012, and again in 2017 and 2019.

**Recovery and Growth:** After each decline, there are periods of recovery where energy consumption increases. Notable peaks are visible in 2010, 2014, and 2018.

**Overall Trend:** Despite the fluctuations, the overall trend appears relatively stable, with no consistent long-term increase or decrease in energy consumption. However, the values seem to oscillate within a certain range.

**Recent Years:** In the most recent years, the graph shows a slight upward trend after a dip, indicating a possible recovery or increase in energy consumption post-2020.

**Discussion:**

According to the graph global or regional energy consumption is subject to various external factors, potentially including economic events, technological advancements, or policy changes. The sharp drops and subsequent recoveries could correlate with economic downturns or other significant global events.

4.2 Total renewable energy and its consumption and production country wise

A close-up of a graph

Description automatically generated

The visual representation you provided consists of two circular (donut/pie) charts

**Findings from the left Chart pie: Sum of Energy Consumption and Production (GWh) by Country**

Each segment of the donut chart represents a different country, with the size of the segment corresponding to the sum of energy consumption and production.

**Countries like the USA, China, and India** seem to have larger segments, indicating that they contribute significantly to global energy consumption and production.

**Other notable contributors** include countries like Germany, Brazil, and Japan, though their shares are smaller compared to the top contributors.

**Comparison:**

The chart suggests that energy consumption and production are concentrated among a few large economies, which is consistent with global trends where developed and emerging economies tend to have higher energy demands.

The nearly equal distribution between energy consumption and production implies that these countries are not only major consumers but also major producers of energy, which might include both renewable and non-renewable sources.

**Findings from the right pie chart: Sum of Different Types of Renewable Energy**

**Hydropower (Sum of Hydro-Energy)** appears to be the largest segment, suggesting it is the dominant form of renewable energy in the dataset.

**Wind and Solar Energy** also contribute significantly, though their shares are smaller compared to Hydropower.

**Other Renewable Energy Sources** (likely including bioenergy, geothermal, etc.) form a smaller but still notable portion of the total.

**Comparison:**

Hydropower is a major source of renewable energy, which aligns with global data where hydroelectric plants are some of the largest renewable energy installations.

The presence of Wind and Solar energy indicates growing adoption of these technologies, which is expected given the global shift towards cleaner energy.

The relatively smaller share of Other Renewable Energy types suggests that while diverse renewable technologies are in use, their overall contribution is still emerging compared to the more established ones like Hydro, Wind, and Solar.

**Discussion:**

**Energy Distribution:** The first chart highlights the concentration of energy consumption and production among a few key countries, indicating these nations' significant roles in the global energy landscape.

**Renewable Energy Breakdown:** The second chart emphasizes the predominance of hydropower in renewable energy production, while also showcasing the growing importance of wind and solar power.

These visualizations are useful for understanding which countries are the largest players in energy consumption and production, and which renewable energy sources are currently leading in terms of global production.

4.3 Sum of different types of renewable energy (2000-2022)

A graph of blue and orange bars

Description automatically generated

The visual representation provided is a stacked bar chart combined with a line graph, representing the sum of various types of renewable energy (Wind, Hydro, Solar, and Other Renewable Energy) by year.

**Key for Stacked Bar Chart of Renewable Energy Types by Year**

The bars are divided into different segments, each representing a specific type of renewable energy:

* + - **Wind Energy (purple)**
    - **Hydro Energy (dark blue)**
    - **Solar Energy (orange)**
    - **Other Renewable Energy (light blue)**

Each year, the sum of these components gives the total renewable energy produced.

**Findings (Trends Over Time):**

**Hydro Energy (dark blue):** Consistently the largest segment, indicating that hydropower is a major contributor to renewable energy production across all years.

**Wind Energy (purple):** Also shows a substantial contribution, especially in more recent years, reflecting the global trend of increasing wind energy adoption.

**Solar Energy (orange):** Though smaller in contribution compared to hydro and wind, solar energy is gradually increasing over the years.

**Other Renewable Energy (light blue):** This category remains relatively small, but its presence is consistent, indicating steady production from other sources such as biomass, geothermal, etc.

**Yearly Variations:** The total height of each bar represents the total renewable energy production for that year. The variation in bar heights suggests fluctuations in renewable energy production, likely influenced by policy changes, economic conditions, technological advancements, and other factors.

**Sum of Total Renewable Energy (Trends):** The line fluctuates, indicating the overall trend in total renewable energy production. Peaks and troughs suggest years of higher and lower production, respectively.

Despite some fluctuations, there is a general upward trend, especially noticeable in the later years, indicating growth in renewable energy capacity and output.

**Discussion:**

**Growth in Renewable Energy:** The chart illustrates a general increase in renewable energy production over time, driven primarily by wind and hydro energy.

**Significant Role of Hydro Energy:** Hydro energy consistently dominates the renewable energy mix, although wind and solar are increasingly contributing more to the total.

**Fluctuations:** The line graph highlights fluctuations in total renewable energy production, which could be attributed to various factors such as changes in weather patterns, investment levels, and technological advancements.

