International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

Trends: Energy Efficiency and Energy Security

Jerusha Joseph[1,*] and Freddie L. Inambao[1]

[1]*Department of Mechanical Engineering, University of Kwazulu-Natal Durban, South Africa.*

**Orcid: 0000-0001-9922-5434*

Abstract

As awareness is growing that the carbon emissions on our planet are excessive, there are ongoing efforts to arrest the increase. The nature of the initiatives and methodologies used to curb emissions vary due to the dynamics present in each country. Replacing incandescent and fluorescent lighting technologies with light emitting diode (LED) technology is one of the most popular energy efficiency initiative implemented by businesses, organisations and citizens. Insulating pipelines and furnaces, fixing leaks on compressed air lines and implementing controls on energy consuming equipment and systems are some of the initiatives employed by industry. There are organisations in the commercial sector such as hotels, airports, hospitals, banks and businesses that go a step further to employ renewable energy sources as a matter of corporate responsibility and for marketing purposes. Increasingly, such strategies make business sense as well. Governments have committed themselves to various climate change agreements and policies, as well as legislation regarding "green buildings". This paper reviews the trends in global energy sources, its carbon footprint and evolution, the cost-effective modern fuel of energy efficiency together with the approaches adopted and the alternative "less carbon intensive" energy sources in focus. This paper reviews South Africa's unique challenges in energy supply and demand, and the role of energy efficiency and an alternative energy mix. Trends are highlighted and motivations for specific trends are explored and investigated, distinguishing between the world's developed and developing economies. The shallowness of the penetration of energy efficiency and the adoption of environmentally sustainable energy sources, despite the efforts and resolutions of many countries, highlights the fundamental challenge of the need for a solution that will entrench a culture of energy efficiency and sustainable energy in our way of life.

Keywords: Energy efficiency, energy security, carbon emissions, renewable energy, green buildings, sustainability, climate change

I. INTRODUCTION

Energy is a basic human need and is required to power our technologies and drive our economies. Energy is needed to grow, process and prepare food, in manufacturing processes, for health purposes, in transportation and communication as well as in our homes for daily conveniences. Energy is used to drive machinery that manufactures goods for human consumption and the construction of infrastructure that drives the financial economy. Transportation and our buildings use a significant amount of energy to keep us mobile and sheltered from the elements of the weather (such as wind, temperature, humidity, solar radiation, precipitation).

Globally, energy used can be categorised into four main sectors namely transport, industry, buildings and non-combustion uses such as lubricants, bitumen, plastics and feedstocks for petrochemicals, as shown in Fig. 1. The industrial sector is the most energy intensive of the four sectors for the time period 1970 to 2020. This is indicative of the industrial revolution starting in the 1800s with the machinery era, continuing in the 1900s the electrification era, the 1970s with the electronic information era to the present with the smart manufacturing era. By the 1970s much of the world had caught on to industrialisation with developed economies maturing energy hungry technologies and developing economies adopting the least-cost industrial revolution technologies for economic development, resulting in an exponential increase in carbon emissions.

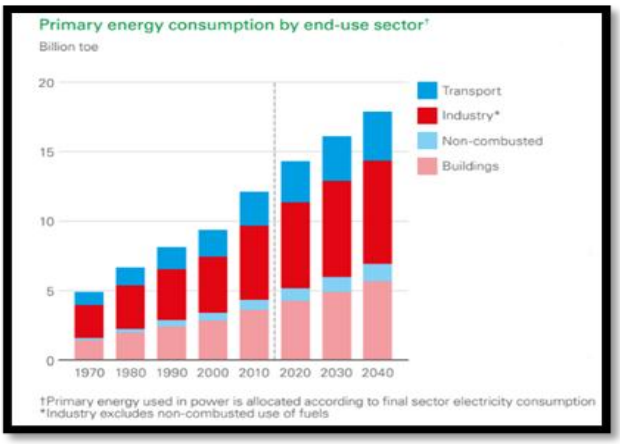


Fig. 1. Energy source breakdown of four main end-use sectors [1]

Fig. 2 shows that coal, oil and natural gas were popular choices in the industrial sector throughout the 1990s and at the turn of the 21st century, however, it seems that gas is becoming the energy source of choice from 2020 and beyond, with coal and oil stagnating in terms of growth. Fig. 2 also shows that oil is most commonly used for transport due to crude oil being the basis of fuels such as petroleum, diesel and aviation fuel. Oil is also used as an input for manufacturing products in plastics, lubricants, etc. Electricity is the most popular energy source in buildings according to Fig. 2.

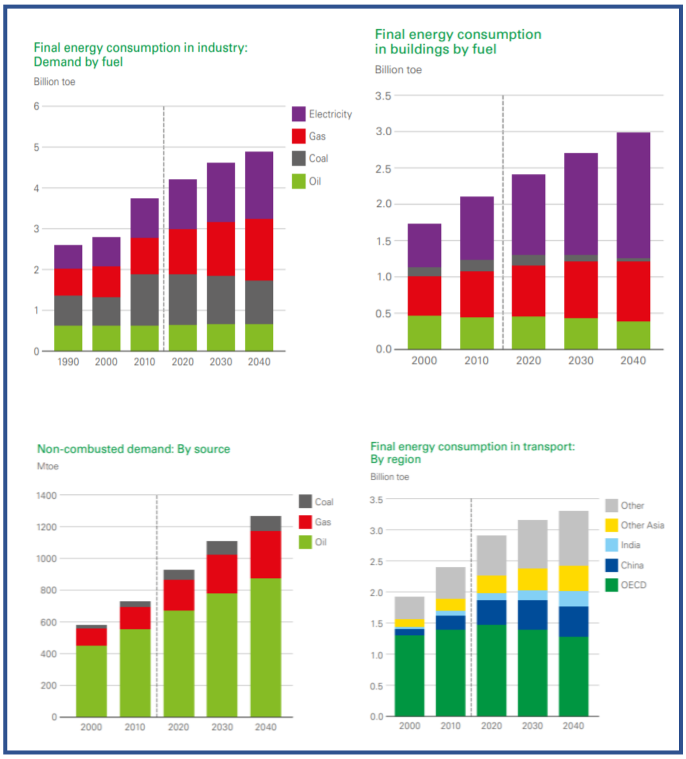


Fig. 2. Energy source breakdown of four main end-use sectors [1]

Fig. 3 shows the growth in primary energy alongside the inputs to power. Almost all growth in power demand stems from developing economies, led by China and India. Demand growth in the Organisation for Economic Co-operation and Development (OECD) is much smaller, reflecting both slower economic growth and a weaker responsiveness of power demand to economic growth in more mature, developed economies.

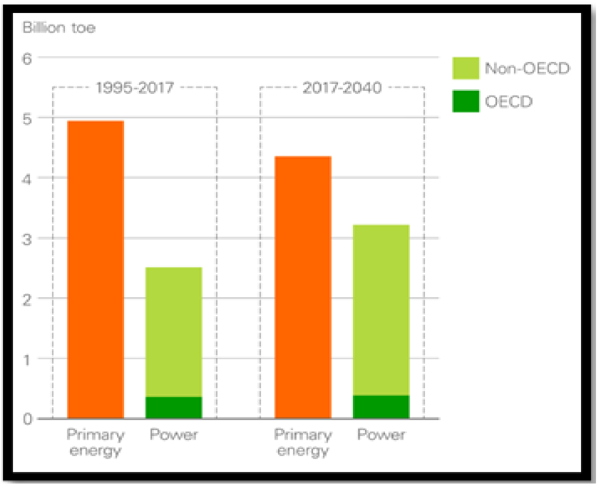


Fig. 3. Growth in primary energy and inputs to power [1]

The mix of fuels in global power generation has shifted significantly, with renewables gaining share at the expense of coal, nuclear and hydro. The share of natural gas is broadly flat at around 20 % [1]. The economy of the United States of America (USA), one of the largest if not the largest economy in the world, is powered by a mix of petroleum, natural gas, coal, renewable energy and nuclear electric power. Petroleum makes up 37 % of energy demand in the USA and serves the largest end-use sector of energy, i.e. transportation (37 %). Natural gas powers the industrial, residential and commercial sectors (Fig. 4).

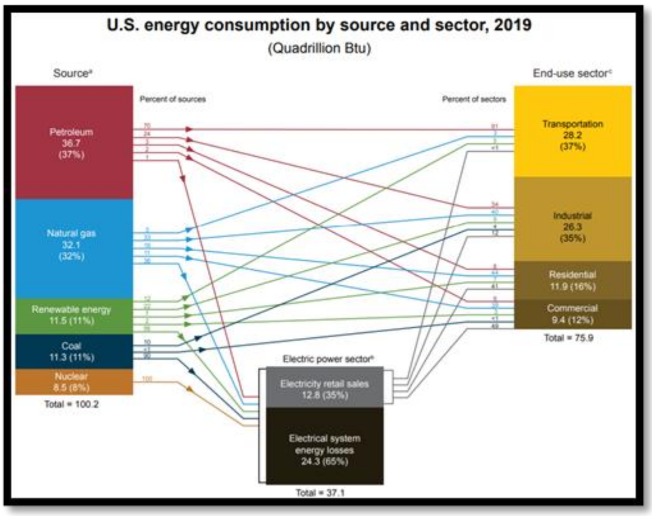
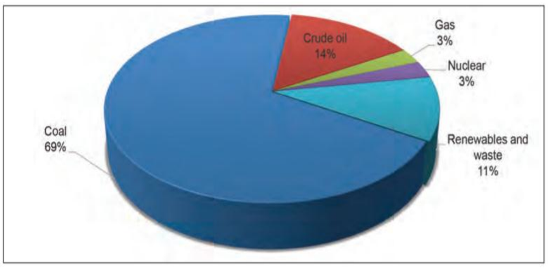
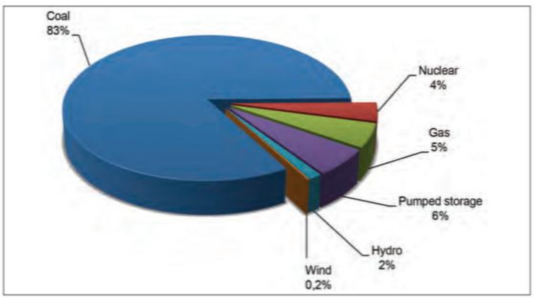


Fig. 4.US Energy Consumption by source and sector, 2019 [2]

South Africa is a developing economy. As per 2016 data, its energy supply is dominated by coal with 69 % of the primary energy supply followed by crude oil with 14 %, renewables and waste with 11 %, and natural gas and nuclear with 3 % each. Eskom is South Africa's national electricity provider whose main energy source is coal. The energy mix to produce electricity can be seen in Fig. 5.



(A) Source: DoE Energy Balances, 2016



(B) Source: Eskom Integrated Results, 2018

Fig. 5. South African primary energy supply by source (A) and electricity energy mix by source (B) [3]

The largest energy end-use sector is industry at 52 % followed by the transport sector at 19%, the commercial and public sectors at 14 %, residential sector at 8 % and agricultural sector at 6 %. The industrial sector is a heavy user of coal, using it in its natural form and in the form of electricity. Coal is also dominant in the residential sector. Petroleum is naturally dominant in the transport and agricultural sector (Fig. 6).

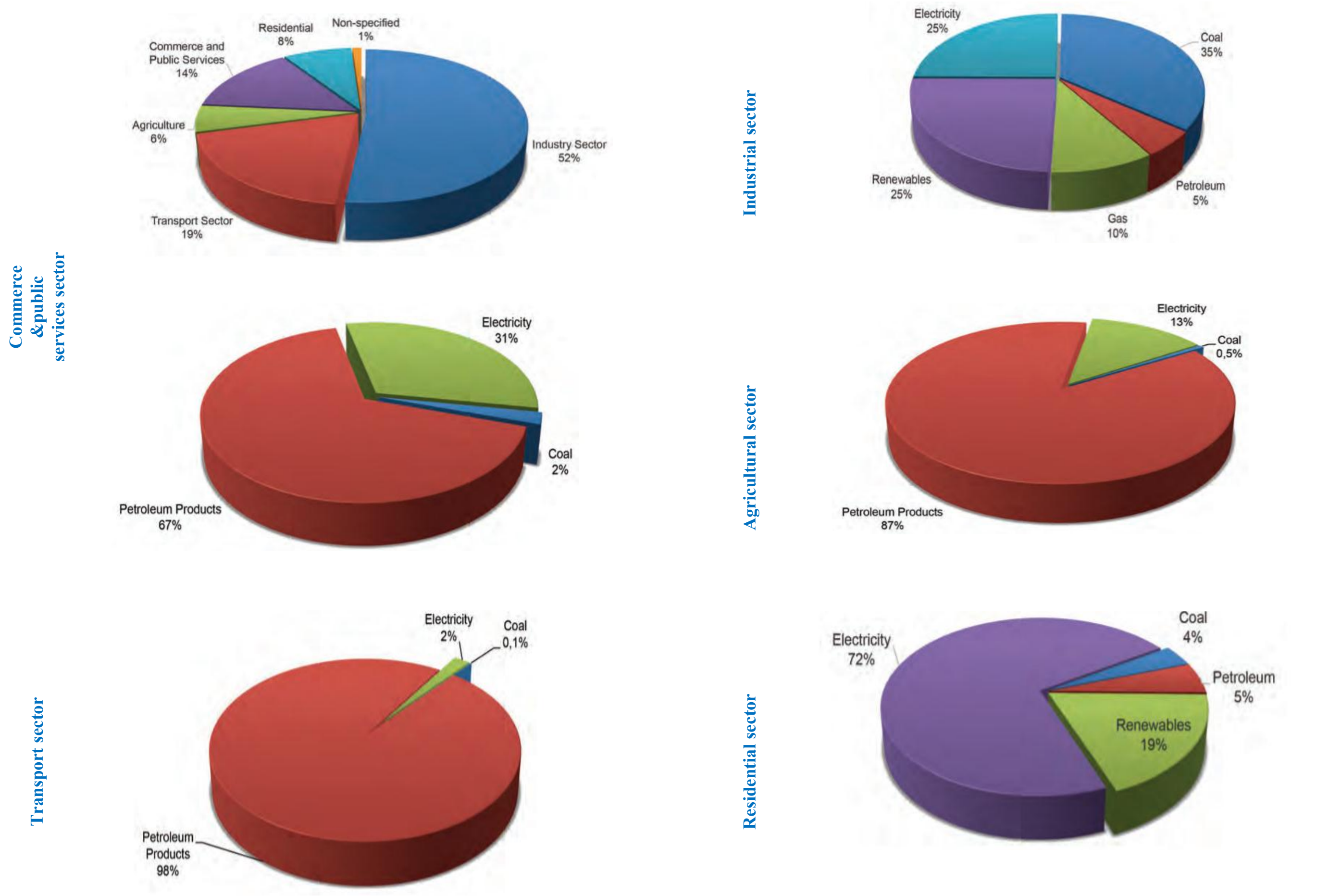


Fig. 6. Energy use by end-use sector and energy mix for each energy end-use sector [3]

Energy consumption will differ from country to country based on various factors such as stage of industrial development, size and type of industry, penetration of urbanisation, etc. Energy sources employed will have similarities (such as petroleum being popular for the transport sector) and differences (such as natural gas being a popular energy choice for America and coal for South Africa). There is a strong correlation between energy consumption and the development of countries' economies. Developed economies are highly carbonised while developing economies have a less intense carbon footprint. This is not due to developing countries being more environmentally conscious, but due to less economic and industrialised activities. Fig. 7 shows that CO_2 emissions per capita are generally higher for countries with more developed economies like the US, Canada, Germany, and Japan, while countries like India, Brazil, Mexico, and South Africa with transitional/developing economies have lower CO_2 emissions per capita .

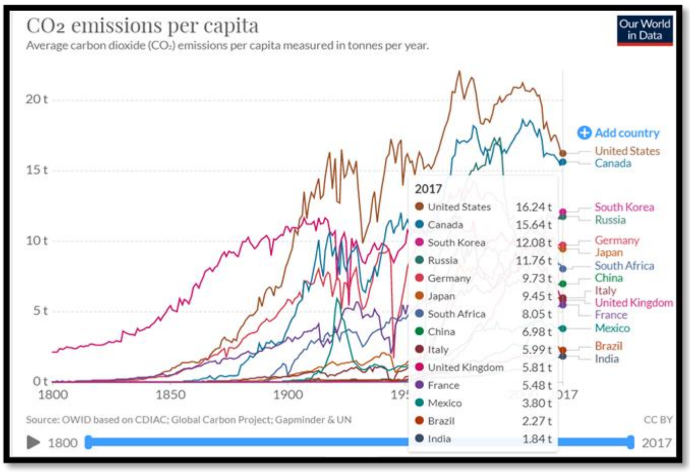


Fig. 7. CO_2 emissions per capita [4]

Energy available across the planet varies due to the energy sources available in each country and the ease of extraction and processing for usable energy. The costs that the extraction and processing of energy sources comes with includes the risks to human health and cost of mitigation. The following sections will review the world's energy consumption and the associated carbon footprint, and examine the shifts in energy sources following climate change imperatives. This includes the world's renewable energy uptake, renewable energy potential and various initiatives employed by countries to reduce their carbon footprint. The review focuses on the unique challenges faced by South Africa, a country with a developing economy, showcasing the dynamics of securing energy supply for economic development while satisfying the requirement to decarbonise. The paper concludes by highlighting the three scenarios of our continued economic activity and their impacts as well as two scenarios for desired pathways that the energy landscape of our globe can take to arrest climate change, ultimately showing the need for a lasting approach which is embedded in our way of life as opposed to the current approach as revealed in this literature review.

II. ENERGY TRENDS

Understanding what has lead up to the current global warming crisis is key to moving towards a solution that will make a difference. This section outlines the history of the use of the traditional energy sources of coal, oil and natural gas which are not only the primary energy sources of the majority of the countries of the world fueling the first three industrial revolutions, but also are responsible for the resulting carbon footprint.

A. The World's Carbon-Intensive Energy History

The world's first oil wells were drilled in China around the 4th century AD. The Chinese used simple bamboo poles to drill these wells. The material they extracted was then used primarily as a source of fuel. In later centuries, oil was found across Asia and Europe. The modern oil industry began in the mid-19th century. On August 27, 1859, Colonel Edwin Drake discovered the first underground oil reservoir near Titusville, Pennsylvania (USA) after drilling a well just 21 metres deep. Drake worked for the Pennsylvania Rock Oil Company which wanted to use the oil to light streetlamps. Drake's well initially produced 30 barrels of oil per day (b/d) (one barrel is equal to 159 litres or 42 US gallons). Its success marked the beginning of the modern oil industry. Oil soon began to receive more attention from the scientific community. After some research, a variety of products were eventually developed from crude oil. For example, kerosene for heating was one of the first products [5].

In 1870, John D. Rockefeller incorporated Standard Oil Co. in Ohio. The company quickly emerged as the dominant player, driving prices down and buying up competition. Standard Oil expanded across the country and began exporting to overseas markets including China. It was so successful that by 1890 it controlled nearly 90 % of refined oil in the US [6]. Soon other products like gasoline and diesel to run engines were also on the market. In 1890, the mass production of automobiles began creating a huge demand for gasoline and pushing companies to find more oil fields [5].

Many of the major petroleum companies that are recognisable today can trace their origins to events that occurred over the next decade:

- Gulf Oil and Texaco were established in 1901, following the discovery of oil at Spindletop, Texas.
- Royal Dutch and Shell merged in 1907 to form Royal Dutch/Shell, with the aim of remaining competitive in the face of increased price competition from US firms.
- The Anglo-Persian Oil Company (now BP) was formed in 1908, following the discovery of oil in the south-west of modern-day Iran.
- Chevron, Exxon and Mobil (now Exxon Mobil) were formed in 1911 when Standard Oil was split up by the Supreme Court of the United States as a result of antitrust violations.

These international oil companies (IOCs) (BP, Chevron, Exxon, Gulf Oil, Mobil, Royal Dutch/Shell and Texaco) became known as the 'seven sisters' and went on to control 85 % of the world's oil reserves at their peak in the early 1970s [6].