**Diversity in Renewable Sources:** The presence of multiple colours in the bars indicates that a mix of renewable energy sources is being utilized, with some sources like solar energy gaining prominence over time.

This visualization effectively conveys the trends in renewable energy production over time, highlighting the growing role of wind and solar energy, the dominance of hydropower, and the overall increase in renewable energy output globally.

4.4 Renewable electricity generation per capita in comparison to sum of electric from non-renewables (2000-2020)

A graph with a red line and blue bars

Description automatically generated

The visual representation you provided is a combination of a stacked bar chart and a line graph. It illustrates trends in electricity generation capacity and production from different sources over time.

**Key for Stacked Bar Chart of Renewable Electricity Generation Capacity and Production**

The stacked bar chart shows different sources of electricity generation:

**Sum of Renewable-Electricity-Generating Capacity per Capita (light blue):** Represents the per capita capacity for generating renewable electricity. This metric increases steadily over time, reflecting growth in renewable energy infrastructure.

**Sum of Electricity from Renewables (dark blue):** This segment shows the total electricity produced from renewable sources .The increase in this segment suggests that more electricity is being generated from renewable sources over time.

**Key for Line Graph of Electricity from Fossil Fuels and Nuclear**

**Sum of Electricity from Fossil Fuels (orange line):** This line tracks the total electricity generated from fossil fuels (coal, oil, natural gas). The line shows a consistent upward trend, indicating that despite growth in renewables, fossil fuels continue to contribute significantly to electricity generation.

**Sum of Electricity from Nuclear (purple line):** This line represents the electricity generated from nuclear power. It is relatively flat, indicating that nuclear energy's contribution to electricity generation has remained stable over time.

**Findings:**

**Growth in Renewable Energy:** The stacked bar chart shows a clear increase in both renewable energy capacity per capita and the actual production of electricity from renewable sources. This trend reflects global investment in renewable energy as a means of reducing carbon emissions and transitioning to cleaner energy sources.

**Continued Dependence on Fossil Fuels:** Despite the growth in renewables, the orange line indicates that electricity generation from fossil fuels has also increased over time. This suggests that fossil fuels remain a dominant source of energy, although their growth rate may not be as steep as that of renewables.

**Stable Nuclear Energy Production:** The flat purple line suggests that nuclear energy's role in electricity generation has not seen significant growth or decline. It remains a steady, albeit less dynamic, contributor compared to fossil fuels and renewables.

**Trend Over Time:** The height of the bars increases consistently over time, indicating that both renewable electricity generating capacity and actual production are growing. This reflects global efforts to expand renewable energy infrastructure and increase renewable energy output.

**Discussion:**

**Energy Transition:** The chart highlights the ongoing transition towards renewable energy, with significant increases in both capacity and production. However, it also underscores the continued importance of fossil fuels in the global energy mix.

**Balancing Act:** The steady growth in fossil fuel-based electricity generation alongside renewables suggests that while there is progress towards cleaner energy, there is still a reliance on traditional energy sources to meet global energy demands.

**Nuclear Stability:** The stable contribution of nuclear energy suggests it plays a consistent role, possibly due to its capacity for reliable baseload power generation, even as other sources fluctuate.

This visualization provides a comprehensive overview of the dynamics in electricity generation from different sources over time, highlighting both the progress and challenges in the global energy transition.

4.5 Global distribution of renewable energy production

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The visual representation is a donut chart showing the sum of different types of renewable energy (likely including Solar, Hydro, and Other Renewable Energy) by country. Each segment represents a country, with the size of the segment indicating that country's contribution to the total renewable energy production from these sources.

**Findings:**

**Distribution of Renewable Energy by Country:**

**India (Blue):** Appears to have the largest segment, indicating that it has a significant share in the production of renewable energy, particularly from sources like solar and hydro energy.

**France (Dark Blue) and China (Teal):** These countries also have large segments, suggesting they are major contributors to global renewable energy production.

**Other Notable Countries:** Brazil, the USA, and Canada have moderately sized segments, showing their contributions are also substantial but not as dominant as India or China.

**Proportion of Renewable Energy Types:**

**Sum of Solar, Hydro, and Other Renewable Energy:** The chart likely represents these three types of renewable energy, although the exact breakdown for each country isn’t directly visible in the donut chart. However, the overall size of each segment suggests how much each country contributes to the combined total of these renewable energy types.

**Diversity of Contributors:** The variety of colours and sizes in the donut chart indicates that while a few countries dominate, many other nations contribute smaller but still significant portions to the global renewable energy mix.

**Global Renewable Energy Landscape:** The chart provides a snapshot of the global distribution of renewable energy production, emphasizing the contributions of both large and smaller economies to the global energy transition.

**Discussion (Insight for decision-making):**

**India, China, and France** stand out as major producers of renewable energy, particularly in solar, hydro, and other categories, which aligns with their significant investments in renewable infrastructure.

**The USA, Brazil, and Germany** also make notable contributions, reinforcing their roles as leaders in renewable energy, though on a somewhat smaller scale compared to the top three.

The diversity in the distribution highlights a global effort, with many countries participating in the shift towards renewable energy.