Officials from Kuwait, Iran, Iraq, Saudi Arabia and Venezuela met in Baghdad in 1960 to discuss how to handle the price cuts imposed by the IOCs. They agreed to form the Organization of Petroleum Exporting Countries (OPEC), with the aim of reducing competition between their nations and controlling prices. Over the next two decades OPEC expanded to include Qatar, Indonesia, Libya, United Arab Emirates, Algeria, Nigeria, Ecuador and Gabon. Many of these nations also took control of their oil reserves between 1960 and 1976, by buying out or forcibly taking shares from the IOCs [6].

From 30 b/d of oil produced in the mid-19th century, the rate of extraction rose to close to 100 million b/d (Fig. 8). The total world average annual growth of oil production over the last decade (2008-2018) was around 1.4 %, with 2019 seeing an overall decline of about 0,1 % to about 95 million b/d. It can be observed from Fig. 8 that the Middle East is the largest producer of oil contributing 32 % of the global share followed by North America (US, Canada and Mexico) at 25,9 % and the Commonwealth of Independent States (CIS) made up of Armenia, Azerbaijan, Belarus, Kazakhstan, Russian Federation and other states at 15.4 %. The CIS and the Middle East were among the lowest oil consumers at 4,3 % and 9,6 % respectively in 2019. The largest oil consumer in 2019 was the Asia Pacific at 36 million b/d or 36,8 % of global consumption, followed by North America at 23,5 million b/d (23,9 %). South Africa consumed 569 thousand b/d constituting 0,6 % of the global share. The total world average growth rate of oil consumption over the last decade (2008-2018) was 1,3 % and in 2019 was 0,9 % which is below the average annual growth rate of the last decade.

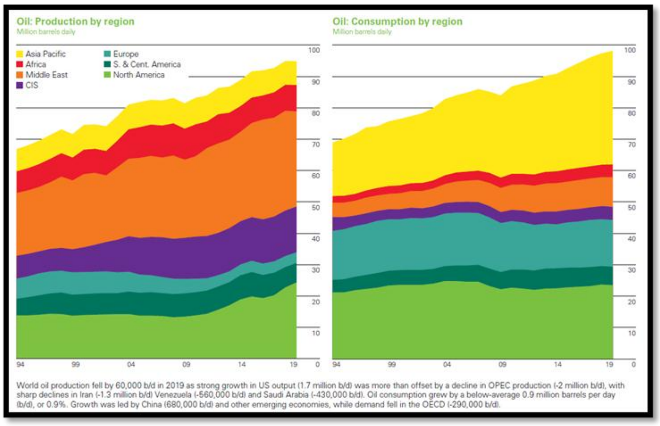


Fig. 8. World oil production and consumption by region fro m 1994 to 2019 [7]

Since primitive humans first began to use fire, energy has been an essential resource for human survival. Easily accessible timber satisfied heating, cooking and other basic needs for the survival of primitive humans. With technological advances in coal mining, coal, which had higher energy density, was widely used. In 1769, Watt invented the steam engine. In 1875, the French built the first coal-fired power plant in the world. The progress of human civilisation accelerated the development of the coal industry, and coal accounted for the largest share in primary energy mix in the 1780s, surpassing wood for the first time. This was the first transformation – from wood to coal. [8]

In 2019 China, Indonesia, Australia and India made up the majority of the Asia Pacific's 74,4 % (124,72 EJ) contribution to the global total production of 167,58 EJ (Fig. 9). South Africa's 6 EJ energy production in 2019 contributed to 3,6 % of the world's coal energy production. The average annual growth rate of coal energy production over 2008-2018 was 1,4 % and in 2019 the growth rate was 1,5 %, higher than the decade average [7]. World coal energy consumption was 157,86 EJ in 2019 which represented a decrease in the annual growth rate by 0,6 % as opposed to an average annual growth rate of 0,8 % over 2008-2018. The Asia Pacific coal energy consumption of 122,22 EJ makes up 77,4 % total world energy consumption and South Africa consumed 3,81 EJ making up 2,4 %. The figures indicate that there is a slower growth rate and notable decline in the use of coal as an energy source.

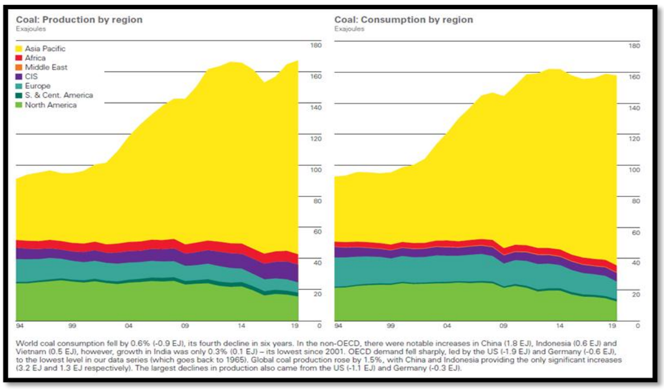


Fig. 9. World coal production and consumption by region fr om 1994 to 2019 [7]

Naturally occurring natural gas was discovered and identified in America as early as 1626, when French explorers discovered natives igniting gases that were seeping into and around Lake Erie. The American natural gas industry got its beginnings in this area. In 1859, Colonel Edwin Drake (a former railroad conductor who adopted the title 'Colonel' to impress the townspeople) dug the first well. Drake hit oil and natural gas at 69 feet below the surface of the earth [9].

The world produced 3989,3 billion cubic metres of natural gas which is around 143,62 EJ in 2019 (Fig. 10). 28,9 % came from North America (23 % by the US) followed by the CIS producing about 21,1 %, and the Middle East and Asia Pacific 17,4 % and 16,8 % respectively. The growth rate of natural gas production per annum over the last decade (2008-2018) has been 2,4 % with a significant increase in 2019 to 3,4 %. The world consumption of natural gas has been 3929,2 billion cubic metres (141,45 EJ) in 2019 (growth rate of 2 % versus an average annual growth rate of 2,5 % over 2008-2018). The North American region used 26,9 % of this followed by the Asia Pacific at 22,9 % and three regions around 14 % each, i.e. CIS (14,6 %), Middle East (14,2 %) and Europe (14,1 %). South Africa consumed 4,3 billion cubic metres of natural gas in 2019, representing 0,1 % of the total world consumption.

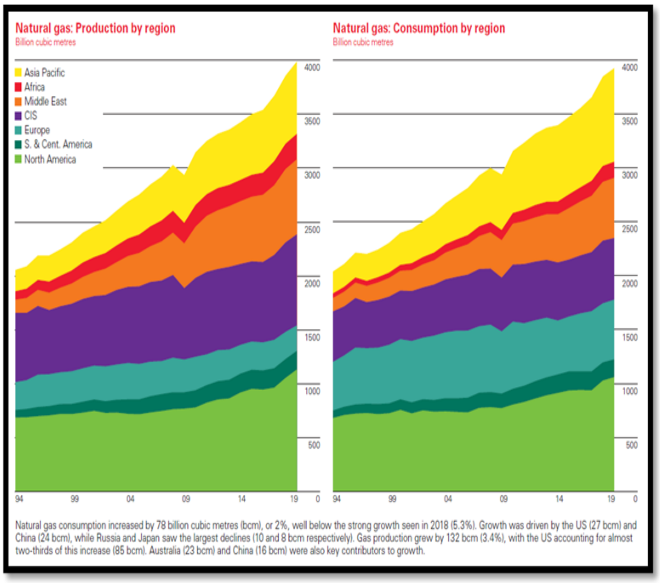


Fig. 10. World Natural Gas production by region from 1994 t o 2019 [7]

From the trends of oil, coal and natural gas production and consumption, one can see that the highest production and consumption growth rate over the period 2008-2018 is natural gas and the lowest production and consumption rate is coal. The world's energy mix used to be dominated by oil in the 1970s and has evolved to an almost balanced amount of coal, oil and natural gas as can be seen in Fig. 11.

Other trends that can be observed are that most of the countries with developed economies in the world consume a lot of energy (whether it be in the form of coal, oil or natural gas) and produce a significant amount of energy as well. The sources of primary energy consumption per region can be seen in Fig. 12. Oil is the dominant primary energy consumption source for all of America, the Europe and Africa, coal is the dominant primary energy consumption source for the Asia Pacific region, notably in China, India and Indonesia, and natural gas is the dominant primary energy consumption source for the Middle East and CIS. It can also be observed from the trends that even though the Middle East produces a significant amount of oil, they have a small oil consumption footprint; this implies that oil exports are significant and *vice versa* for South and Central America where much less oil is produced and yet their oil footprint is larger in relation, thus oil imports are significant.

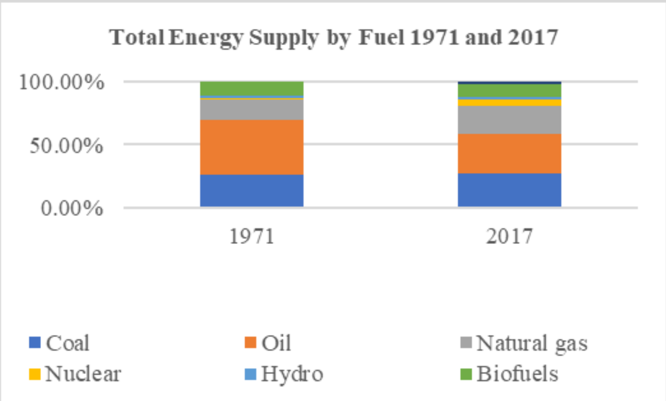


Fig. 11. Total Energy Supply by fuel, 1971 and 2017 [10]

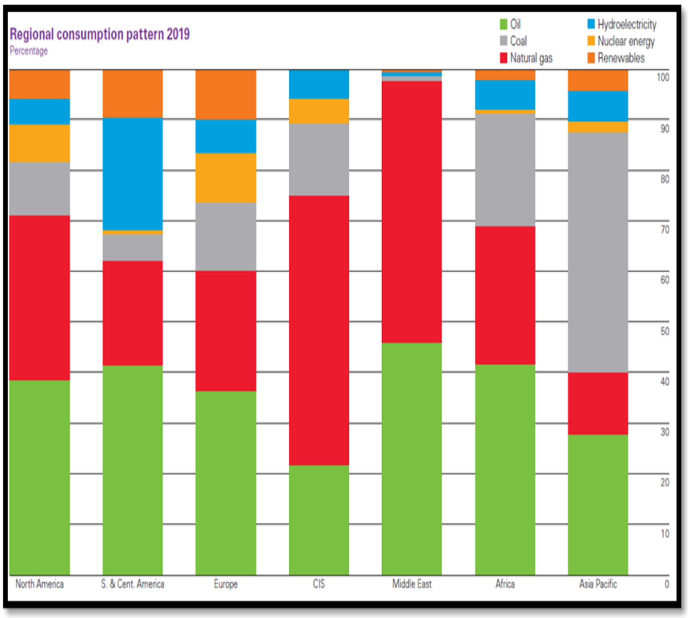


Fig. 12. Primary energy consumption sources per region [7]

The production and consumption of coal, oil and natural gas has shaped the carbon footprint for the world over the industrial revolution era as is described in the following section.

B. World'sCarbon Footprint

In 2017, thirty-six billion tonnes of CO_2 were emitted, reaching a concentration of over 400 ppm. This number has increased exponentially from the 2 billion tonnes of emissions in 1900, just 117 years ago. The growth of CO_2 emissions since the 1750s to the present can be seen in Fig. 13. The energy intensity varies across continents according to dynamics at play such as the economy and economic activity, the geo-politics and history, natural environmental endowments and types of control over the resources through governments, monarchies and other regimes, etc. Fig. 14 shows the share of the world's global carbon emissions over half-century periods (1750 to present) and tells the story of industrialisation via coal, oil and natural gas across the world as the various countries' economies began developing.

In 2017 China, an emerging economy, was the world's largest CO_2 emitter accounting for more than 25 % of the global emissions, followed by the USA (a developed economy) accounting for about 15 %, the European Union (EU) about 10 %, India (an emerging economy) about 6 %, and Russia (a developed economy) about 5 %. South Africa, a developing economy, contributed 1,26 % of the carbon emissions (Fig. 15).

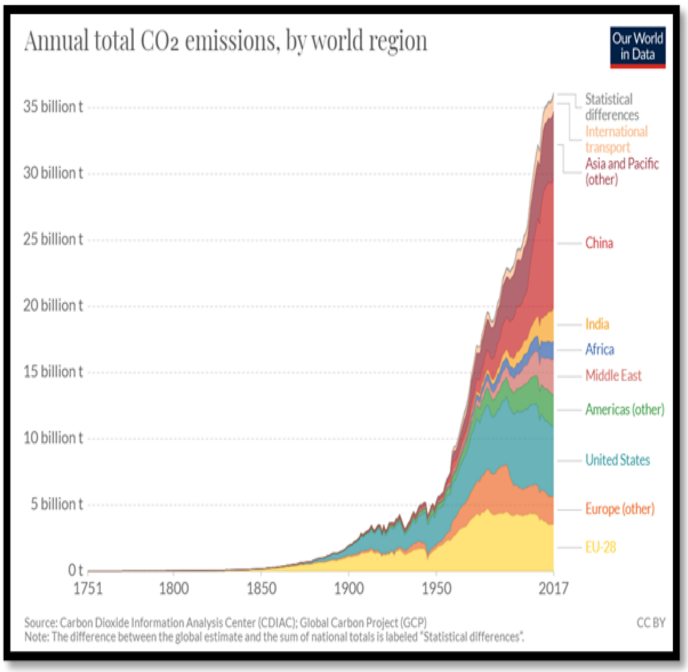


Fig. 13. Annual CO2 emissions [12]

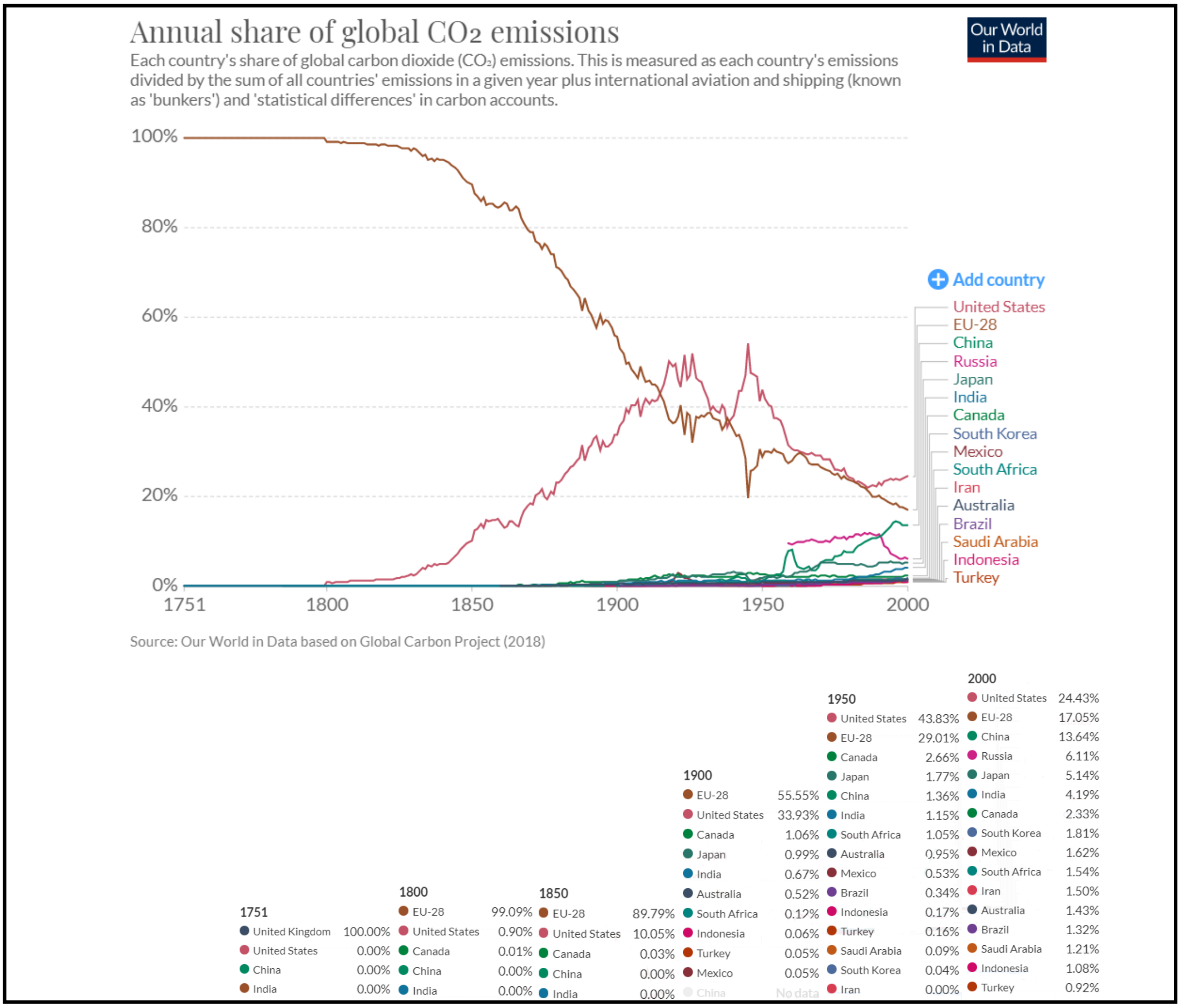


Fig. 14. Share of the world's global carbon emissions over half-century periods [12]

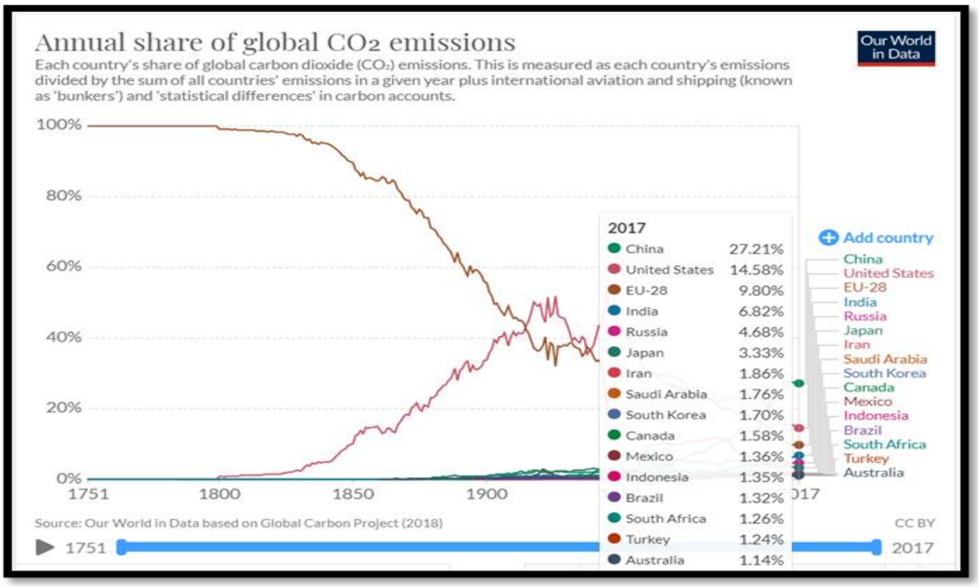


Fig. 15. 2017 Carbon-dioxide emissions of the world [12]

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

The International Monetary Fund (IMF) and the United Nations (UN) classify the world's countries into developed, developing and least developed categories based on their industrial base development and their human development index (HDI) in relation to other countries. It is not a universally accepted definition though; in 2015, the World Bank declared that the "developing/developed world categorization" is becoming less relevant and that they will phase out the use of that descriptor. The term "developing" describes a currently observed situation and not a changing dynamic or expected direction of progress. Since the late 1990s, developing countries tended to demonstrate higher growth rates than developed countries. Developing countries include, in decreasing order of economic growth or size of the capital market: newly industrialised countries, emerging markets, frontier markets, "least developed countries". Therefore, the least developed countries are the poorest of the developing countries [11] (Fig. 16). It is not a hard and fast rule that countries with high HDIs are developed countries. As can be seen from Fig. 17, Russia is indicated to have a high HDI but is classified as a developing country according to Fig. 16.

What is clear from Fig. 14 is that in the 18th, 19th and 20th centuries (during the industrial revolution), the developed countries of the world dominated the emission of carbon. The United Kingdom (UK), a developed country was the highest contributor of carbon emissions recorded in 1751 through to the 1800s with USA and Canada then appearing and growing to around 10 % of the world's carbon emissions by 1850. By the 1900s, the EU (the UK is captured in this number) share dropped to just over 50 % and the USA rose to just over 30 %. Emerging countries such as Canada, Japan, India, Australia, South Africa started appearing with the spread of industrialisation. The USA took over as the largest contributor in 1950 with almost half of world carbon emissions in the years leading up to the turn of the millennium, but now its contribution is proportionately less largely due to China. In 2017, China became the world's largest carbon emissions contributor in the world. Reduced proportion of carbon emissions does not imply a decrease in carbon emissions, but rather an indication of carbon emissions in relation to other countries of the world. Fig. 7 shows that the USA is still the largest carbon emissions contributor if one looks at the per capita amount. Fig. 7 is an indication of the carbon intensity of some of the countries of the world. The common trend here is that developed countries have high carbon intensities. The further implication that can be drawn is that if developing countries continue to grow their industrial bases and improve their HDIs through the methods and sources of energy adopted by the developed world, the situation will be a lot worse as industrialisation expands to all parts of the globe, with the added characteristic of developing countries being densely populated.

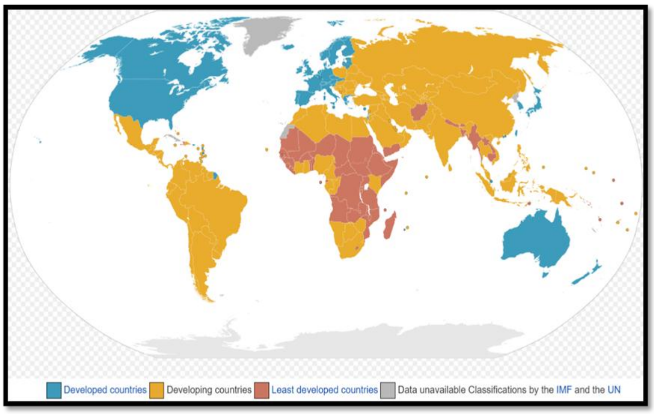


Fig. 16. Classification of the world's countries into developed, developing and least developed [11]

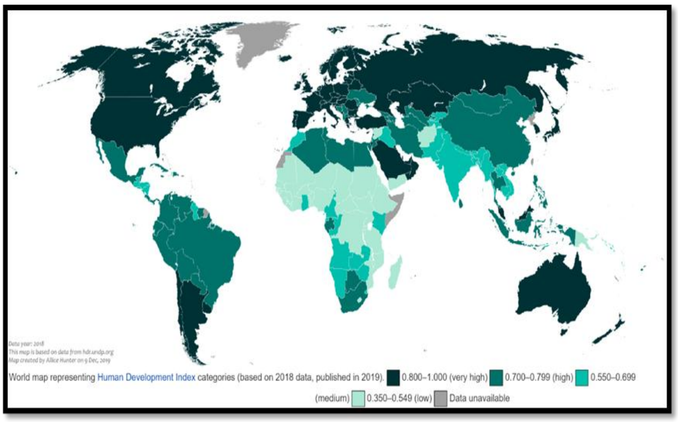


Fig. 17. World Human Development Index [11]

The world's governments and ruling entities have now agreed that these numbers are not sustainable and have joined efforts in the form of various task forces to bring about sustainable development. The sustainable development goals of the United Nations as well as the Intergovernmental Panel for Climate Change (IPCC) are a product of these efforts. The sustainable development goals (SDGs), adopted by the United Nations General Assembly (UNGA) in 2015 provide a powerful framework for international cooperation to achieve a sustainable future for the planet. The 17 SDGs and their 169 targets are at the heart of Agenda 2030, and define a path to end extreme poverty, fight inequality and injustice, and protect the planets environment. Sustainable energy is necessary for the success of Agenda 2030. The global goal on energy – SDG 7 – encompasses three key targets: ensure affordable, reliable and universal access to modern energy services; increase substantially the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency [13]. The IPCC, made up of hundreds of countries both from the developed and developing economies of the world, released a report in 2011 that will guide policy makers on renewable energy to arrest the CO_2 concentrations in the earth's atmosphere. "There are multiple options for lowering GHG emissions from the energy system while still satisfying the global demand for energy services. Some of

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

these possible options, such as energy conservation and efficiency, fossil fuel switching, renewable energy, nuclear and carbon capture and storage (CCS) were assessed. A comprehensive evaluation of any portfolio of mitigation options would involve an evaluation of their respective mitigation potential as well as their contribution to sustainable development and all associated risks and costs." [14].

The challenge of arresting the CO_2 concentration in the atmosphere can be anything but equal among the continents of the planet as the various continents have made unequal contributions to the CO_2 concentration and have benefited economically from this unequally as well.

Even though the total energy supply has grown 2,5 times its size over the last four decades or so, there has been a shift in the sources of energy as a result of various dynamics. Fig. 11 shows that there has been a negligible increase in the use of coal, biofuels and hydro, and there has been a significant decline in the adoption of oil, a gradual increase in the adoption of natural gas and an exponential increase in the uptake of nuclear energy (0,5 % in 1971 to 4,9 % in 2017) and renewable energy (0,1 % in 1971 to 2 % in 2017). Fig. 11 also shows a shift from the traditional fuels of coal and oil being in the majority in 1971 to natural gas, and a stagnation of the use of coal.

The shift away from oil could be related to the geopolitical dynamics of the Middle East and the USA and the effect this has on the cost of doing economic activity which is not sustainable for the world. Fig. 18 shows a history of crude oil prices and the various dynamics at play. The shift from coal has a lot to do with its decreasing popularity due to its CO_2 emissions coupled with the knock-on effect of the cheaper, less carbon intensive alternative of natural gas becoming available and the evolution of nuclear technology becoming less controversial. The emerging pattern among countries (both developing and developing economies) is the consideration of investment in either natural gas or nuclear power for their baseloads and adoption of renewable energy plants instead of renewing old coal powered plants or adoption of new coal powered plants for supplying energy demand.

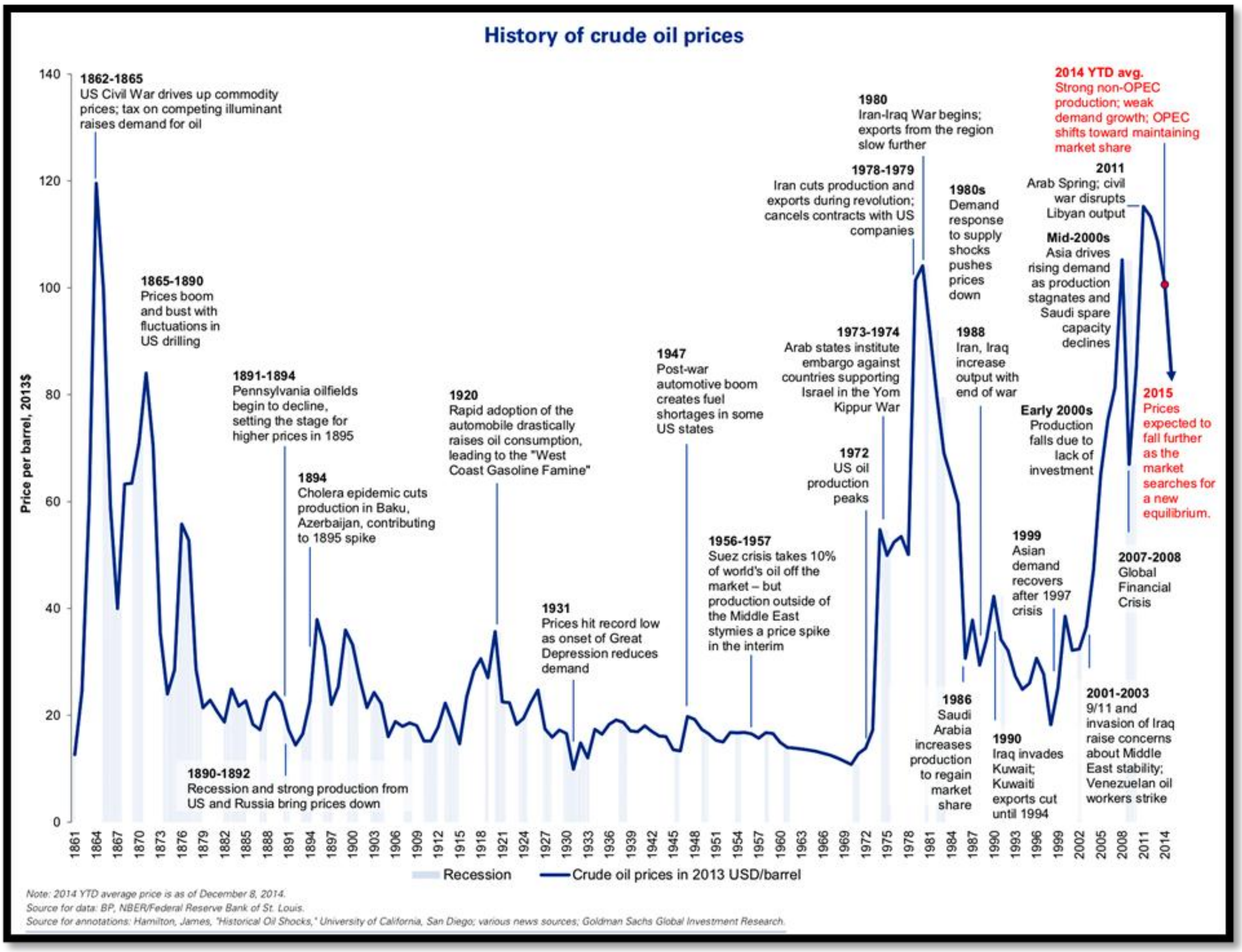


Fig. 18. History of crude oil prices [15]

Energy efficiency and introduction of alternative energy sources that are less carbon intensive have been the two main vehicles in arresting the exponential increase in CO_2 emissions. There have been many government incentives, economic packages and programmes driven by various reasons, not just environmental and climate change, but also energy demand and supply mismatches, energy baseload grid parities being met and exceeded, international markets for various products, international investors and international aid, and more. The following sections will review the various climate change imperatives of energy efficiency, renewable energy, green buildings and the policies surrounding some of these.

III. CLIMATE CHANGE IMPERATIVES

Countries with developed economies usually make the transition to alternative energy from traditional sources of coal, oil and natural gas sooner not only because it allows for transition to a lower carbon footprint, but also because this brings additional benefits of energy security through reduced dependency on energy sources not found locally, breaking dependence on imported energy sources and thus reliance on other countries for its energy supply. They also had the finances to pay the additional premium that renewable energy came with when this movement started a few decades ago.

Renewable energy technology has gained momentum over time, bringing greater efficiency and benefits such as energy sources being freely available and abundant, not being logistics or process intensive like coal, oil and natural gas which must be transported and processed for the energy to be extracted. For these reasons renewable energy technology has come to be regarded as a viable alternative especially for developing countries who do not particularly have well developed and all-encompassing national electricity grids (Fig. 19). Decentralized power is now being viewed as a way to stimulate economic development outside urban areas.

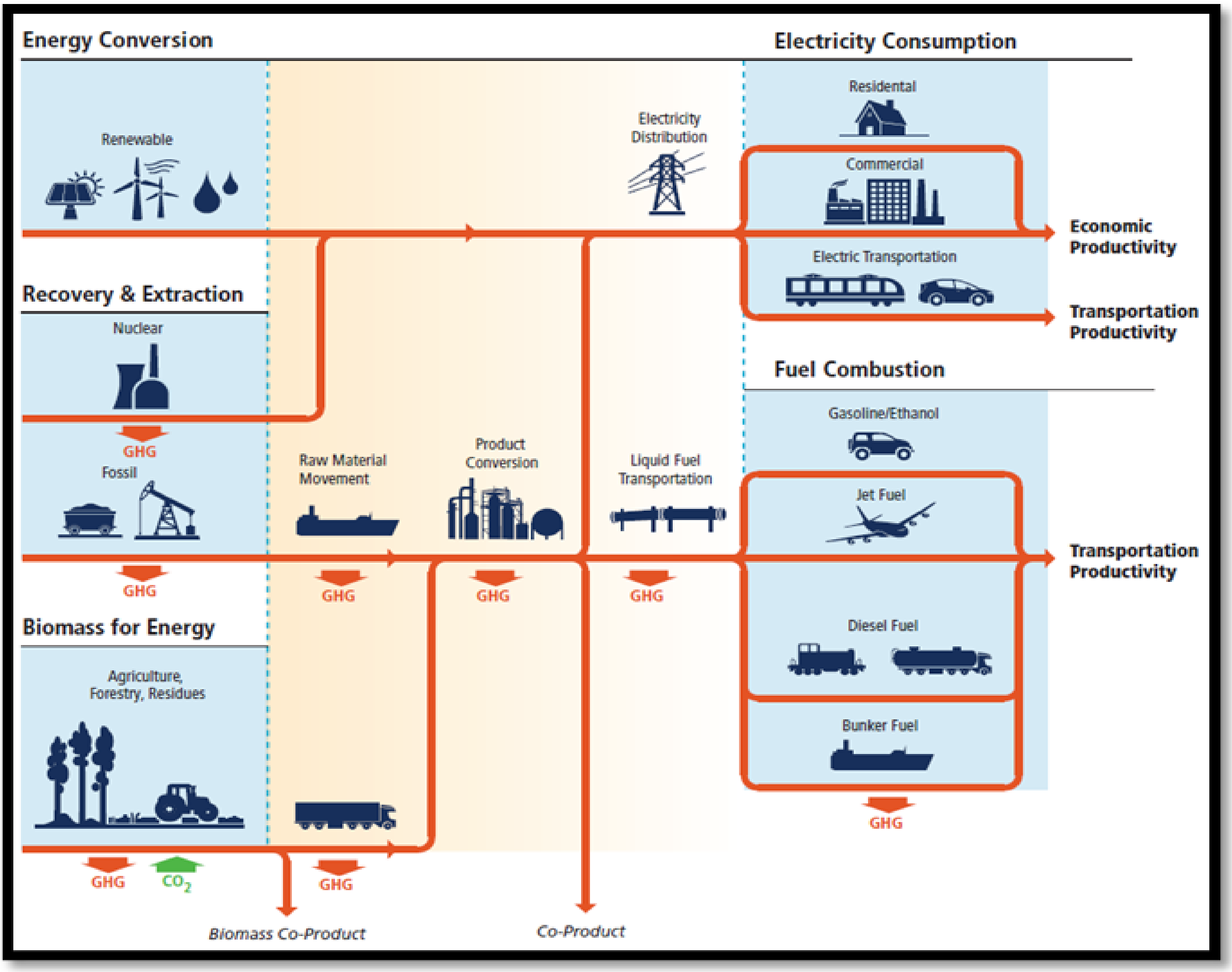


Fig. 19. Illustrative system for energy production and use illustrating the role of renewable energy along with other options [16]

For urban areas whose growth has been exponential causing electrical demand to exceed electrical supply, energy efficiency has become the most popular "fuel" as it not only saves costs, but also makes operations more efficient, having a ripple effect of benefits. For example, changing to LED technology saves on electricity costs and has the benefit of increased lifespan, thus lowering maintenance costs and disposal cost if the LED technology replaces compact fluorescent lighting (CFLs). Similarly, fine tuning of HVAC systems and keeping filters and heat exchangers clean results not only in decreased electricity costs, but also decreased load on chillers, increase in longevity of equipment, etc. Awareness of fresh-water shortage as well as the growing issue of waste disposal for about 8 billion people on our planet among other environmental issues prompted the development and popularity of sustainable or "green" buildings in the built environment. Building infrastructure is constantly under scrutiny as it is a water intensive, electricity demanding and waste producing activity yet it is necessary for economic development.

The following sections review the renewable (and alternative) energy uptake of the world, their energy efficiency activities and the adoption of green buildings in construction of infrastructure which all collectively play a role in addressing the reduction of greenhouse gas emissions through energy efficiency and energy security.

A. The World's Renewable Energy Uptake

The world's renewable energy uptake has increased significantly since 1965, from 1000 TWhs to over 6000 TWhs. Exponential increase can be observed from the turn of the century (Fig. 20). The main renewable energy source has been hydropower. Solar energy began gaining popularity around 2010 and wind energy around 2000.

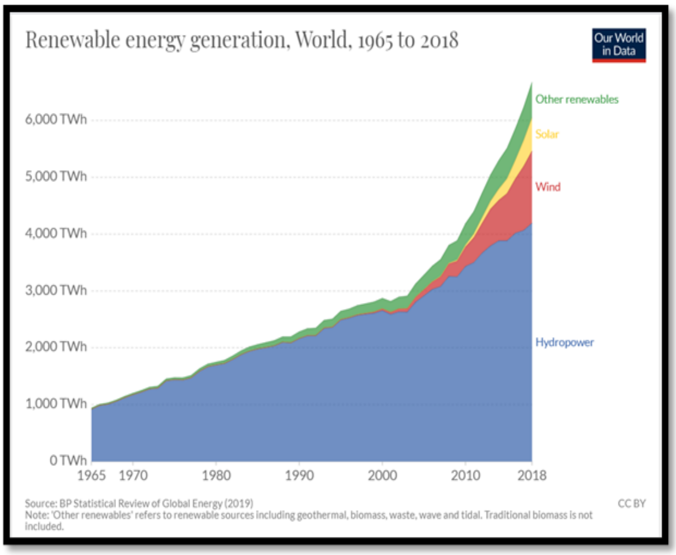


Fig. 20. Renewable energy generation 1965 to 2018 [17]

Today, hydropower is most popular in China and parts of Korea. Other countries where hydropower is installed are India, Russia, Canada, the USA and Brazil (Fig. 21). The USA, Canada, Germany, France, Sweden, Finland, Norway, Japan had major hydroelectric installations in 1965, followed by Brazil in 1978, Russia in 1985, China in 1987 and India in 1995.

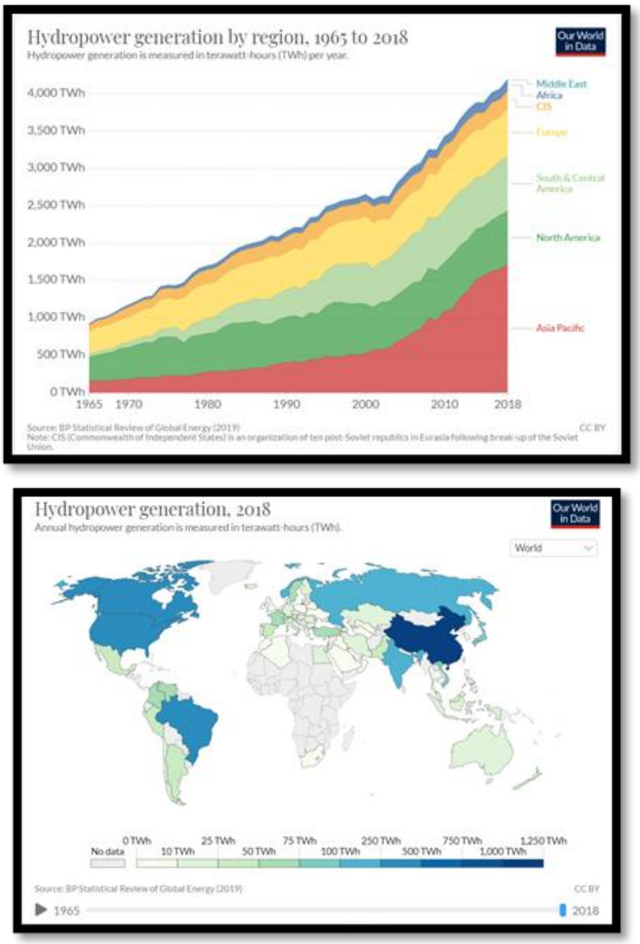


Fig. 21. Hydropower generation by region [17]

The hydropower potential of the world has not yet been tapped in Africa, Australia and parts of South America as can be seen in the world map of hydropower potential of the world in Fig. 22.