This chart is useful for understanding how different countries contribute to global renewable energy production, with a clear emphasis on the top contributors.

4.6 CO2 Emission in respective to its investments(2000-2022)

A graph with blue lines

Description automatically generated

The visual representation provides a combined bar and line graph that tracks the "Sum of CO2 Emissions (kt)" and the "Sum of Investments (USD)" over the years

**Findings from Bar Chart for Sum of CO2 Emissions (kt)-(CO2 Emissions Trend):**

The height of the bars represents the total CO2 emissions in kilotons (kt) for each year.

There is a noticeable fluctuation in CO2 emissions over the years, with peaks and troughs indicating varying levels of emissions.

**Higher Emissions Periods:** Some years show significantly higher emissions, such as around 2005, 2010, and 2015.

**Lower Emissions Periods:** There are also noticeable dips in emissions, particularly around 2003, 2008, and 2020.

**Findings from Line Graph for Sum of Investments (USD)-(Investment Trend):**

The line graph tracks the amount of investment in USD, which could be related to renewable energy, environmental policies, or other relevant sectors.

The line also fluctuates, but there appears to be an overall trend of increasing investments, particularly after 2015.

**Peak Investment Years:** There are peaks in investment during certain years, such as 2010 and 2015, and again around 2020.

**Investment Dips:** There are also years where investment significantly decreases, like in the early 2000s and around 2013.

**Discussions and insights:**

**The graph illustrates a complex interplay between CO2 emissions and investments in relevant sectors (likely renewable energy or environmental policies).** While increased investments often correspond with reduced or stabilized emissions, other factors clearly influence emissions levels, as evidenced by the fluctuations.

**This visualization highlights the importance of consistent and sustained investment to achieve significant and lasting reductions in CO2 emissions**, indicating that while progress is being made, more work is needed to ensure that emissions continue to decrease over time.

**Inverse Relationship Between Emissions and Investments:** The visual suggests a potential inverse relationship between CO2 emissions and investments, particularly in the renewable sector. For example, during years when investments peak, CO2 emissions often dip or do not increase as sharply.

**Possible Interpretation:** Increased investment in renewable energy or other environmental initiatives could be contributing to reductions in CO2 emissions during certain periods. However, this relationship is not consistent every year, indicating that other factors are also influencing CO2 emission levels.

**CO2 Emission Volatility:** The volatility in CO2 emissions over the years might reflect economic cycles, changes in energy production methods, industrial activity, or the implementation of environmental regulations.

The spikes in emissions could correspond to periods of economic growth or increased industrial activity, while the drops might be associated with economic downturns, increased regulation, or the adoption of cleaner technologies.

**Investment Patterns:** The pattern of increasing investment over time, especially in recent years, aligns with global trends towards more significant investments in sustainable energy and technologies aimed at reducing carbon footprints.

4.7 GDP and GDP per capita(2000-2020)

A graph showing a graph

Description automatically generated with medium confidence

The visual representation provides an area chart that shows the trends in "GDP Growth" and "GDP Per Capita" over time.

**Key Components of the Chart:**

**GDP Growth (Light Blue Area and Line):**

This represents the aggregate GDP growth over the years.

The left y-axis measures the "Sum of GDP Growth," likely in percentage terms.

**GDP Per Capita (Dark Blue Area and Line):**

This represents the sum of GDP per capita over the years.

The right y-axis measures the "Sum of GDP Per Capita," typically in USD.

**Findings (Trends Over Time):**

**Early 2000s:**

**GDP Growth:** Starts at a moderate level, with fluctuations indicating varying rates of economic growth across countries or regions.

**GDP Per Capita:** Also begins at a lower level but shows a gradual increase as the decade progresses.

**Mid-2000s (2005-2010):**

**GDP Growth:** The light blue area peaks sharply around 2005-2007, indicating a period of strong economic growth. This could correlate with global economic expansion during this time.

**GDP Per Capita:** The dark blue area also shows a consistent upward trend, reflecting increasing average incomes across countries.

**Post-2008 Financial Crisis:**

**GDP Growth:** There is a noticeable dip around 2008-2010, corresponding with the global financial crisis, which caused widespread economic contraction.

**GDP Per Capita:** The impact is less pronounced on GDP per capita, but growth slows, and the chart reflects a more modest increase.

**2010-2020:**

**GDP Growth:** After a brief recovery, GDP growth appears to fluctuate, with a gradual decline after 2015. This could reflect various economic challenges, including slowdowns in global growth, trade tensions, or other economic factors.

**GDP Per Capita:** Continues to rise until around 2015, after which it appears to stabilize and slightly decline by 2020. This suggests that while economies may have grown overall, the benefits per individual (in terms of GDP per capita) started to plateau or decrease.

**Discussion and Insights:**

**Economic Growth Cycles:** The chart reflects the cyclical nature of global economic growth, with periods of rapid expansion followed by slowdowns or contractions.

**GDP Per Capita vs. GDP Growth:** While GDP growth reflects the overall economic performance, GDP per capita gives an idea of how this growth is translated into individual wealth or income. The divergence after 2015 suggests that even as some economies grew, this growth may not have been evenly distributed or felt at the individual level.

**Impact of Global Events:** The sharp decline in GDP growth around 2008 and the more recent decline after 2015 align with known economic challenges, such as the global financial crisis and the subsequent slow recovery, followed by more recent economic uncertainties.

This chart provides a broad overview of economic performance over two decades, highlighting the interaction between total economic growth and per capita income. It suggests that while there were periods of strong growth, there were also significant challenges that impacted both overall GDP growth and the benefits felt by individuals.

4.8 Primary consumption in respect to the renewable electricity generation capacity per capita(2000-2020)

A graph showing a line going up

Description automatically generated

The visual representation provides a combined bar and line chart that tracks the "Sum of Primary Energy Consumption per Capita (kWh/person)" and the "Sum of Renewable Electricity Generating Capacity per Capita" over the years. Here's an interpretation based on the likely data:

**Findings from Bar Chart for Primary Energy Consumption per Capita (kWh/person)**

**Energy Consumption Trend:**

The bars represent the sum of primary energy consumption per person, measured in kilowatt-hours (kWh/person), over time.

The height of the bars varies, indicating fluctuations in energy consumption per capita over the years.

**Early 2000s:** The bars start at a moderate level and then show some fluctuations with periods of growth and slight declines.

**Mid-2000s to 2010:** There is a general increase in energy consumption per capita, with some stabilization around 2007-2010.

**2010s to 2020:** After some fluctuations, there is a more consistent pattern of growth in energy consumption per capita, peaking around 2015 before stabilizing slightly.

**Findings from Line Graph for Renewable Electricity Generating Capacity per Capita**

**Renewable Capacity Trend:**

The line graph represents the sum of renewable electricity-generating capacity per capita, likely measured in kWh/person.

The line shows a consistent upward trend, particularly from around 2010 onwards, indicating a steady increase in the capacity for generating renewable electricity on a per-person basis.

**Early 2000s:** The growth is modest, reflecting the early stages of renewable energy adoption.

**Post-2010:** There is a noticeable acceleration in the increase of renewable generating capacity per capita, indicating significant investments and expansion in renewable energy infrastructure.

**Discussion and Insights:**

The graph illustrates the positive trend of increasing renewable energy capacity, which is crucial for transitioning to a more sustainable energy system.

At the same time, the increase in primary energy consumption per capita highlights the need for continuous growth in renewable energy to keep pace with rising energy demands and reduce the environmental impact.

This chart effectively conveys the progress being made in expanding renewable energy while also highlighting the ongoing challenge of managing and potentially reducing per capita energy consumption.

**Growth in Renewable Energy Capacity:** The line graph's upward trend highlights a significant increase in renewable electricity-generating capacity per capita, especially in the last decade. This suggests that countries are increasingly investing in renewable energy infrastructure, leading to more renewable energy being available per person.

**Stable or Increasing Energy Consumption:** The bar chart shows that primary energy consumption per capita has generally increased over time, albeit with fluctuations. This indicates that as populations grow and economies develop, energy consumption per person tends to rise, placing more demand on energy systems.

**Balancing Energy Needs with Renewable Growth:** The simultaneous rise in energy consumption and renewable energy capacity suggests a global effort to meet growing energy demands with cleaner, more sustainable sources. However, the consistent increase in energy consumption also underscores the ongoing challenge of reducing dependence on fossil fuels and lowering overall carbon emissions

4.9 Economic Freedom and Ease of Doing Business

A graph with blue lines

Description automatically generated

The visual representation provides a combined bar and line chart showing the "Sum of Economic Freedom Index" and the "Sum of Ease of Doing Business" over the years.

**Findings from Bar Chart of Sum of Economic Freedom Index**

**Economic Freedom Index:**

The bars represent the aggregate Economic Freedom Index for each year. The Economic Freedom Index typically measures the degree to which the policies and institutions of a country are supportive of economic freedom, often including factors like business freedom, trade freedom, fiscal health, and property rights.

The height of the bars fluctuates, indicating variations in economic freedom over the years.

**Early 2000s:** The index starts relatively high and shows some fluctuations, with a noticeable dip around 2005.

**2005-2015:** The index shows a gradual increase, peaking around 2010 and again around 2015, suggesting periods of enhanced economic freedom.

**2015-2020:** There are fluctuations with slight declines and recoveries, indicating varying levels of economic freedom in recent years.

**Findings from Line Graph of Sum of Ease of Doing Business**

**Ease of Doing Business:**

The line graph tracks the ease of doing business over time. The Ease of Doing Business index typically measures regulatory efficiency, including the ease of starting a business, dealing with construction permits, getting electricity, registering property, and enforcing contracts.

The line fluctuates, indicating that the ease of doing business has experienced ups and downs over the years.

**Early 2000s:** There is a gradual increase in the ease of doing business, peaking around 2005.

**2005-2015:** The index declines slightly after 2005, then recovers around 2010 before fluctuating again.

**2015-2020:** The index shows some volatility but trends slightly upward towards 2020.

**Discussion and Insights:**

**Economic Conditions and Business Environment:** The chart reflects the dynamic nature of economic freedom and the ease of doing business over time. Changes in these indices could be driven by economic reforms, shifts in government policies, or global economic conditions.