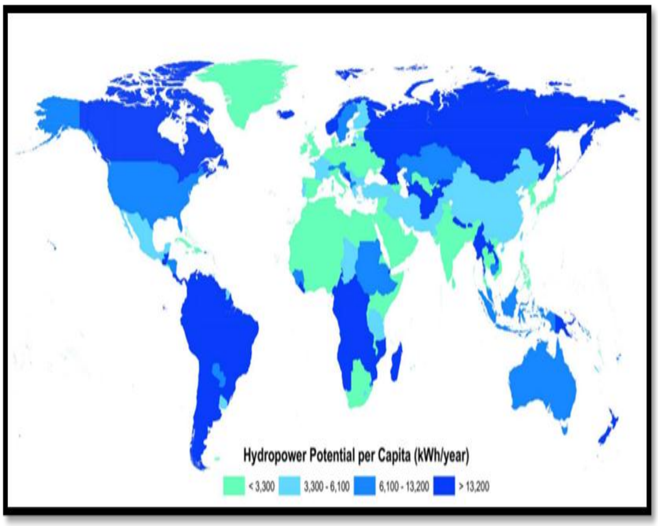


Fig. 22. World Hydropower Potential [18]

Wind energy is most popular in China and parts of Korea. Parts of Europe including the UK, parts of Asia, India, the USA, Brazil, Canada and Australia have wind installations (Fig. 23). Wind energy generation started becoming popular in 2000 with the USA, Germany, Spain and ten years later, China, India, Brazil and Australia.

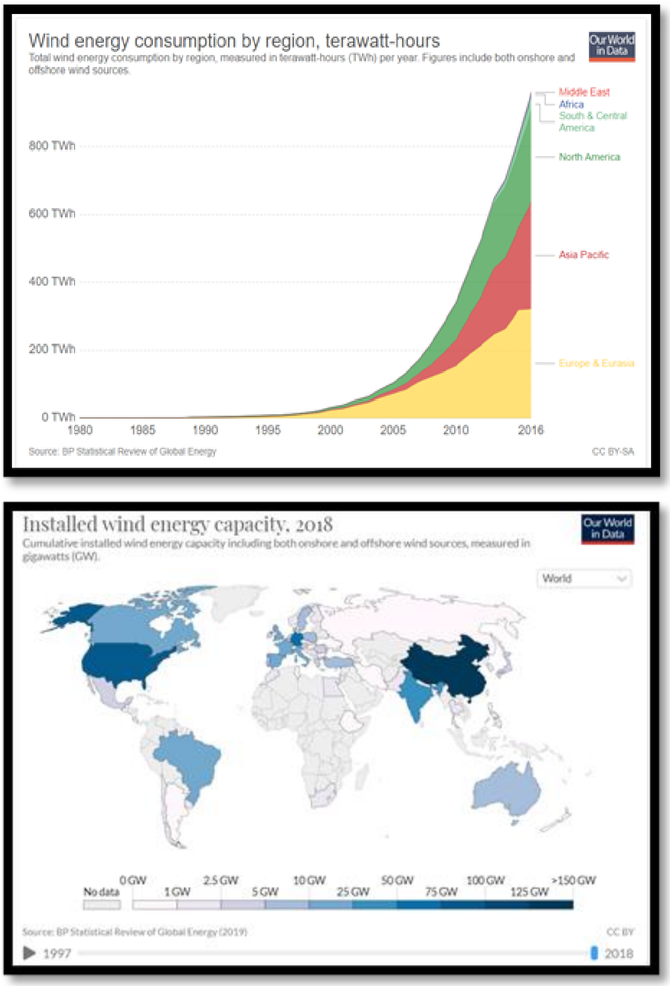


Fig. 23. Wind energy generation [17]

The wind energy potential of the world can be seen in Fig. 24. When one compares the wind energy potential of both onshore and offshore wind energy installations, there is clearly a significant potential still to be tapped into. Russia and parts of South America have not yet tapped into their abundantly available wind energy sources. Similarly, with solar energy which is abundantly available throughout the world, if one compares the solar energy installations around the world (Fig. 25) with the global solar insolation (Fig. 26), South America, Africa and Australia, which account for almost 50 % of the world's landmass, are not using this solar energy. It is clear that in the early years (before 2000) when renewable energy did not reach economies of scale, it was popular only in the developed economies of the world, but since 2000 the uptake of renewable energy is increasing rapidly in the developing economies of China, India, Brazil and South Africa. Fig. 27 shows the renewable energy investment as a percentage of GDP in 2015. South Africa, South America and China have been making significant investments in renewable energy.

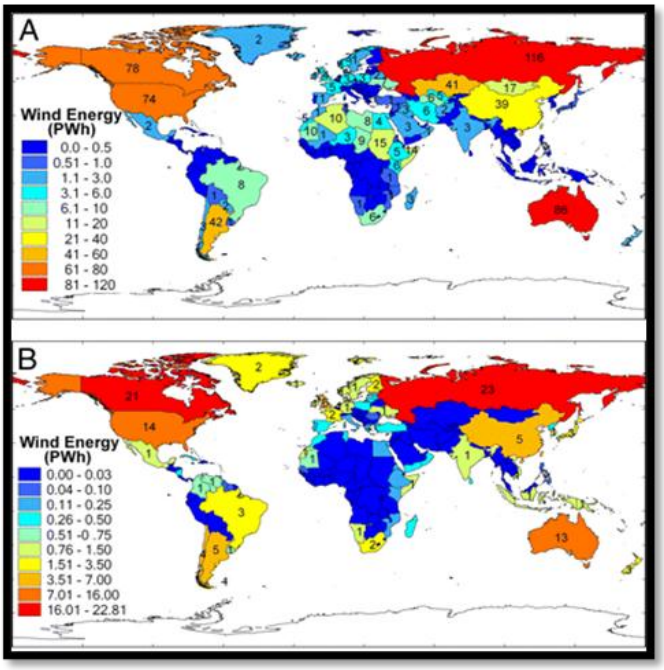


Fig. 24. Annual wind energy potential country by country, restricted to installations with capacity factors >20% with siting limited. (A) Onshore. (B) Offshore [19]

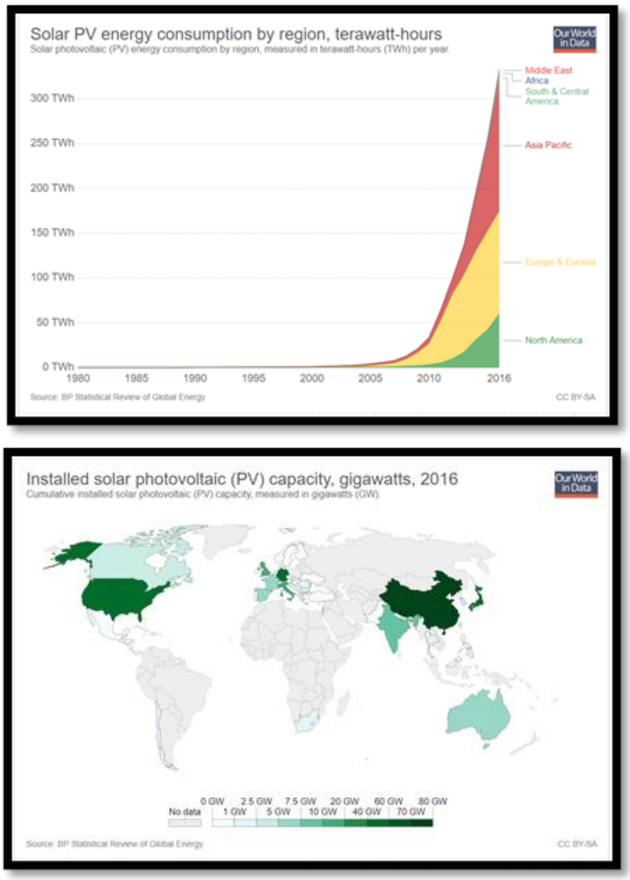


Fig. 25. Solar energy installations by region [17]

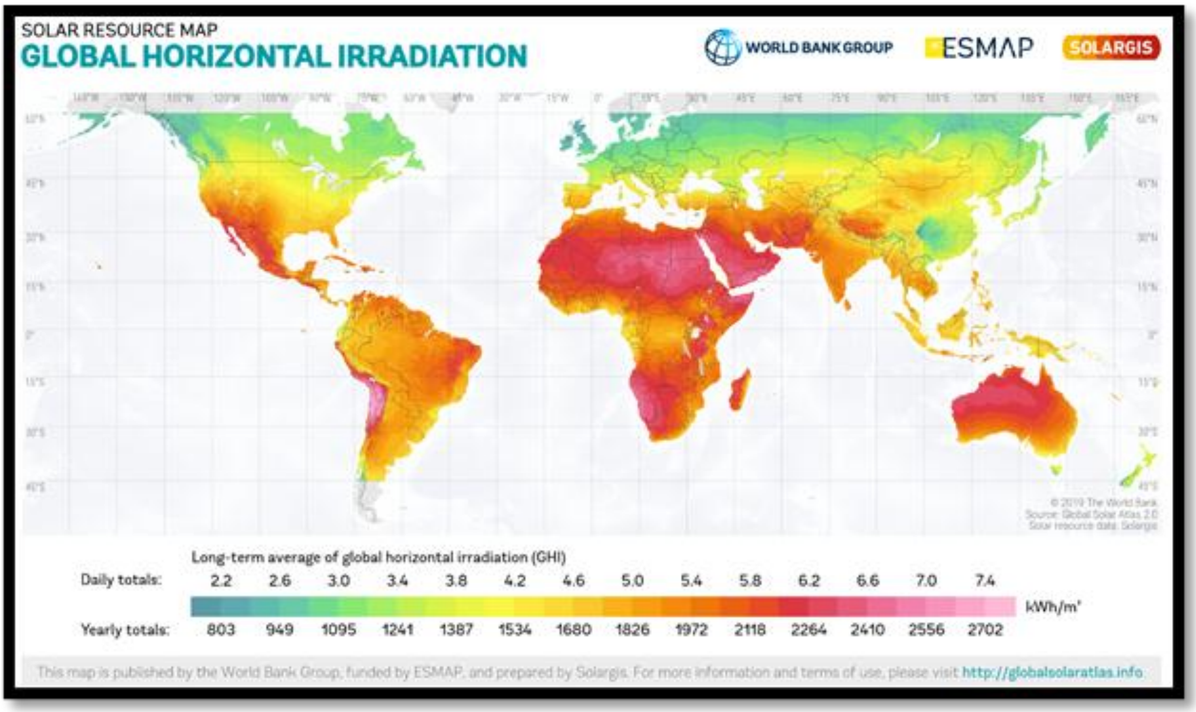


Fig. 26. Global horizontal solar irradiance [20]

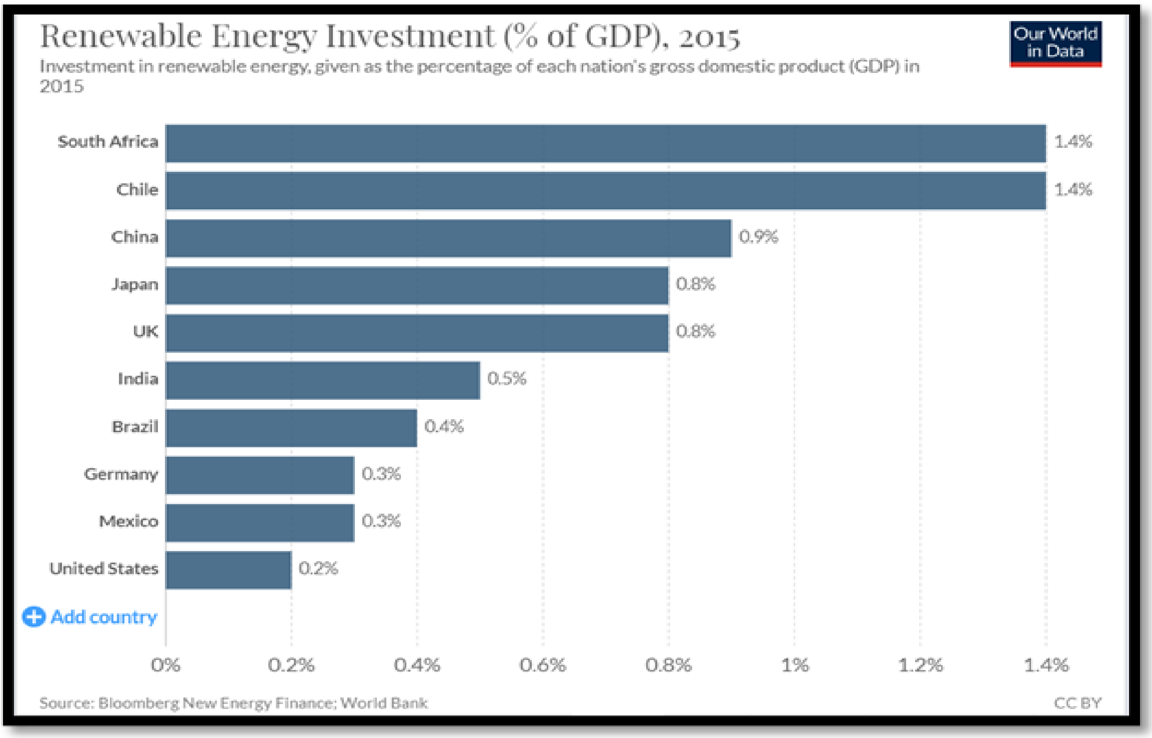


Fig. 27. 2015 Renewable energy investment as a percentage of GDP [17]

The promotion of renewable energy in developed economies are supported by tax arrangements, incentives and promotion programmes, and its uptake is ensured by laws, regulations and environmental policies promulgated by the developed countries' governments. Table 1 lists the laws, regulations, promotion programmes, tax arrangements and environmental policies in place in developed countries.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

TABLE I. DEVELOPED COUNTRIES' INSTRUMENTS FOR PROMOTION OF RENEWABLE ENERGY [21]

Laws/Regulations	**Promotion Programmes**	**Tax Arrangements/Incentives**	**Environmental Policies**
European Union (EU) • Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources 22.1 % of electricity from REN sources in 2010 • Directive on Energy Savings in Buildings (proposal) COM (2001) 226	**European Union (EU)** • White Paper for a Community Strategy and Action Plan [COM (97) 599 final (29/11/1997)] • Green Paper: Towards a Europe Strategy for the Security of Energy Supply [COM (2001) 769 final (29/11/2000)] • "Intelligent Energy – Europe" EIE program (2003-2006)	**European Union (EU)** • Indicative financial framework for EIE €200m (69.8m for SAVE, 80m for ALTENER, 32.6m for STEER and 17.6m for COOPER). • Contributions from expected EU enlargement is expected ~€50m	**European Union (EU)** • European Climate Change Program (ECCP) • European strategy to implement the Kyoto Protocol • To cut emissions by some 122 to 178 million tons of CO_2 equivalent • Renewable certificates trade support
United Kingdom (EU Member) • Renewable Obligation (RO) obliges licensed electricity supplies to supply specified proportion of their electricity from renewable sources • Target: 5 % of electricity by renewables in 2003; 10 % in 2010 • Renewable Obligation Certificates (ROCs) (current value over £40 /MWh)	**United Kingdom (EU Member)** None noted	**United Kingdom (EU Member)** • Capital grants for offshore wind and energy crops projects • Landfill tax credit scheme (Landfill Regulations 2002)	**United Kingdom (EU Member)** • Climate Change Levy (CCL) defines various "taxable commodities" and applies different tax rates (LPG - 0.07 p/kWh; natural gas, coal – 0.15 p/kWh, electricity 0.43 p/kWh). Those meeting reduction targets will receive 80 % levy discount • Emissions Trading Scheme (ETS) – launched in April 2002 • For emissions trading
Denmark (EU Member) • Electricity Act (1999) subsidies for wind energy are to be replaced by Green Certificates	**Denmark (EU Member)** • Target for renewables – 20 % of primary energy sources by 2020 should be renewable • Obligation to buy electricity produced from renewables • Until 1999 production subsidy for wind (€0.03/kWh) was paid	**Denmark (EU Member)** • None noted	**Denmark (EU Member)** • Emissions trading program (2002) – to comply with a 21 % GHG reduction target from 1990 levels • Total caps for power company emissions (quota system) • Every ton of excess emission is fined with non-compliance tax ($5)
France (EU Member) • None noted	**France (EU Member)** • Obligation to buy electricity produced from renewables • National Programme for Energy Efficiency Improvement (2000): feed-in tariffs for renewable energy electrical production • Wind energy promotion • "Eole 2005" – competitive tendering • Solar Heat – "Helios 2006"	**France (EU Member)** • Tax credit for renewables installation • Grants for off-grid renewables (up to 95 % in rural zones and 60 % urban zones. • Reduced VAT and income tax credit (15 % in 2002) for household expenses • Loan guarantees of up to 70 % of the amounts of loans	**France (EU Member)** • None noted
Germany (EU Member) • Renewable Energy Sources Act (2000) • Purchase obligation • Premium guaranteed prices • Co-Generation Act (2000)	**Germany (EU Member)** • "100 000 Roof" program for PV promotion (1999) • Loans at low interest rates target 300 MWp in 2003 • State funded programmes for bioenergy (subsidies)	• Germany (EU Member) • Low interest loans for small renewable projects • Feed-in tariffs for wind energy (€91 /MWh), biomass (€87 /MWh to 102 /MWh), geothermal energy (€71.6 /MWh to 89.5 /MWh), small hydro, up to 5MW (€76 /MWh) and solar (€506 /MWh) • Soft loans from KfW for small (up to 500 kW) hydro plants and small CHP biomass plants	**Germany (EU Member)** • None noted
Australia (OECD Country) • Australian Renewable Energy (Electricity) Act • Mandated Renewable Energy Target (MRET) • The Office of the Renewable Energy Regulator (ORER) sets up mandated portions of renewable energy sources utilization for electricity suppliers and issues RECs (Renewable Energy	**Australia (OECD Country)** • Prime Minister's Measures for a Better Environment (1999) • The Renewable Remote Power	**Australia (OECD Country)** • None noted	**Australia (OECD Country)** • Renewable Energy

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

Certificates) to demonstrate compliance with the requirements. • Penalty for non-compliance $40 /MWh **USA (OECD Country)** • Energy Policy Act (1992) EPACT • Clean Air Act and amendments (tradeable permits for SO_2 allowance) • Renewable Portfolio Standards (RPS) – expected on the federal level in 2005. Target: by 2019/20 – 10 % of electricity from renewable sources **Korea (OECD Country)** • Promotion Act of New and Renewable Energy Development, Utilization and Dissemination **Canada (OECD Country)** • None noted	Generation Program (RRPGP) funded from excise paid on diesel. Support up to 50 % of the capital cost • Photovoltaic Rebate Program (PVRP) – rebates for households **USA (OECD Country)** • Export Promotion. Special Advisory committee at US ExIm Bank to promote renewable industry exports • “Wind Powering America” – US DOE program. Goal – 5 % of US electricity powered by wind • Strategic Plan for Geothermal Energy (June 1998) prepared by the US DOE Office of Geothermal Technologies (OGT) • GeoPowering the West goal: 10 % of electricity in 8 states in US west powered by geothermal sources; 7 million homes • US Geothermal Resource Exploration Definition (GRED) program – joint program of US DOE and geothermal industry. DOE funds portion of initial risks • “Million Solar Roofs”, PV promotion program of the US DOE Office of Solar Energy Technology • Zero Net Energy Buildings (ZEB) **Korea (OECD Country)** • Target for renewables – 2 % of total primary energy supply by 2003 **Canada (OECD Country)** • Action Plan on Climate Change and Wind (feed-in tariffs for wind) • Wind Energy Research and Development Program (WERD) coordinated by Natural Resources Canada (including financial incentives) • Small hydro promotion accelerated tax write-off for equipment of hydro-electric installations not exceeding 15 MW	**USA (OECD Country)** • Section 45 Production Tax Credit (PTC) for renewable energies (biomass, wind, geothermal, solar) • Investment Tax Credits (ITC) • Sales Tax Reductions Property Tax Reductions (on state level different incentives exist, for example investment grants, production incentives, loan subsidy Programmes, grants for demonstration projects) • Net metering in several states **Korea (OECD Country)** • Low interest loans for renewable projects • Tax credit for renewables installation • Feed-in tariffs **Canada (OECD Country)** • Tax incentives for business investments in energy conservation and renewable energy (Canadian Renewable and Conservation Expenses [CRCE]) • At least 50 % of the capital cost eligible for income tax write-offs • Support for renewables – foreign entities get 20 % investment credit against future tax payments	Certificates (RECs) • Australian Greenhouse Office (AGO) looks after GHG matters/runs certification program “greenhouse friendly” **USA (OECD Country)** • Green certificates (tradeable in several states) • SO_2 allowances trade • Renewable Energy Certificate System (RECs) pilot scheme • More than third of consumers have option to purchase green power GHG trading – voluntary • trading scheme – US Chicago Climate Exchange (CCX) **Korea (OECD Country)** • None noted **Canada (OECD Country)** • None noted

The trend within developed countries is that they are driven by clear strategies. For example, the EU provides guidance for all its member states. Each member state has a programme, backed up by environmental policy and legislation, some even to the point of making it an obligation for citizens to purchase electricity from renewables (Denmark) to ensure the uptake of renewable energy happens as well as providing the financial backing through incentives and financial aid. There are clear targets for reduction in carbon emissions as well as emissions trading programmes to promote this target. The OECD

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117
© International Research Publication House. http://www.irphouse.com

countries make use of laws and legislation with the financial backing of incentives and other programmes such as feed-in tariffs to make renewable energy a viable business investment. A point to note is that most programmes were established in the first decade of the 21st century/last decade of the 20th century.