**Long-Term Trends:** While there are fluctuations, the general trend suggests efforts to improve both economic freedom and the business environment, especially towards the latter half of the observed period.

**Areas for Improvement:** The fluctuations also highlight the challenges and potential areas for improvement, indicating that maintaining a consistent and supportive environment for economic freedom and business operations can be complex and influenced by various external and internal factors.

**Fluctuations in Economic Freedom:** The Economic Freedom Index shows several peaks and troughs, suggesting that policies and institutions supporting economic freedom have varied over the years. The overall trend indicates periods of increased freedom followed by slight contractions.

**Variability in Business Environment:** The Ease of Doing Business line shows that the regulatory environment has also experienced changes, with improvements and setbacks. This could be due to changes in regulations, economic conditions, or political factors.

**Potential Correlation:** There may be a correlation between the Economic Freedom Index and the Ease of Doing Business, as both indices are influenced by similar factors, such as regulatory policies and institutional efficiency. Periods where the Economic Freedom Index increases may coincide with improvements in the Ease of Doing Business, although the relationship is not perfectly linear.

4.10 Sustainability in terms of consumption country-wise(2000-2022)

A graph of colorful lines

Description automatically generated

The visual representation is a multi-line chart that tracks the "Sum of Energy Consumption" over time (by year) for various countries. Each line represents a different country, allowing for a comparative analysis of energy consumption trends among these nations.

**Key Components of the Chart:**

**X-Axis (Year):** Represents the years from 2000 to 2020.

**Y-Axis (Sum of Energy Consumption):** Represents the total energy consumption, likely in a consistent unit such as gigawatt-hours (GWh) or megawatt-hours (MWh).

**Lines Representing Different Countries:** Each country is represented by a distinct color, with labels indicating which color corresponds to which country.

**Findings (Trends and Patterns):**

**Fluctuations in Energy Consumption:**

The chart shows significant fluctuations in energy consumption for all countries over time.

**Sharp Peaks and Troughs:** Countries like the USA (green) and China (red) show more significant peaks and troughs, indicating periods of rapid increases or decreases in energy consumption. This could reflect economic booms, recessions, changes in industrial output, or energy policy shifts.

**Comparative Energy Consumption:**

**USA and China:** These two countries often exhibit higher peaks, reflecting their large economies and substantial industrial bases, which consume a vast amount of energy.

**Germany, Japan, and France:** These countries (represented by various colors) tend to show more stable, though still fluctuating, energy consumption trends. Their peaks are generally lower than those of the USA and China, which is consistent with their smaller populations or more energy-efficient economies.

**India and Brazil:** These countries show varied energy consumption trends, often with noticeable peaks, reflecting their emerging economy status with growing energy demands.

**Discussion and Insights:**

This multi-line chart effectively shows the relative energy consumption trends of major economies over two decades.

**For countries like the USA and China,** significant peaks and troughs may correlate with economic cycles, shifts in industrial production, or policy changes.

**For other countries,** the more stable trends may reflect a more consistent energy demand, possibly due to greater energy efficiency or a different economic structure.

**Diversity in Energy Consumption:** The diversity of the lines indicates that while some countries experience similar energy consumption trends, others may have quite different patterns. This could be due to differences in economic growth, energy efficiency, industrialization levels, population growth, or energy policy changes.

**High Variability:** The chart underscores the high variability in energy consumption across different countries and over time. This variability could be due to several factors, including changes in energy production capacity, economic growth, shifts in energy policies, and external factors such as global economic crises.

**Global Trends:** The chart may reflect broader global trends, such as increased energy consumption in rapidly developing economies (like China and India) or more stable consumption in mature economies (like the USA, Germany, and Japan).

**Economic Indicators:** Energy consumption is often a proxy for economic activity, and the trends observed may correlate with periods of economic expansion or contraction in these countries.

4.11 Renewable energy in total consumption country-wise(2000-2020)

A graph of different colored lines

Description automatically generated

The visual representation provides a multi-line chart that tracks the "Sum of Renewable Energy Share in Total Final Energy Consumption (%)" over time (by year) for various countries. Each line represents a different country, and the chart allows for a comparative analysis of how the share of renewable energy in total energy consumption has evolved in these nations.

**Key Components of the Chart:**

**X-Axis (Year):** Represents the years from 2000 to 2020.

**Y-Axis (Sum of Renewable Energy Share in Total Final Energy Consumption %):** Represents the percentage of total energy consumption that comes from renewable sources.

**Lines Representing Different Countries:** Each country is represented by a distinct colour, with labels indicating which colour corresponds to which country.

**Findings (Trends and Patterns):**

**Decreasing Trends:** Some countries, like **Morocco (yellow)** and **Sri Lanka (olive green)**, show a declining share of renewable energy in their total final energy consumption. This decline could be due to increased reliance on non-renewable energy sources, economic growth leading to higher energy consumption that outpaces renewable energy production, or changes in energy policy.