The prime reason for the need for policies and legislation combined with incentives is that new technologies are bound to be more expensive than their competitors (coal, oil and natural gas) which are established in the market and have economies of scale to make them affordable and competitive.

Comparing these initiatives to encourage renewable energy uptake with programmes run by developing countries, referring to Table 2, it can be observed that programmes are still in the development phase. There are few to no policies from the countries included in the table that are reliant on foreign investment (as can be seen with India). Chile, Morocco, Argentina, Vietnam have a rural electrification focus which is characteristic of developing countries. Two barriers for establishing renewable energy in developing countries can be seen here, i.e. financial barriers and the barrier of lack of policies and legislation to drive the establishment of renewable energy.

In this respect, foreign aid is available for developing economies, some for specific countries and others applicable to a wider category. Table 3 shows the financial instruments available especially for developing countries.

TABLE II. PROMOTION OF RENEWABLES IN DEVELOPING COUNTRIES [22]

Laws/ Regulations	Promotion Programmes	Tax Arrangements/ Incentives	Environmental Policies
Chile • Project GEF: Barrier removal for rural electrification with renewable energies **Brazil, South Africa, Bolivia, Vietnam** • None noted **China** • Renewable energy plan • Government is considering • "Mandated market share" for renewable energy **India** • Renewable energy program issued by Ministry of Non-Conventional Energy Sources (MNES) **Argentina** • Regimen Nacional de Energía Eolica y Solar – law from end of 1999 to transfer resources for development of wind and solar projects **Morocco** • Global Rural Electrification Program (PERG) by Office National d'Electricité (ONE) to boost rural electrification from 20% in 1995 to 80 % in 2008	**Chile** • Goal – 90 % coverage for households at a national and regional level by 2006 **Brazil, Morocco** • None noted **China** • Program on New Renewable Energy from 1996-2010 • "Sunlight programme" to promote solar energy **India** • Solar Energy Center of MNES initiates: • ─ Solar thermal program • ─ Solar PV program • ─ Solar building program • Center for Wind Energy Technology of MNES coordinating foreign funding for wind projects **South Africa** • Implementation Strategy for Renewable Energy in South Africa (consultative draft document published by Department of Minerals and Energy). Target – solar energy promotion including off-grid electrification by PV (PV in 1.5 million homes in 10 years) **Argentina** • Renewable Energy and Rural Markets program (PERMER) rural electrification; concessions and funding of rural electrification (wind, PV, etc.) **Bolivia** • National rural electrification program (PRONER) **Vietnam** • National rural electrification program to electrify 90% of rural households by 2005 10% is likely to be by renewable energy	**Chile** • Subsidies to investments • Institutional framework **Brazil** • Financial incentives to owners and/or developers of small hydro schemes **China** • Wind development incentives halving the current 17% VAT duty • Tax reductions, interest rate • Subsidies • Demonstration project • Development **India** • Incentive package to accelerate commercialization of renewable energy technologies • ─ soft loans, funding, subsidies • ─ encouraging BOO projects • ─ 100% foreign direct investment possible (by IREDA – Indian Renewable Energy Development Agency) • PV purchase and subsidy **South Africa, Bolivia, Morocco, Vietnam** • None noted **Argentina** • Tax relief	**Chile, Brazil, China, India, South Africa, Argentina, Bolivia, Morocco, Vietnam,** None noted

TABLE III. SCHEMES BY INTERNATIONAL ORGANIZATIONS TO PROMOTE RENEWABLE ENERGY IN DEVELOPING COUNTRIES [23]

Organisation	Continent of Operation	Renewables Category	Programme	Remarks
Global Energy Facility (GEF)	General	General	Of-grid renewable energy support	US$200m in grants and over US$1bn co-financing
GEF/ United Nations Environmental Program (UNEP)	General	General	Sustainable Alternatives Net (SANet)	Sustainable technologies in emerging markets (including information and guidance on project finance, co-funding, pre-investment and feasibility studies
World Bank/GEF	General	General	Strategic Partnership for Renewable Energy	Target-financing $150m annually; simplified approval process
US Government	Africa	General	African Growth and Opportunity Act (AGOA)	Goal: to expand US exports to Africa
European Commission (EC)	Asia	General	Promotion of Renewable Energy Systems in South-East Asia (PRESSEA)	Renewable energy network. Gathering and disseminating information to attract investments
Inter-American Development Bank (IDB)	Latin America	General	Sustainable markets for Sustainable Energy (SMSE)	Hemisphere Sustainable Energy and Transportation (HSET) Funds for support of renewable energy and energy efficiency projects

From all the programmes shown in Table 1, Table 2 and Table 3, it is evident that the penetration of renewable energy over time has been fluctuating, and hydroelectric sources have been dwindling. This could be due to the lifecycle of existing stock as well as an increase in energy consumption from traditional fossil fuel energy. However, renewable energy sources excluding hydroelectric sources, have been steadily increasing since the turn of the century (Fig. 28).

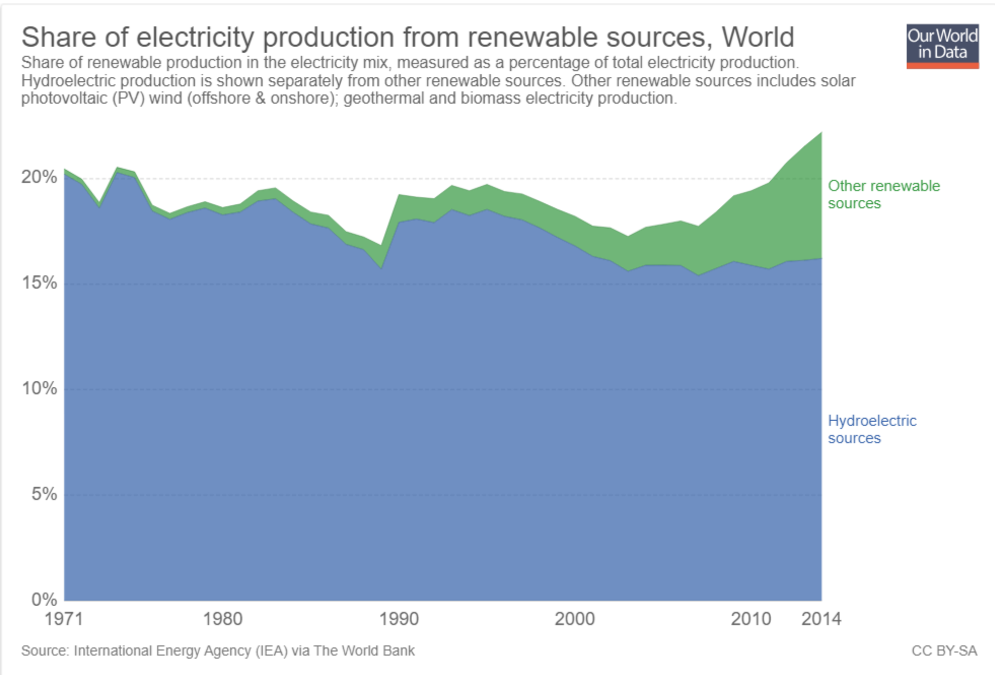


Fig. 28. World share of electricity production from renewable sources [17]

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

Whichever way the picture is interpreted, the penetration of renewables is not yet at the point of making a significant difference in addressing climate change, even though there has been a notable increase in adoption of renewables over the past two decades. There has been a pattern of moving towards a less carbon intensive energy mix through the use of natural gas.

B. Making way for Natural Gas as the new Baseload Energy Source

Natural gas is one of the mainstays of global energy. Worldwide consumption is rising rapidly and in 2018 gas accounted for almost half of the growth in total global energy demand. Gas plays many different roles in the energy sector and, where it replaces more polluting fuels, it also reduces air pollution and limits emissions of carbon dioxide [24]. Coal to gas switching in the world since 2010 has helped prevent faster growth in carbon dioxide emissions by around 525Mt CO_2 between 2010 and 2018, using 2010 as a baseline (Fig. 29) [25]. These emissions would have been closer to 40 Gt without changes in the global economic and energy system since 2010. These include reductions in the energy intensity of the world economy, in part due to greater efficiency, as well as reductions in the carbon intensity of the energy sector related to the rise of renewables and switching to less carbon-intensive fuels. Fig. 30 shows the CO_2 emissions of coal, oil, gas, biofuel and non-combustible sources. Gas has the lowest fossil fuel impact in CO_2 emissions when combusted to release energy and is much cleaner in terms of particulate matter than any other fuel.

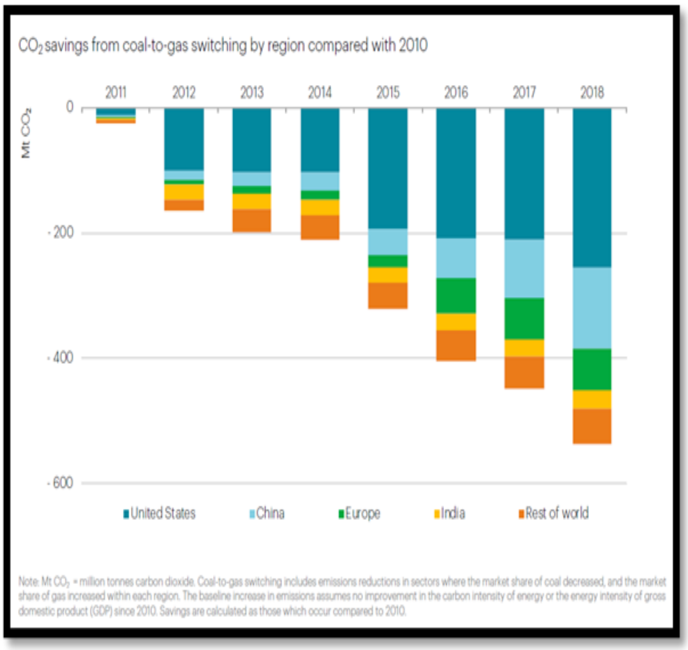


Fig. 29. CO_2 savings from coal to gas switching between 2010 and 2018 (2010 baseline) [25]

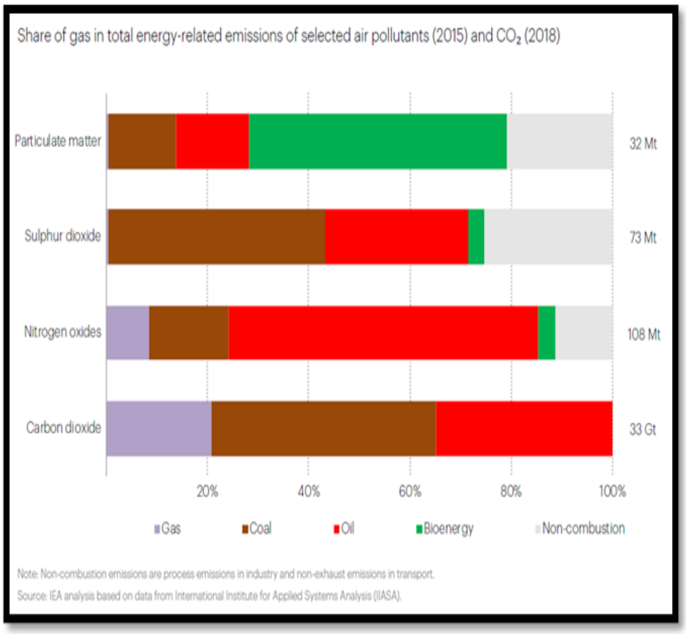


Fig. 30. Share of gas in environmental impact including CO_2 emissions of gas [25]

Coal-to-gas switching avoided more than 500 million tonnes of CO_2 emissions over this period. The majority of the coal to gas switching can be noted in USA and China. The largest emissions savings from coal-to-gas switching occurred in the USA. The remarkable rise of shale gas has pushed down natural gas prices and underpinned large-scale switching from coal to gas in the power sector, where emissions have dropped by a fifth since 2010. In China, gas demand has risen very quickly in recent years because of a major policy push to improve air quality. Gas has substituted for coal-fired industrial and residential boilers in many urban areas; however, switching is much less evident in the power sector [25].

With the notable exception of the UK, coal-to-gas switching has not been a major factor in Europe in recent years, but today's configuration of low gas prices and higher CO_2 prices in the EU is now giving this process renewed momentum (Fig. 31). In India, gas currently has a small share of the energy mix. Large-scale switching has been held back by supply constraints and affordability issues, as well as a lack of infrastructure [25]. In mature markets like the USA and the EU, coal-to-gas switching is a compelling near-term option for reducing emissions, given existing infrastructure and spare capacity (Fig. 32). The cost of coal-to-gas switching has not only to do with the availability of gas, but also the availability of infrastructure, the agility of available infrastructure and the cost of competitor energy sources. The ageing coal powered infrastructure of the USA (more than 80 % being over 30 years old) means that large amounts of coal-to-gas switching can be done at much lower gas prices. More than 50 % of Europe's coal powered infrastructure is over 30 years of age, but the price of coal is very competitive which makes the transition to gas more highly priced.

Gas plays a more prolonged role in emerging economies that are very carbon-intensive today, helping to push more polluting fuels out of the system, notably in China and India's industrial sectors. [25] One can see from Fig. 31 that the transition to gas for Asia's young coal powered fleet (almost 50 % of China's fleet and over 50 % of India's fleet is under 10 years – Fig. 32) is more limited.

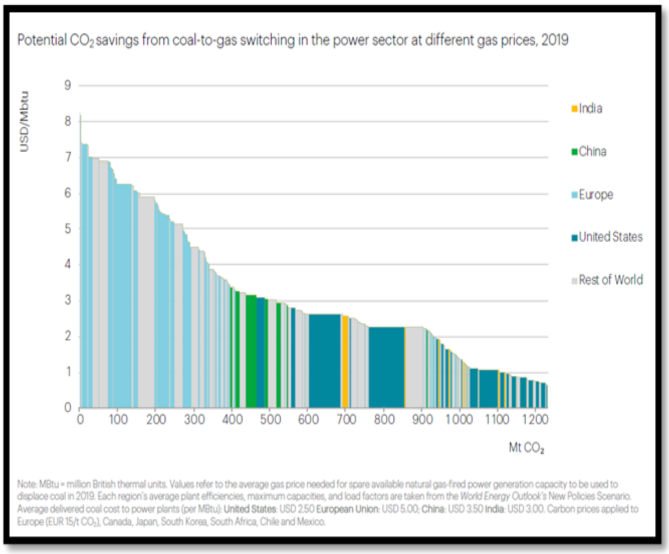


Fig. 31. Potential CO_2 savings from coal-to-gas switching in the power sector at different gas prices, 2019 [25]

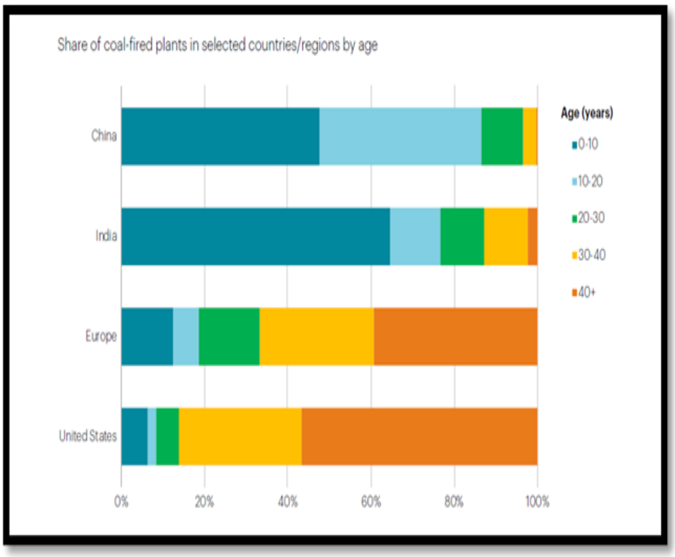


Fig. 32. Share of coal fired plants in selected regions, classifi cation by age [25]

Given the need for decarbonisation efforts to intensify, a role for unabated gas in the energy mix becomes increasingly challenging beyond 2030 [25]. Some countries can use policy instruments and even CO_2 taxes to promote the switch from coal to gas, while other countries may need infrastructure support as well as human capability of building in order to successfully facilitate the transition, especially in developing countries.

Other efforts to decarbonise are occurring in the built environment (construction of infrastructure) where building sustainably reduces overall environmental impact.

C. Green Star Rated Buildings

Green buildings incorporate design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and people. Green buildings are:

- Energy efficient;
- Resource efficient;
- Environmentally responsible; and
- Healthy and productive environments for people.

In short, a green building approach ensures that whatever the development is, whether office, public building, commercial building, etc. it is built to reduce demand and impact on the environment and health of humans. This means rainwater harvesting, onsite processing of waste into useful products, generation of energy, reducing energy and water consumption, using recycled building materials and materials low in greenhouse gas emissions, better air quality, etc. Fig. 33 is a pictorial representation of a typical green building.

There are over 98 individual and recognised green building councils worldwide whose mission is to abate climate change through green building. The World Green Building Council is an umbrella organisation that gives guidance to the different green building councils, of which the Green Building Council South Africa (GBCSA) is a member, alongside Australia, the USA and the UK among others. Green buildings or environmentally sustainable buildings are already widely adopted globally, with strong growth expected in most countries. Fig. 34 shows the increase in green building activity from findings in a report entitled World Green Building Trends 2018 which reveals that more than 47 % of respondents plan to build more than 60 % of their projects green by 2021. The results in this report are drawn from over 2000 survey respondents in 87 countries spanning 5 continents, with statistically significant results on 19 countries.

Fig. 33. Typical green building features [26]

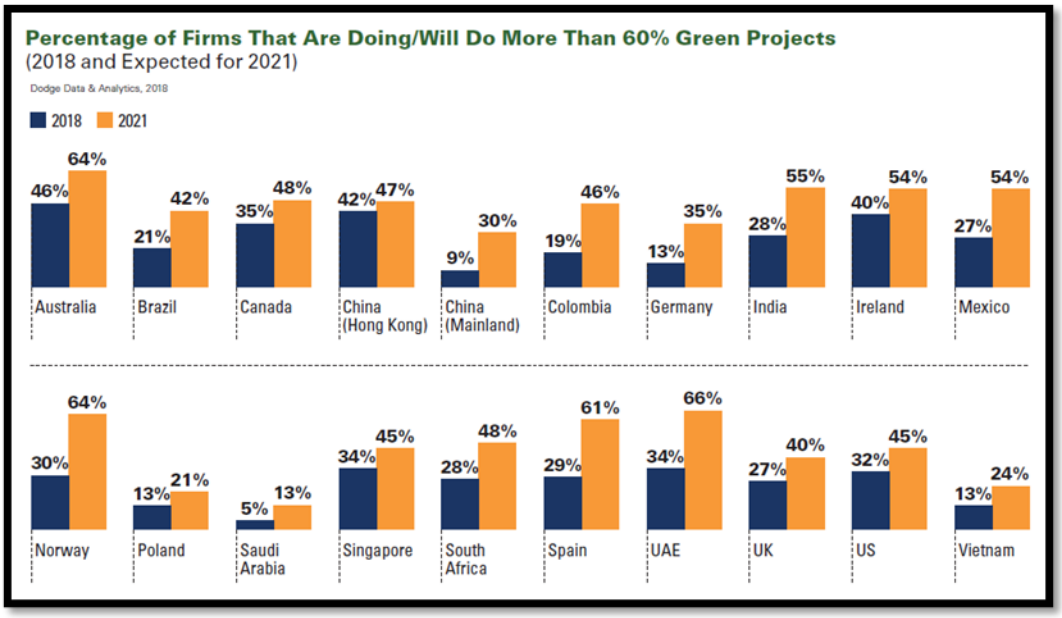


Fig. 34. Anticipated growth in green buildings [27]

South Africa, a developing country, expects to do a significant amount of certification of infrastructure projects, i.e. 48 % of respondents plan to have more than 60 % of their buildings green by 2021. The GBCSA has adopted, adapted, and contextualised the Green Star rating system. Originally developed by the Green Building Council of Australia, this rating system has been used as a base and has been significantly modified to fit the local market and environmental context. The GBCSA is an independent, non-profit member-based company that was formed in 2007 to lead the greening of South Africa's commercial property sector. GBCSA provides the tools, training, knowledge, connections and networks, to promote green building practices across the country and build a national movement that aims to change the way the world is built.

The GBCSA started off with the Green Star rating tools for residential, office, public and education buildings, retail developments and existing buildings as well as Green Star rating of interiors of developments. Their tools have extended to rating sustainable precincts, net zero (carbon, water, waste, ecology) rating tools, energy and water performance tools and many more that meet the South African market demand. There have been over 400 green star certifications between 2007 and 2018 in South Africa. As can be seen in Fig. 35, the conceptual market diffusion for net zero energy targets will reach 100 % market saturation by 2030 for new construction.

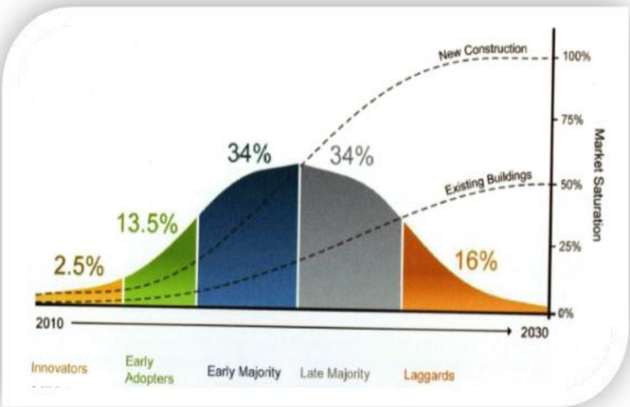


Fig. 35. Conceptual Market diffusion for Zero Net Energy Targets [28]

Fig. 36 shows that the top triggers for green buildings in South Africa are reduced operating costs, healthier buildings and "the right thing to do" which exceeded the global average triggers, whereas the triggers of legislation and client demand seems to be lagging behind the global average triggers. Fig. 37 shows that the payback period for new green buildings is 7 years and for retrofitted green buildings is 5 years (in 2018). The corresponding savings in operational cost in 2018 is 23 % (new buildings) and 22 % (retrofitted buildings) over a five-year period. The top reasons that South Africans selected for going green is reduction in energy consumption and reduction in water consumption, the third reason being protection of natural resources.

The main challenges reported by South Africans with going green is the perceived high initial costs associated with going green which originates from the second challenge of the perception that going green is for high-end projects only and the third challenge is making a business case due to capital and operating expenses being split and the lack of political support and incentives [27].

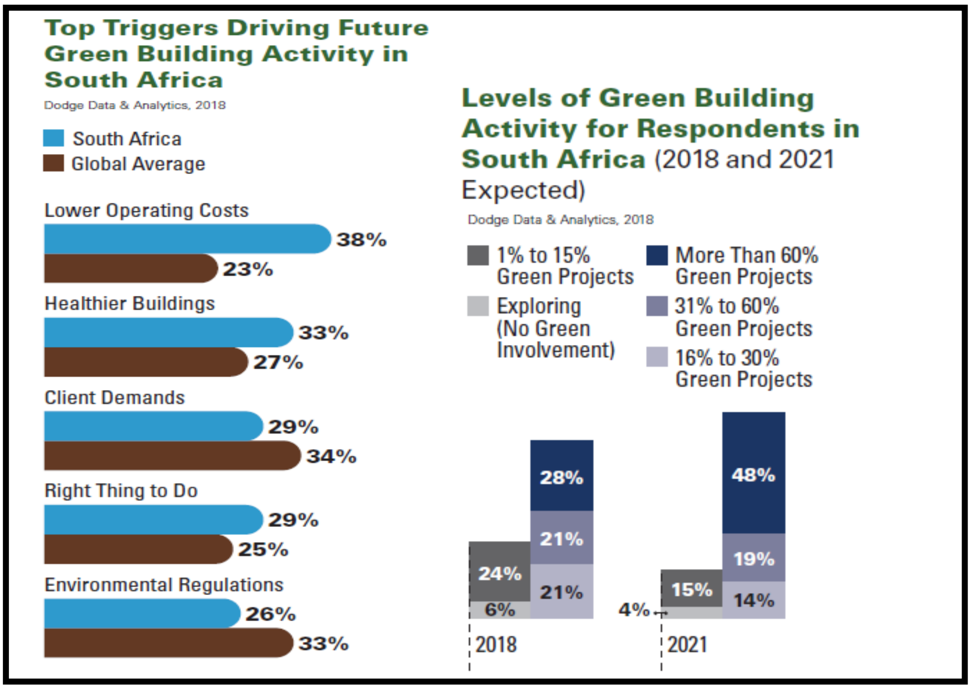


Fig. 36. Green building activity and top triggers for green building activity in South Africa [27]

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117

Expected Business Benefits of Green Building in South Africa

	New Green Building		Green Retrofit	
	2015	2018	2015	2018
Decreased Operating Costs Over One Year	18%	8%	9%	8%
Decreased Operating Costs Over Five Years	19%	23%	29%	22%
Payback Time for Green Investments (Years)	8	7	6	5

Fig. 37. Benefits of Green Buildings in South Africa [27]

The GBCSA has trained more than 7 000 professionals; however, the growing green building industry is also experiencing challenges. Locally and internationally, research has indicated that there is a widespread perception that green building attracts a cost premium as high as 15 % to 25 % compared to conventional construction. These perceptions hamper the progress of green building.

The GBCSA Cost and Trends report 2019 includes a sample of 91 office buildings owned by 52 companies that were certified from 2015 to 2018. The profile of the combined study population size of 146 projects provides context for the study results which follow. The study population size is made up of 54 projects (37,0 %) certified from 2009 to 2014 and 92 projects (63,0 %) certified from 2015 to 2018. A total of 99 projects (67,8 %) have a 4 Star Green Star certification, 38 projects (26,0 %) have a 5 Star Green Star certification and 9 projects (6,2 %) have a 6 Star Green Star certification. Fig. 38 shows the cost premium of green buildings in the period 2009 to 2018 [2].

Fig. 38 is representative of costs two years ago. A recent study (2020) of going green for an actual project in Airports Company South Africa has been conducted and is included in Table 4. From Table 4, the cost of going for a 4-star green star rating of Terminal 2 in Cape Town International airport (approximately 46 000 m^2 gross construction area to be completed in November 2023) is 0,3 % at R7.2m of the total project budget of R2,4bn and for a 5-star rating 0,61 % at R14,7m. These cost indications are way below the GBCSA study indicated in Fig. 38. These figures include GBCSA certification costs, management and consulting fees, capital and specialist modelling costs for the additional technologies and design features for the green star ratings.

The analysis of the operational cost savings is given together with the additional operational expenditure (OPEX) requirements for the Terminal 2 Development project in Cape Town International Airport (CTIA). Using a simple payback for the 4-star green rating, payback can be achieved within two years, considering the 5-star green rating, simple payback can be achieved in just within four years.

GREEN COST PREMIUM – CONSTRUCTION AREA

Construction area – Green cost premium (%)	MIN	AVERAGE	MAX
TOTAL	1,1%	3,9%	14,2%
< 5,000 m^2	3,4%	5,1%	12,2%
< 10,000 m^2	1,7%	4,0%	14,2%
< 25,000 m^2	2,7%	5,2%	12,0%
< 50,000 m^2	1,1%	3,2%	5,0%
> 50,000 m^2	2,0%	2,4%	3,9%

Fig. 38. The South African cost perspective from GBCSA [29]

TABLE IV. COSTS AND SAVINGS BETWEEN 4-AND 5-STAR GREEN RATING FOR TERMINAL 2 DEVELOPMENT (CTIA)

	4-star green rating	**5-star green rating**	**Salient points**
Electricity savings per annum	R4 105 550	R4 935 585	Difference between 4 and 5-star is a Solar PV plant of 500 kWp producing 810 kWh/annum to 185 kWh/annum
Water savings per annum	R 251 972	R 251 972	Air conditioning condensate recovery, rainwater harvesting, low flow toilets and urinals
Sewerage handling savings per annum	R 96 795	R 96 795	Volume of water for flushing of toilets reduced
Total OPEX savings per annum	R4 454 317	R5 284 352	Difference in savings is R 830 035 per annum between a 4-star and 5-star (owing to Solar PV plant)
Capital outlay required	R 7 228 920	R14 728 920	Approximately double the amount capital outlay between a 4-star and 5-star owing to Solar PV plant
Additional OPEX required per annum	R0 (From conventional building to 4-star building)	~R 400 000 (From 4-star to 5-star building)	Calculated using R800 /kW installed of solar PV per annum Note: no additional OPEX required for 4-star green rating

Both options make financial sense and both options can be considered when it comes to green buildings, the advantages points are as follows:

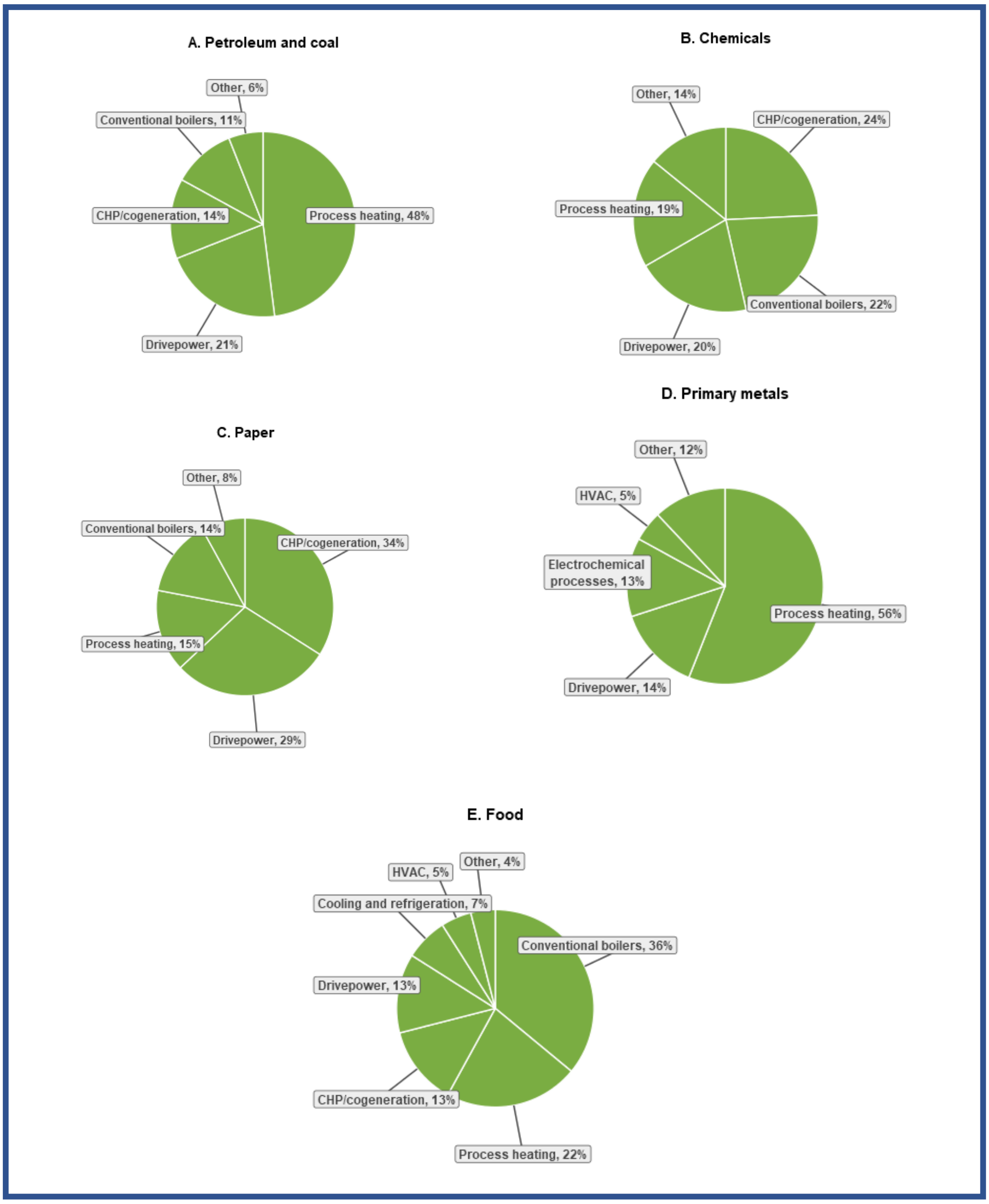
- 5-star green rating supports the organizational goal of ACI carbon accreditation and Carbon Neutrality Roadmap stronger than the 4-star green rating for Cape Town International Airport (CTIA).
- 5-star green rating gives a larger operational cost saving overall, even if payback takes a little longer than the 4-star green rating.

The 4-star green rating model electricity savings involves energy conservation and energy efficiency which is the first "fuel" of developed economies who leverage low hanging fruit with best available technologies and well run engineering building infrastructure as opposed to projects requiring vast amounts of capital outlay, human capability as well as infrastructure capacity to transition energy generation to low carbon (renewable energy), so this makes business sense.

D. The Fuel of Energy Efficiency

Energy is commonly used to produce heat that is needed for transformation of raw materials into usable goods. The industrial sector accounts for approximately 31 % of all energy consumption in the USA (consuming just over 21 000 trillion Btu annually) and much of this energy is used for manufacturing processes. On average, manufacturing facilities use 95.1 kWh of electricity and 536 500 Btu of natural gas per square foot annually, though actual consumption varies widely depending on the subsector.

Fig. 39 shows a breakdown of energy use for the five manufacturing subsectors that consume the most overall energy in the USA. The petroleum and coal subsectors are the largest consumers of energy, accounting for 25 % of the entire manufacturing sector's energy use. The chemicals subsector is second, consuming about 20 % of the sector's energy. The paper subsector accounts for about 10 % of sector energy use, followed by primary metals and food, each of which represent about 5 % of consumption [3].



Notes: CHP = Combined Heat and Power. Sectors shown are in order of total energy use. The "Other" category combines all end uses that consume less than 5% of the overall energy for this sector, including lighting.

Fig. 39. Breakdown of energy use for 5 manufacturing subsectors consuming the most overall energy in the USA [30]

In South Africa, the industrial sector accounted for 52 % of energy consumption in 2016 (Fig. 6). The domestic or residential sector share was 8 %. The typical energy sources for the industrial sector and their industrial sub-sectors can be seen in Fig. 6. The industrial sector is mainly powered by coal (electricity is also primarily from coal sources) and the industrial subsectors of iron and steel, mining and quarrying and the petrochemical industry make up almost half of the energy demand in the industrial sector as seen in Fig. 40 and Fig. 6. The energy use breakdown for the residential sector can be seen in Fig. 41. The rural residential sector primarily uses energy for cooking, water heating and space heating, whereas the middle income-high income residential sector uses energy for a range of different purposes such as pool pump, cool storage, etc. as captured in Fig. 42.

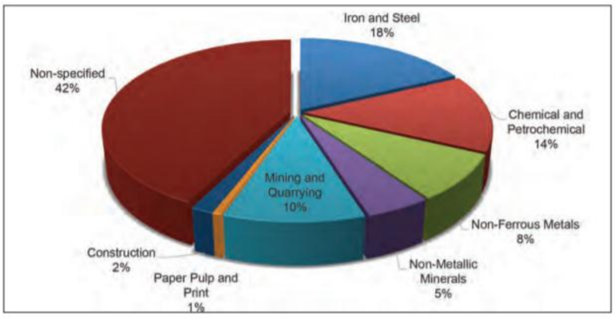


Fig. 40. Energy Demand in the industrial sector, including their subsectors (2016) [31]

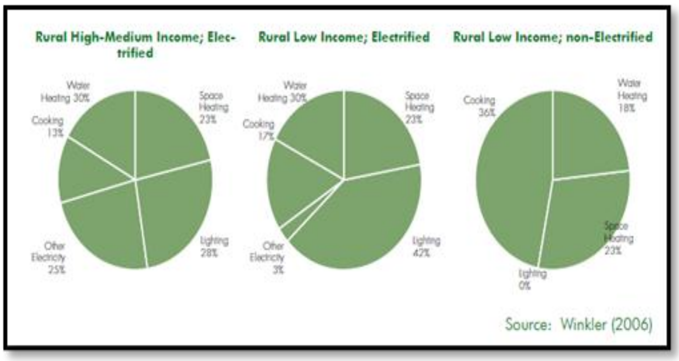
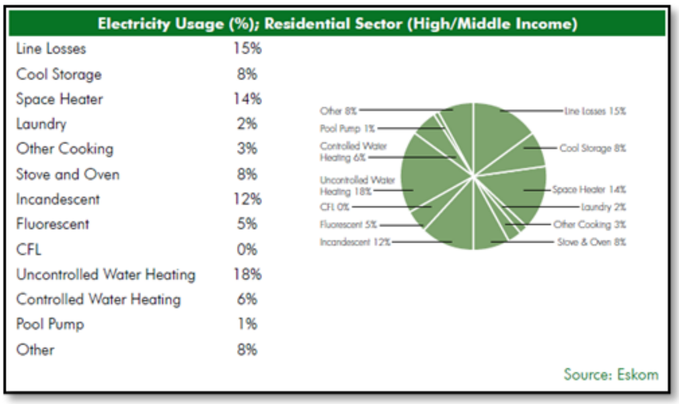


Fig. 41. Rural Residential sector energy use breakdown, 2006 [32]



Electricity Usage (%); Residential Sector (High/Middle Income)	
Line Losses	15%
Cool Storage	8%
Space Heater	14%
Laundry	2%
Other Cooking	3%
Stove and Oven	8%
Incandescent	12%
Fluorescent	5%
CFL	0%
Uncontrolled Water Heating	18%
Controlled Water Heating	6%
Pool Pump	1%
Other	8%

Fig. 42. High/Middle Income Residential Sector energy use breakdown, 2006 [32]

Eskom is South Africa's primary electricity supplier, generating more than 90 % of the electricity in South Africa, and about 40 % of that in Africa [33]. Owned by the South African government, Eskom has been facing demand and supply challenges and investing in energy efficiency to reduce demand has been the focus over the last decade or so. There are many projects funded to reduce electrical energy demand. One of such programmes is the Industrial Energy Efficiency (IEE) Project co-ordinated by the United Nations, funded by various international institutions. The Industrial Energy Efficiency (IEE) Project was established in South Africa in 2010 in response to the need to improve energy efficiency. The United Nations Industrial Development Organizatio (UNIDO), along with the Swiss Secretariat for Economic Affairs, the UK Department of International Development and partnered by the Department of Trade and Industry (the DTI) and the Department of Energy (DoE) of South Africa, embarked on a program to address the need for greater energy efficiency.

The UNIDO programme on energy management system implementation (EnMS) combines capacity-building and pilot implementation. It builds understanding, expertise and skills of consultants and enterprises for implementing EnMS in line with ISO 50 001 and provides the expert advisory services needed to ensure implementation [34]. Providing three elements, the EnMS uses an awareness seminar targeted at executive management, user training tailor-made for engineers and operators of energy intensive equipment and systems, as well as an advanced expert level training aimed at the technical specialist or implementer of an ISO 50 001 aligned EnMS within an organisation. This UNIDO programme has an active portfolio across the world and its footprint can be seen in Fig. 43. Since Fig. 43, Durban in South Africa has been an active participant in the UNIDO EnMS programme.