**Stable or Slightly Increasing Trends: Brazil (dark green)** and **India (orange)** exhibit relatively stable trends, with minor fluctuations. This could indicate that while these countries are increasing their overall energy consumption, they are also managing to maintain or slightly increase the share of renewables.

**Increasing Trends:** Countries like **Pakistan (light blue)** and **Ecuador (light pink)** show a slight increase in their renewable energy share. This suggests growing investments in renewable energy or more aggressive policies to increase the use of renewables in the energy mix.

**High Initial Share with Decline: South Africa (purple)** and **Philippines (magenta)** start with a high share of renewables but show a noticeable decline over time. This could be due to a relative increase in fossil fuel consumption or other non-renewable energy sources, even as their total energy demand grows.

**Discussion and Key Insights:**

The multi-line chart provides a clear comparison of how different countries have managed their renewable energy shares in total final energy consumption over two decades.

**Countries with increasing or stable trends** may serve as examples of successful energy policy and investment in renewables.

**Countries with declining trends** highlight the challenges of sustaining renewable energy growth in the face of rising energy demands and possibly insufficient renewable energy capacity expansion.

**Diverse Approaches to Renewable Energy:** The chart highlights the diversity of approaches and outcomes across different countries regarding renewable energy adoption. Some countries have managed to increase their share of renewables, while others have seen declines.

**Economic and Policy Impacts:** Countries that show increasing or stable renewable energy shares may be those that have implemented effective policies, made significant investments in renewable energy infrastructure, or have natural advantages (e.g., abundant hydro resources).

Declining trends could be due to factors like economic growth leading to increased energy consumption, shifts towards more fossil fuel use, or challenges in expanding renewable energy capacity fast enough to meet growing demand.

**Global Energy Transition Challenges:** The varying trends reflect the complex challenges involved in the global energy transition. While some countries are making progress, others may face difficulties in maintaining or increasing their renewable energy share, especially as their energy needs grow.

4.12 Energy consumption versus Efficiency programs(2000-2022)

A graph with blue lines

Description automatically generated

The visual representation is a combined bar and line chart that tracks the "Sum of Energy Consumption" and the "Sum of Energy Efficiency Programs" over time (by year). Each component of the chart provides insight into how energy consumption and the implementation of energy efficiency programs have evolved over the years.

**Findings from the Bar Chart of Sum of Energy Consumption**

**Energy Consumption Trend:**

The bars represent the sum of energy consumption, likely measured in megawatt-hours (MWh) or gigawatt-hours (GWh), for each year.The height of the bars fluctuates, indicating varying levels of energy consumption over the years.

**Early 2000s:** Energy consumption begins at a moderate level with some fluctuations.

**Mid-2000s:** The bars show periods of higher energy consumption, peaking around 2010 and again in the mid-2010s.

**Late 2010s to 2020:** Energy consumption appears more volatile, with periods of both high and lower consumption.

**Findings from the Line Graph of Sum of Energy Efficiency Programs**

**Energy Efficiency Programs Trend:**

The line graph represents the sum of energy efficiency programs implemented each year, with the right y-axis showing the scale (likely the number of programs or an index value).The line shows fluctuations, indicating that the number or effectiveness of energy efficiency programs has varied over the years.

**Early 2000s:** There is an initial rise in energy efficiency programs, reaching peaks around 2005 and 2010.

**2010-2020:** The number or effectiveness of energy efficiency programs shows considerable volatility, with noticeable peaks followed by declines.

**Discussion and Insights:**

**Relationship Between Energy Consumption and Efficiency Programs:** The chart suggests a complex relationship between energy consumption and energy efficiency programs. For example, in some years where energy efficiency programs peak, there is a corresponding decline or stabilization in energy consumption, indicating that these programs might be effective in reducing or managing energy consumption. However, this relationship is not consistent every year. There are periods where both energy consumption and energy efficiency programs increase or decrease simultaneously, suggesting that other factors (e.g., economic growth, industrial activity) might influence energy consumption beyond just the number of efficiency programs.

**Volatility in Both Metrics:** Both energy consumption and energy efficiency programs exhibit volatility, indicating that external factors (such as economic conditions, technological advancements, policy changes) significantly impact these trends. The significant dips in energy efficiency programs, especially post-2015, could suggest challenges in maintaining or expanding these programs, possibly due to shifts in policy, funding, or changes in priority.

**Recent Trends (Post-2015):** There is a noticeable decline in energy efficiency programs after 2015, followed by a partial recovery in 2020. This decline could be associated with reduced focus on efficiency measures, economic downturns, or other policy shifts during this period. Energy consumption, while also volatile, shows periods of stabilization in the late 2010s, which may suggest that, despite fewer efficiency programs, other factors helped keep consumption in check.

The chart provides an overview of how energy consumption and the implementation of energy efficiency programs have evolved over the past two decades. It highlights the potential impact of efficiency programs on managing energy consumption but also underscores the volatility and complexity of these trends.

**Periods of increased energy efficiency programs** often correlate with stabilization or reduction in energy consumption, suggesting effectiveness, but the inconsistency in this relationship indicates that broader economic or structural factors also play a significant role.