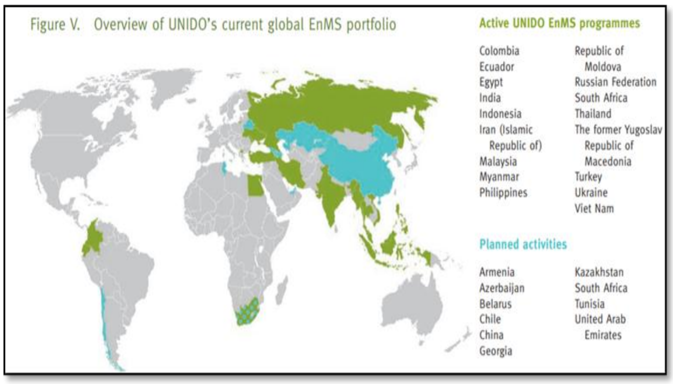


Fig. 43. Overview of UNIDO's EnMS footprint [34]

The programme has since produced results of which five case studies can be seen in Table 5. The first case study is from a hot-rolled coil steel products producer in South Africa (ArcelorMittal Saldanha Works Plant), the second from a milk processing and dairy producing company in Moldova (S.A. Lactis), the third from a petrochemicals company in Egypt (SIDPEC), the fourth from a food processing company using wheat products in Vietnam (Colusa Miliket Foodstuff) and the fifth from an automotive parts producer in Ecuador (INDIMA S.A.).

TABLE V. CASE STUDIES OF ENERGY EFFICIENCY FROM THE UNIDO ENMS PROGRAMME [34]

ArcelorMittal Saldanha Works Plant (Energy Efficiency Achievements, 2011-2012) (South Africa)	**S.A. Lactis achievements through the implementation of an EnMS, 2011-2012 (Moldova)**	**SIDPEC achievements through the implementation of an EnMS in 2014 (Egypt)**	**Colusa Miliket Foodstuff achievements through the implementation of an EnMS in 2012 (Vietnam)**	**INDIMA S. A. achievements through the implementation of an EnMS in 2014 (Ecuador)**
Total number of EnMS measures: 12	Total number of projects: 11	Total number of projects: 6+	Total number of projects: 5	Total number of projects: 3+
Total investment (US$): 50 000	Total investment (US$): 6 900	Total investment (US$): 367 000	Total investment (US$): No data	Total investment (US$): 66 500
Gross financial savings in 2011 (US$): 9 000 000	Gross financial savings (US$): 22 000	Gross financial savings (US$): 1 171 000	Gross financial savings (US$): 46 805	Gross financial savings (US$): 82 213
Overall payback period (in years): 0.01	Overall payback period (in years): 0.32	Overall payback period (in years): 0.3	Overall payback period (in years): <1	Overall payback period (in years): 0.8
Energy savings for 2011 (GWh): 80	Energy savings for 2011 (MWh): 328	Energy savings in 2014 (MWh): 40 000	Energy savings compared to 2011 (%): 12	Energy savings for 2014 (MWh): 394
GHG emission reduction (tons CO_2: 77 222	GHG emission reduction (tons CO_2: 160	GHG emission reduction (tons CO_2: 53 000	GHG emission reduction (tons CO_2: 1 700	GHG emission reduction (tons CO_2: TBD

Eskom also ran a few programmes when South Africa's energy demand exceeded their generation capacity leading to rolling blackouts in the country in 2008. Their Integrated Demand Management (IDM) programmes typically involved incentivizing geyser improvements, solar geysers, heat pumps and replacing incandescent light bulbs with CFLs. According to Eskom, a total of 3,707 MW has been saved since the implementation of their IDM programmes. Fig. 44 shows the breakdown of performed savings per funding model until the end of 2012. The largest savings come from the first mass roll out programme which consisted of distribution of CFL in exchange of incandescent bulbs. A total of 2,137 MW has been saved by replacing over 53 million incandescent bulbs with efficient CFL bulbs. Savings from this programme have contributed to 70 % of all savings claimed by the Eskom IDM unit [35].

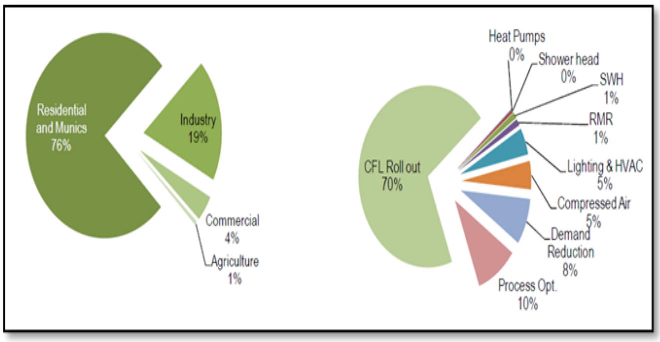


Fig. 44. Energy savings per consumer sector (left) and per tec hnology category (right) [35]

Energy efficiency since 2008 has been the focus of the South African electricity sector due to the demand and supply dilemma that Eskom has faced which has resulted in rolling blackouts even today. South Africa's power station fleet has aged with most of them reaching the end of their lifespan or requiring major upgrades. Output of the power plants can dip to as low as 70 % due to inefficiencies and aged infrastructure.

IV. SOUTH AFRICA'S UNIQUE CHALLENGE

South Africa has a unique challenge in that demand has increased and the materialisation of required power plants in time for the uptake of new demand as well as to serve as a replacement for the demand served by ageing coal powered plants that have reached the end of their lifespan, has failed. South Africa has the added complication of legislation that protects the monopoly of its energy supplier, Eskom, for both political as well as economic advantage reasons, which prevents the markets, organisations and investors from naturally solving this challenge.

In 1998, just four years after the apartheid regime which practised racial discrimination ended, and the first democratic government was sworn in, the Department of Minerals and Energy released its much awaited White Paper on Energy Policy which contained a broad set of policy objectives, organised under five main themes: increased access to affordable energy services, improving energy governance, stimulating economic development, managing energy related environmental impact, and securing energy supply through diversity. One of the factors that led to the demand and supply gap was the mass electrification of around 3,4 million homes between 1994 and 2002 that added demand without a responsive energy generation programme that did not just cater for additional demand but also for the declining efficiency of aging power plants and their decommissioning [36]. The current gap in energy supply and demand can be seen in Fig. 45. The supply gap has two scenarios that were analysed by the Council for Scientific and Industrial Research (CSIR). The "business as usual" scenario looks at converting the coal baseload power stations to nuclear energy as per the Integrated Resource Plan (IRP) 2010 with a small component of renewable energy and new coal developments. The second scenario looks at an optimised electricity mix that utilises the sources of coal, nuclear, gas and renewable energy based on the least cost option as per the demand being catered for [37].

Fig. 46 shows how the two scenarios fill the demand gap and one can see that the primary difference between the scenarios is the significant adoption of renewable energy in the second scenario as opposed to coal and nuclear energy in the first scenario. If renewable energy is considered from a cost basis against nuclear and coal, it makes for a competitive business sense. At 2016 values cost savings would be R330 billion between the two scenarios as can be seen in Fig. 47. Fig. 48 provides the R/kWh generated between the two scenarios if a CO_2 tax was legislated as per the draft legislations being circulated. There is an 18 % cost savings between the scenarios and 21 % if CO_2 tax is legislated.

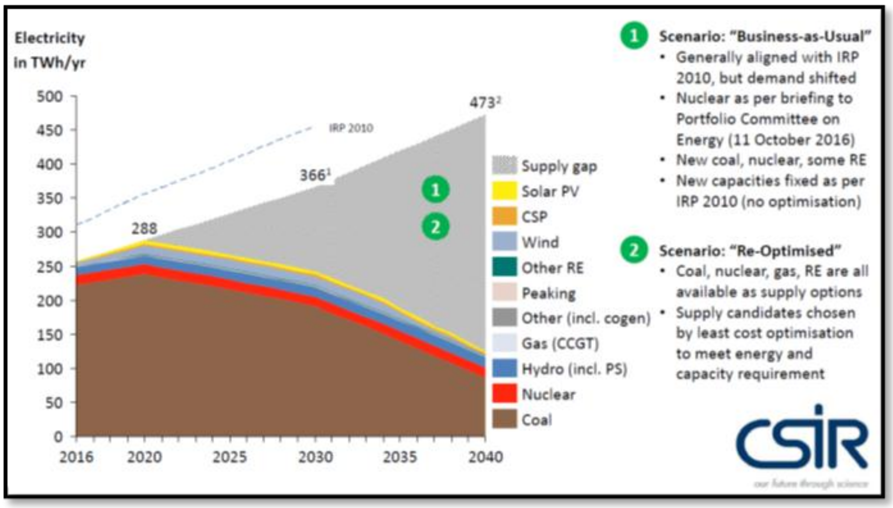


Fig. 45. : Eskom's electricity supply and demand gap and two scenarios for closing this gap [37]

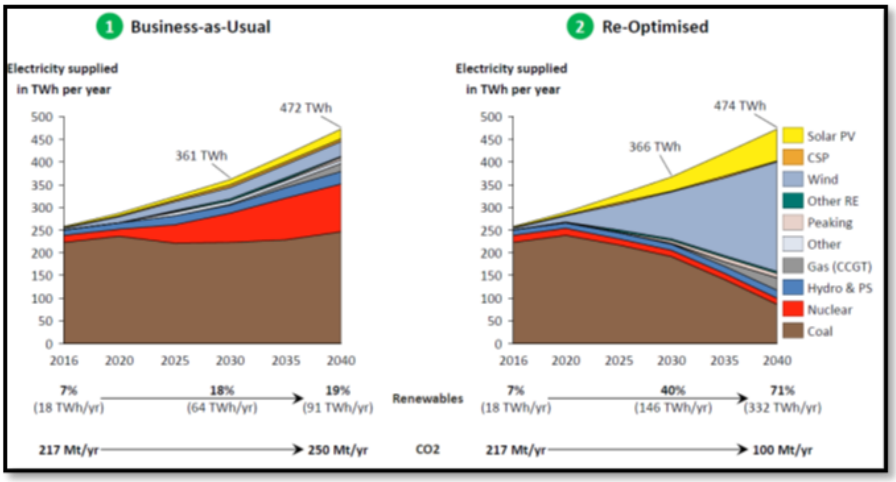


Fig. 46. The two scenarios expanded for meeting the Eskom electricity demand gap [37]

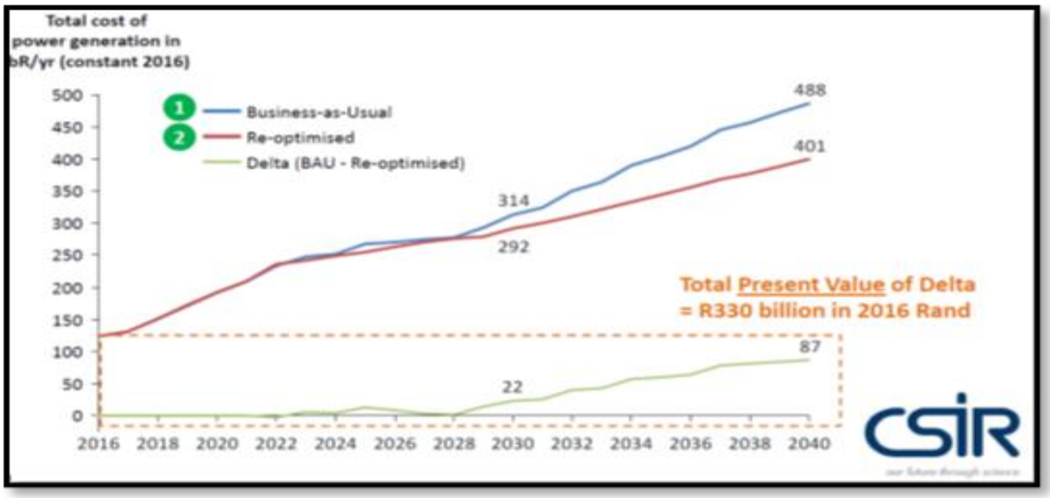


Fig. 47. Cost difference between Scenario 1 and 2 for filling Eskom's electricity supply gap [37]

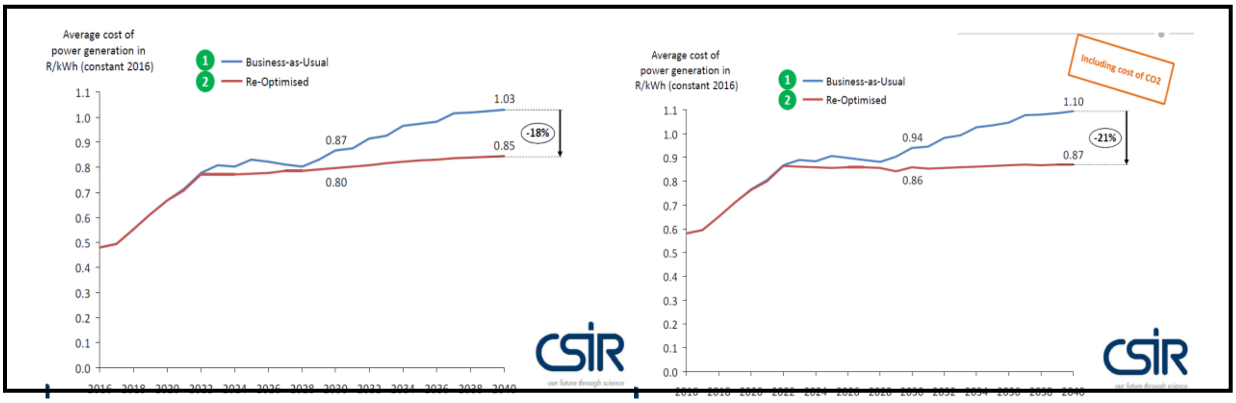


Fig. 48. Cost savings in R/kWh between the two scenarios to satisfy Eskom's electricity supply gap [37]

The production of electricity being mandated to Eskom in South Africa prevents private development and sale of power generation. The South African government expedited the plan for Eskom to purchase power at competitive rates from the private market for resale to the country, this phase was termed the "Bid Window" where wind power and solar energy (solar PV) were purchased from independent power producers and resold to the country. Fig. 49 shows the impact this bid window made in the context of both scenarios of filling Eskom's supply gap. Fig. 50 shows the generation impact in the context of South Africa's existing electricity generation and Fig. 51 shows the geographical locations of the renewable energy plants and this includes hydropower, biomass, landfill gas and concentrated solar thermal plants (CSP). The geographical location of South Africa gives it an advantage of access to a wide range of renewable energy forms available for electricity generation.

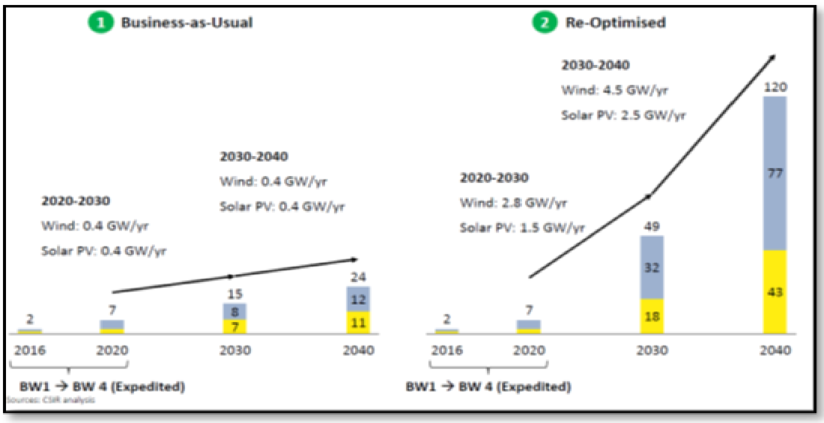


Fig. 49. Eskom's progress with adopting renewable energy in the context of the two scenarios [37]

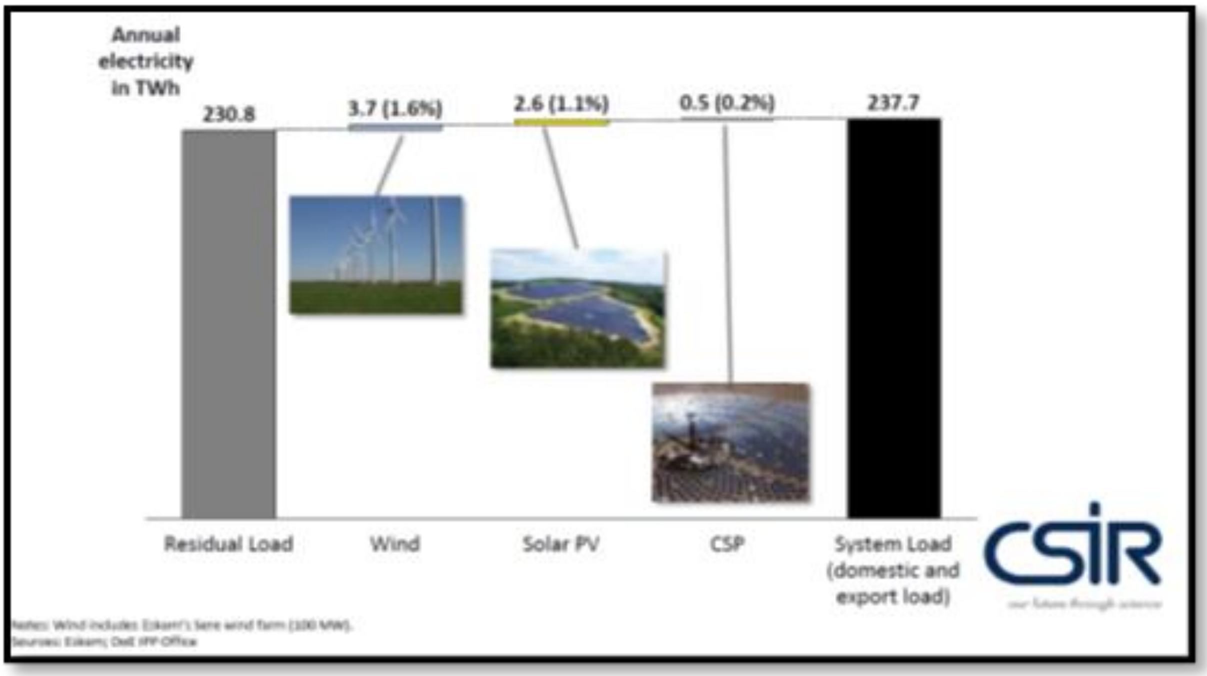


Fig. 50. South Africa's renewable energy installed [37]

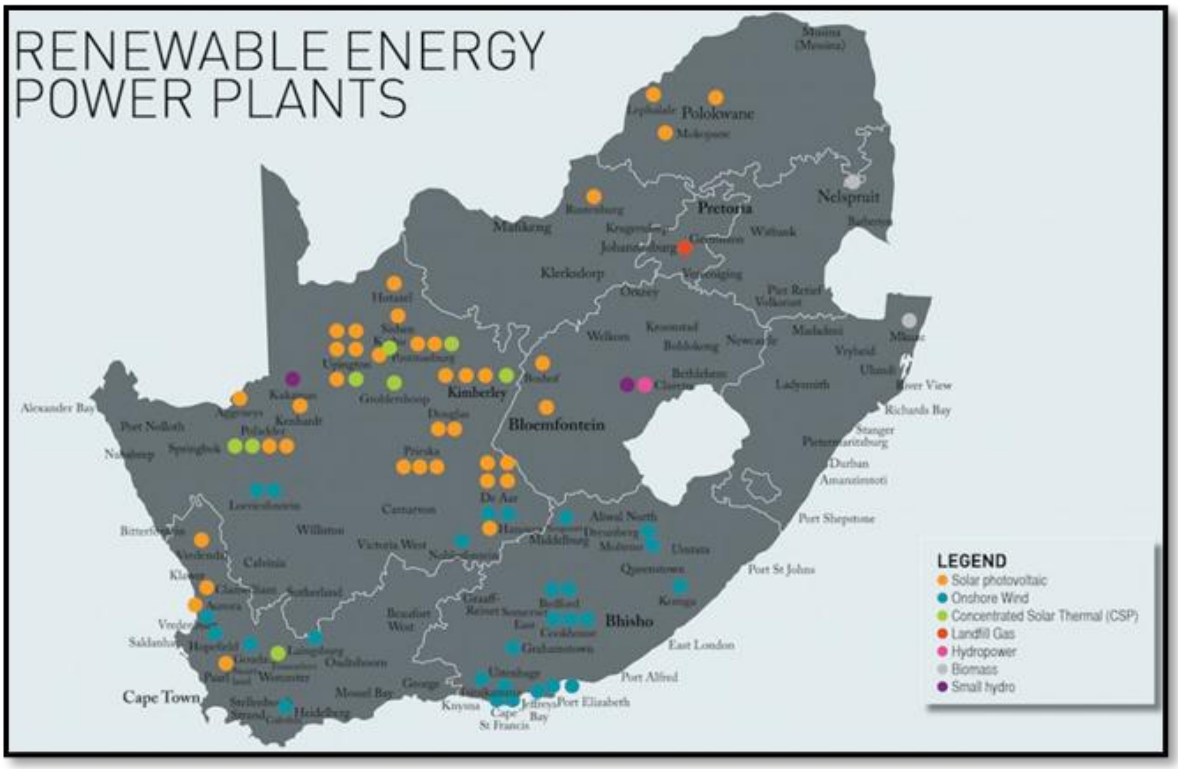


Fig. 51. Geographical location of South Africa's renewable energy plants[38]

The challenge that must be addressed with renewable energy is the capacity factor and the way this plays into the electricity demand profile. At present renewable energy generation mainly serves the fluctuating load and new load in the South African electricity demand profile (Fig. 52).