**The decline in efficiency programs post-2015** may point to challenges in sustaining these efforts, possibly requiring renewed focus or innovative approaches to continue making progress in energy efficiency.

4.13 Energy consumption and primary consumption per capita(2000-2020)

A graph with blue lines

Description automatically generated

The visual representation is a combined line chart that tracks two metrics over time: the "Sum of Energy Consumption" and the "Sum of Primary Energy Consumption per Capita (kWh/person)." Each metric is represented by a distinct line, allowing for a comparative analysis of overall energy consumption versus per capita energy consumption trends over the years.

**Key Components of the Chart:**

**X-Axis (Year):** Represents the years from 2000 to 2020.

**Left Y-Axis (Sum of Energy Consumption):** This axis, measured in units such as megawatt-hours (MWh) or gigawatt-hours (GWh), tracks the total energy consumption.

**Right Y-Axis (Sum of Primary Energy Consumption per Capita):** This axis, measured in kilowatt-hours per person (kWh/person), tracks the average energy consumption per individual.

**Two Lines:**

**Blue Line (Sum of Energy Consumption):** Represents the total energy consumption across all entities included in the dataset.

**Purple Line (Sum of Primary Energy Consumption per Capita):** Represents the average energy consumption per capita.

**Findings (Trends and Patterns):**

**Overall Energy Consumption (Blue Line):**

The total energy consumption shows significant fluctuations over the years.

**Early 2000s:** There is a gradual increase followed by a period of decline, suggesting periods of increased energy demand followed by a reduction, possibly due to economic or policy shifts.

**Mid-2000s to 2010:** The trend shows an increase, peaking around 2010, which could be associated with economic growth or industrial expansion.

**Post-2010:** The energy consumption fluctuates more dramatically, with sharp peaks and troughs, indicating a volatile energy demand or supply situation. The low point around 2020 may reflect the impact of significant global events, such as economic slowdowns.

**Per Capita Energy Consumption (Purple Line):**

Per capita energy consumption shows a generally increasing trend until around 2015, after which it stabilizes and slightly declines.

**Early 2000s to 2010:** There is a steady rise in per capita energy consumption, indicating that, on average, individuals were using more energy, likely due to increased access to energy, economic development, or rising living standards.

**Post-2015:** The line stabilizes and slightly declines, suggesting that while total energy consumption may have fluctuated, the average per capita consumption has become more stable or even reduced slightly, possibly due to energy efficiency measures, shifts in population, or other factors.

**Discussion and Insights:**

**Divergence Between Total and Per Capita Consumption:** In some periods, total energy consumption increases while per capita consumption remains stable or declines. This could indicate population growth, where more people share the total energy consumption, leading to a lower per capita figure. The sharp declines in total energy consumption during specific years are more pronounced than the changes in per capita consumption, suggesting that these might be driven by larger-scale economic or industrial shifts rather than changes in individual behaviour.

**Impact of Global Events:** The fluctuations in the blue line (total energy consumption) could be reflective of global events such as economic recessions, policy changes, or significant disruptions (e.g., financial crises or the impact of global pandemics).

**Energy Efficiency and Population Growth:** The stabilization of per capita consumption after 2015 could indicate improved energy efficiency, where advances in technology or energy-saving measures result in stable or reduced energy use per person, even as the total consumption varies.

The chart suggests that while total energy consumption has experienced significant volatility, per capita energy consumption has shown a more stable trend, especially in the later years. This pattern indicates that, despite fluctuations in total energy demand, efforts to manage energy use per individual (possibly through efficiency measures) may have been effective. The divergence between the two lines in certain years may also highlight the impact of population growth or shifts in energy use patterns, where total consumption can rise or fall without significantly affecting per capita consumption.

4.14 CO2 Emission affecting Annual Temperature(2000-2022)

A graph of blue lines

Description automatically generated

The visual representation is a combined bar and line chart that tracks the "Sum of Average Annual Temperature" and the "Sum of CO2 Emissions (kt)" over time (by year). This chart provides insight into the relationship between average annual temperature and CO2 emissions over a period of time.

**Key Components of the Chart:**

**X-Axis (Year):** Represents the years from 2000 to 2020.

**Left Y-Axis (Sum of Average Annual Temperature):** Likely represents the aggregated sum of average annual temperatures across the dataset's countries or regions. This is displayed as the height of the bars.

**Right Y-Axis (Sum of CO2 Emissions in kilotons (kt)):** Represents the total CO2 emissions measured in kilotons, depicted by the line graph.

**Two Metrics:**

**Blue Bars (Sum of Average Annual Temperature):** Represent the sum of average annual temperatures across the dataset.

**Dark Blue Line (Sum of CO2 Emissions):** Represents the total CO2 emissions for each year.

**Findings (Trends and Patterns):**

**Average Annual Temperature (Blue Bars):**

The sum of average annual temperatures shows some fluctuations over time.

**Early 2000s:** The temperature appears to start at a moderate level and remains relatively stable with slight fluctuations until around 2010.

**Post-2010:** There is noticeable variability, with the temperature sum peaking and then declining around 2015. The fluctuations suggest potential variations in average global or regional temperatures.

**CO2 Emissions (Dark Blue Line):**

The CO2 emissions line shows more dramatic fluctuations.

**Early 2000s to 2010:** Emissions generally increase, peaking around 2010, which could correlate with industrial growth and higher energy consumption.

**Post-2010:** The line shows sharp drops and peaks, indicating significant changes in CO2 emissions over the years. There is a notable peak around 2015, followed by a decline, and then a slight recovery towards the end of the period.

**Discussion and Insights:**

**Relationship Between Temperature and CO2 Emissions:**

While the chart shows both temperature and CO2 emissions trends, the relationship is not directly linear in this representation. However, both variables exhibit fluctuations that might suggest complex interactions influenced by broader environmental, economic, and policy-related factors.

**Post-2015 Trends:** After 2015, the sum of average temperatures declines, while CO2 emissions also decrease. This could indicate the impact of international climate agreements or shifts in energy production methods, though the relationship is likely influenced by many factors.

**Impact of Global or Regional Factors:**

The variability in CO2 emissions could be tied to economic activity, energy use, and industrial output. Peaks in emissions may correspond with periods of economic growth, while declines might reflect economic downturns, policy interventions, or technological advances in energy efficiency.

The variability in the temperature sum could reflect changes in global or regional climate conditions, possibly influenced by the effects of CO2 emissions and other greenhouse gases.

**The chart provides a visual comparison of trends in CO2 emissions and average annual temperatures over two decades.**

**Fluctuations in CO2 emissions** likely reflect changes in economic activity, energy consumption, and policy interventions. These fluctuations might also contribute to changes in temperature, though the relationship is complex and influenced by numerous factors.

**The variability in temperature** over time may indicate the broader impacts of climate change, though this chart alone does not provide sufficient detail to draw direct causal relationships between temperature changes and CO2 emissions without further analysis.

This chart highlights the dynamic nature of environmental metrics over time and the importance of understanding the interplay between emissions and climate variables.

5 Research Limitations

**Data Availability and Quality:**

**Limited Access to Comprehensive Data:** The analysis in this dissertation relies on datasets sourced from platforms like Kaggle, which may not offer the most comprehensive or up-to-date data. Some datasets may lack critical variables or have missing data points, potentially affecting the accuracy and depth of the analysis.

**Data Accuracy and Reliability:** The accuracy of the conclusions drawn in this study is contingent on the quality of the datasets used. If the original data contains inaccuracies, biases, or is outdated, these issues may affect the validity of the research findings.

**Scope of Data:**

**Geographical and Temporal Constraints:** The datasets analysed may only cover specific regions or time periods, limiting the generalizability of the findings to other regions or timeframes. For example, trends observed in one country may not be applicable to others with different energy infrastructures, economic conditions, or policy environments.

**Granularity of Data:** The level of detail available in the datasets (e.g., data aggregated at a national level rather than at a more granular regional or city level) may limit the ability to identify localized patterns or specific areas where energy efficiency interventions might be most effective.

**Methodological Limitations:**

**Analysis Techniques:** The choice of analytical methods and visualization techniques can influence the findings. Certain patterns or trends may only be visible using specific methods, meaning alternative approaches could yield different insights.

**Assumptions in Data Modelling:** The research may involve certain assumptions in data modelling (e.g., linear relationships between variables, constant energy prices) that do not fully capture the complexity of real-world energy consumption behaviours and dynamics.

6 Conclusion

Utilizing the dataset collected(2000-2022) I concluded:

In terms of Energy Production & Consumption: The data collectively suggests that while there is progress towards greater use of renewable energy, overall energy consumption continues to rise, and reliance on fossil fuels remains substantial. These trends emphasize the need for continued efforts in energy efficiency, policy intervention, and technological innovation to further reduce the environmental impact and enhance the sustainability of global energy systems.

In terms of Economics: The visual data collectively suggests that while there have been positive trends in economic freedom, business conditions, and GDP growth, these have not consistently translated into environmental sustainability. The variability in CO2 emissions and the mixed results of investments in mitigating them point to the need for more integrated and effective economic policies that balance growth with sustainability goals. Continued monitoring and refinement of both economic and environmental strategies are essential to achieving long-term economic stability and environmental health.

In terms of Environmental Impact and Sustainability : The visual data highlights both progress and ongoing challenges in the realm of environmental impact and sustainability. While renewable energy capacity is growing, and there are efforts to improve energy efficiency, the fluctuating trends in CO2 emissions, natural disasters, and energy consumption suggest that more consistent and comprehensive strategies are needed. These strategies should focus on expanding renewable energy adoption, enhancing energy efficiency, and addressing the root causes of environmental degradation to achieve true sustainability.

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8 Appendices

8.1 Appendix A– CODE , DATA MODEL, VISUALISATION AND DATA SET REPOSITORY

Available at the GitHub repository.[( https://github.com/Sayen95/CST-dissertation.git)]

8.2 Appendix B – VIDEO SUBMISSION