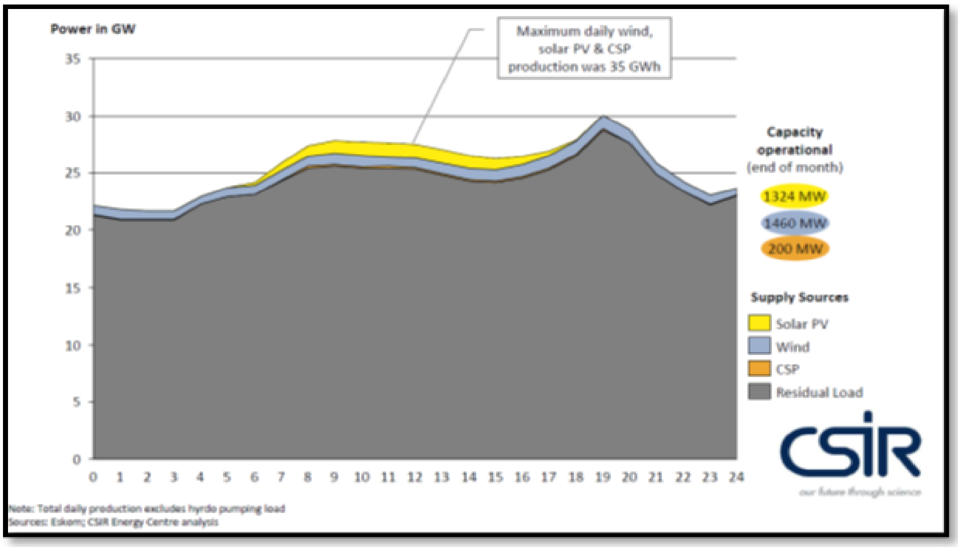


Fig. 52. The installed renewable energy serving the electricity demand within a 24-hour day [37]

Due to the limitation of intermittency due to the nature of renewable energy, the electricity mix is currently designed to incorporate nuclear, coal and natural gas energy sources. In order for Scenario 2 to be realised in South Africa, lots of work remains to be done regarding legislation evolution related to generation entities, the market for energy sources, barriers in relation to the manufacturing sector and capability, and financial barriers.

V. CONCLUSION

The rise of natural gas has been accompanied by a strong increase in renewable energy over the past two decades as a solution to lower overall carbon emissions, particularly in the power sector, where renewables accounted for 45 % of the growth in power generation in 2018. Renewables now account for around one-quarter of total power generation worldwide, second only to coal (at 38 %). Expanding the use of low-carbon electricity is a major vector for energy transitions. There have been noticeable shifts in individual sectors and countries, but the growth in renewables and gas – alongside steady improvements in energy efficiency – has not yet pushed the consumption of other fuels into decline. Global coal use did fall over 2015 to 2016 but has since bounced back. Oil demand has been robust, rising at an annual rate of well above 1 million barrels per day. In 2011, a World Energy Outlook special report asked whether the world might be poised to enter a "golden age of gas" (Fig. 53). This upside scenario for gas was based on supportive assumptions about gas availability and price, as well as policies on the demand side that could promote its use in certain countries, notably China [25].

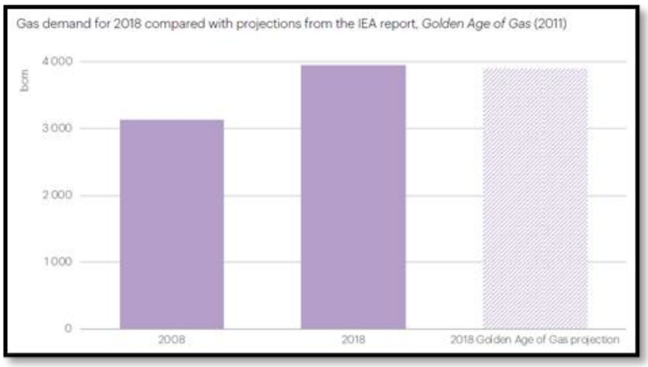


Fig. 53. The golden age of gas reached as per the prediction in 2011 [25]

After three flat years, global energy-related CO_2 emissions resumed growth in 2017 and 2018; annual emissions of more than 33 Gt represent a dangerous disconnect with global climate goals (Fig. 54). This is not good news in in the context of climate change. If one observes the energy reserves of fossil fuels throughout the world (Fig. 55, Fig. 56 and Fig. 57), there is enough proved reserves to keep us going for the next two decades only.

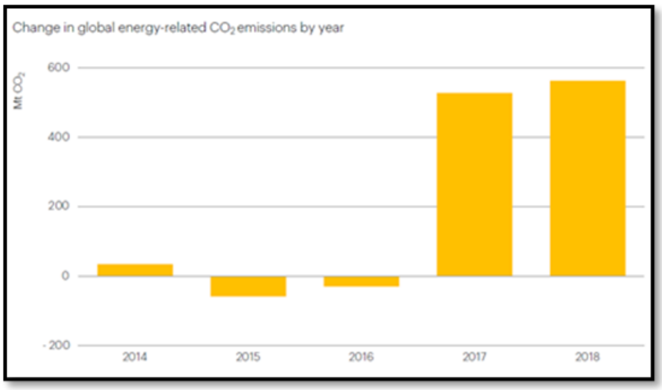


Fig. 54. Change in global energy related CO_2 emissions [25]

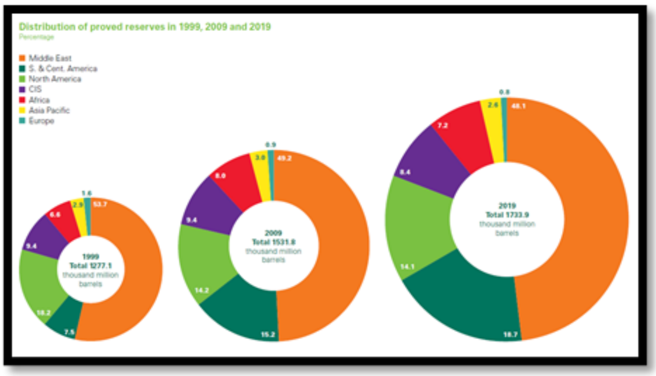


Fig. 55. World distribution of proved crude oil reserves over a 20-year period [39]

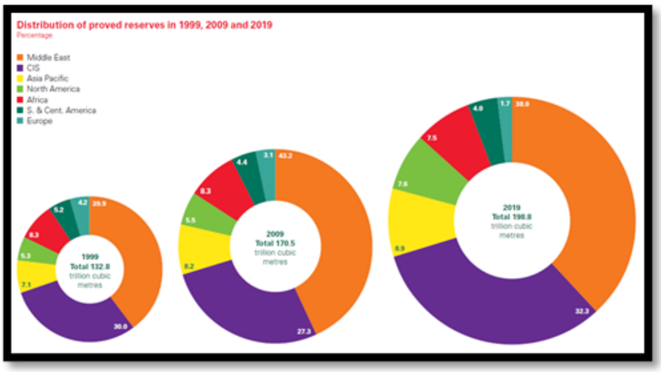


Fig. 56. Distribution of proved natural gas reserves over a 20-year period [39]

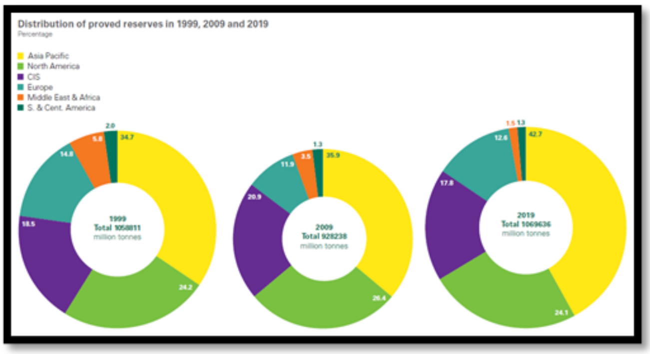


Fig. 57. World distribution of proven coal reserves over a 20-year period [39]

Without restraint or the intervention of climate change policies, a scenario of 4.1 ℃ to 4.8 ℃ warming by 2100 relative to preindustrial temperatures is likely (Fig. 58). Should current climate change policies be applied, the projected warming will be 3.1 ℃ to 3.7 ℃ and if all countries achieve their current targets and pledges set within the Paris climate agreement, the average warming will be in the region of 2.6 ℃ to 3.2 ℃ by 2100. The impact of global warming above 2 ℃ can be seen in Fig. 59. The impact will include falls in crop yields; rising sea levels; reduced availability of water; damage to coral reefs; intensified weather patterns and phenomena such as drought, fires, flooding, heat waves; irreversible melting of the Greenland ice sheets; destruction of Amazon forests and many more.

There is a need to consider two scenarios as depicted in Fig. 58, i.e. a consistent 2 ℃ warming by 2100 and a 1.5 ℃ consistent warming by 2100.

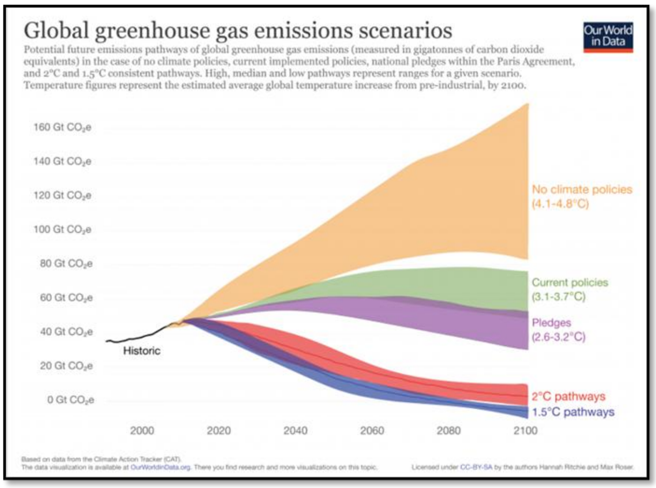


Fig. 58. Global Greenhouse Gas emissions scenarios [12]

The 2 ℃ consistent warming by way of indication will require a significant increase in ambition of the pledges within the Paris Agreement. To achieve the 1.5 ℃ consistent warming pathway, there is an urgent need to aggressively and consistently reduce global greenhouse gas emissions. The behaviour highlighted in Fig. 54, where an increase in greenhouse gas emissions (2017 and 2018) after a period of no or little increase in greenhouse gas emissions (2015 and 2016) is observed, cannot be tolerated in the scenarios of the 2 ℃ and 1.5 ℃ consistent warming pathways. There is clearly a lack of support for sustaining a reduced carbon emissions design and the need for grounding carbon reduction emissions initiatives within the existing business sustainability mesh of economic, social and environmental constructs such that carbon reduction is consistent and naturally achieved. The 2 ℃ and 1.5 ℃ consistent warming pathway scenarios will both require energy efficiency strategies to reduce wastage in energy consumption as well as decarbonising the energy mix generating energy; however, it will need to be achieved naturally, i.e. in the way we do business building and grow our economies.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4084-4117
© International Research Publication House. http://www.irphouse.com

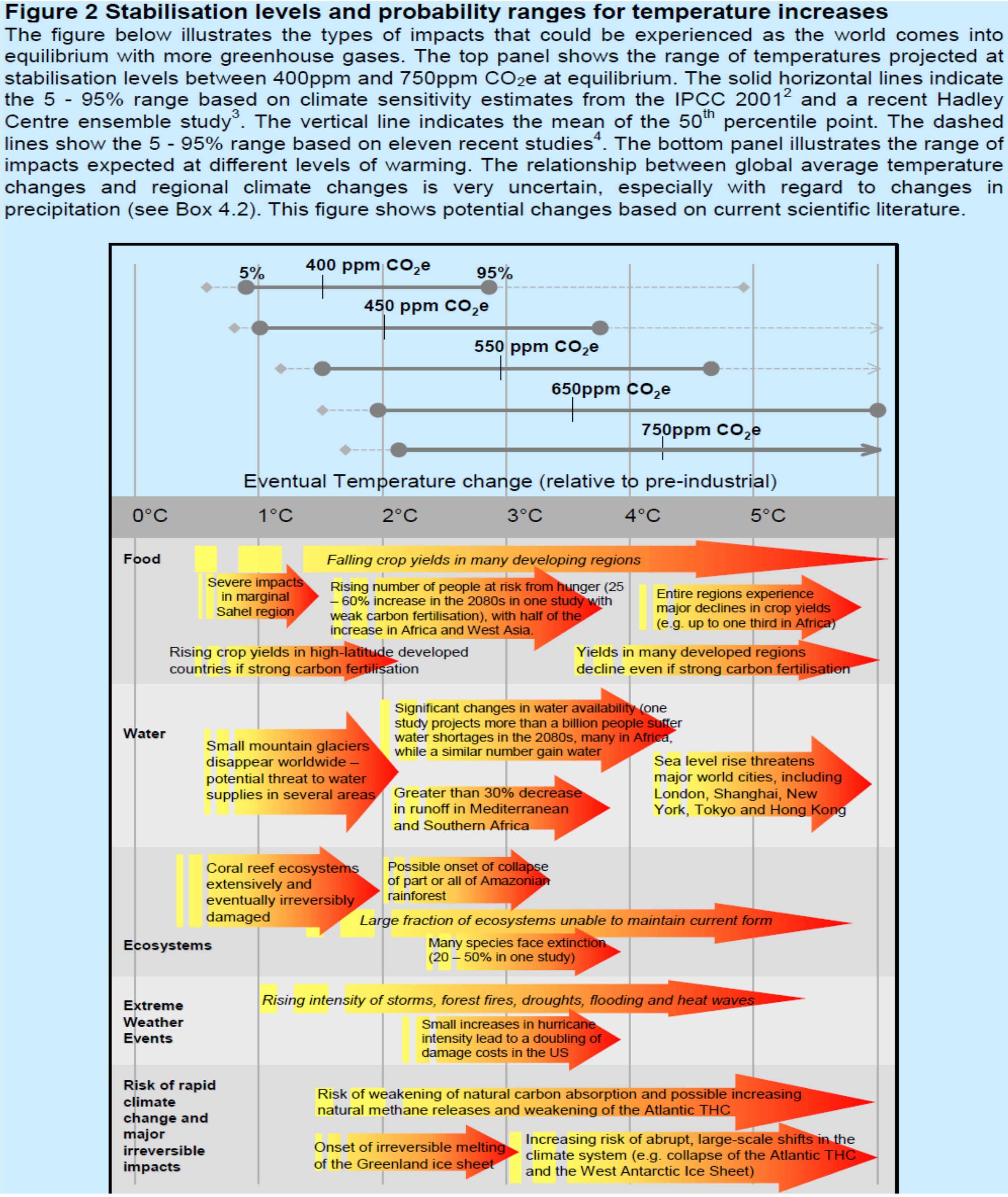


Fig. 59. Adverse effects at various global warming temperature stages [40]

The sustainable solution for ensuring that energy efficiency and energy security has lasting and established penetration in developing countries is the solution that can achieve sustainability in all three spheres of environmental, economic and social constructs. By addressing the priority social concerns and providing an attractive economic alternative, it will be sustained through changing markets, technologies, legislation, personnel and resource availability [41]. This approach to a sustained reduction in carbon emissions must be investigated so as to develop a design that ensures carbon reduction regardless of the dynamics at play in each country across the globe.

REFERENCES

[1] BP Energy Economics, "BP energy outlook 2019 edition," data compilation: Centre for Energy Economics Research and Policy, Heriot-Watt University, 2019.

[2] US Energy Information Administration (EIA), "Consumption by source and sector", https://www.eia.gov/totalenergy/data/monthly/index.php, accessed 12 July 2020.

[3] Republic of South Africa, "The South African Energy Sector Report 2019", Department of Energy. Pretoria: Government Printer, 2019.

[4] Our World in Data, https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions, accessed 12 July 2020.

[5] Organization of the Petroleum Exporting Countries, "Introduction to the Oil Industry and OPEC." Vienna: OPEC, 2013.

[6] Investors Gold (IG) Group, "History of Crude Oil", https://www.ig.com/za/commodities/oil/history-of-crude-oil-price, accessed 12 July 2020.

[7] Centre for Energy Economics Research and Policy, Heriot-Watt University, "Statistical Review of World Energy 2020," 69th Edition. London: Pureprint Group, 2020.

[8] C. Zou, Q. Zhao, G. Zhang, and B. Xiong, "Energy revolution: From a fossil energy era to a new energy era," Nat. Gas Ind. B, vol. 3, no. 1, pp. 1-11, 2016.

[9] W.A. Bakar, R. Ali, "Natural Gas", https://www.researchgate.net/publication/221909211_Natural_Gas, accessed 13 July 2020, August 2010.

[10] Constructed with data from International Energy Agency, https://www.iea.org/data-and-statistics/charts/total-primary-energy-supply-by-fuel-1971-and-2017, accessed 28 April 2020.

[11] Wikipedia, https://en.wikipedia.org/wiki/Developing_country#:~:text=Along%20with%20the%20current%20level,a%20specific%20period%20of%20time.&text=Low%20income%20countries%3A%20%241%2C035%20or,income%20countries%3A%20%244%2C046%20to%20%2412%2C535., accessed 19 July 2020.

[12] Our world in data, https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#annual-co2-emissions, accessed 28 April 2020.

[13] D. Gielen, F. Boshell, D. Saygin, M.D. Bazilian, N. Wagner, and R. Gorini, "The role of renewable energy in the global energy transformation," Energy Strategy Rev., vol. 24, pp. 38-50, 2019.

[14] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds), "Summary for Policymakers. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation". Cambridge: Cambridge University Press, 2011.

[15] Business Insider Intelligence, https://www.businessinsider.com/timeline-155-year-history-of-oil-prices-2016-12?IR=T, accessed 28 April 2020.

[16] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds), Special Report of the Intergovernmental Panel on Climate Change, "Renewable Energy Sources and Climate Change Mitigation". Cambridge: Cambridge University Press, 2011.

[17] Our World in Data, https://ourworldindata.org/renewable-energy, accessed 25 July 2020.

[18] O.A.C. Hoes, L.J.J. Meijer, R.J. van der Ent, and N.C. van de Giesen, "Systematic high-resolution assessment of global hydropower potential," PLOS One, vol. 12, p. 5, 2017.

[19] X. Lu, M.B. McElroy, and J. Kiviluoma, "Global potential for wind-generated electricity," Proc. Natl. Acad. Sci. U.S.A, vol. 106, no. 27, pp. 10933-10938, 2009.

[20] World Bank 2017, Global Solar Atlas 2.0, https://en.wikipedia.org/wiki/Solar_irradiance#/media/File:Global_Map_of_Direct_Normal_Radiation_01.png, accessed 26 July 2020.

[21] World Energy Council, Renewable Energy Projects Handbook. London: World Energy Council, 2004, pp 51-59 extract.

[22] World Energy Council, Renewable Energy Projects Handbook. London: World Energy Council, 2004, pp 67-69 extract.

[23] World Energy Council, Renewable Energy Projects Handbook London: World Energy Council, 2004, pp 64-66 extract.

[24] International Energy Agency (IEA), "The Role of Gas in Today's Energy Transitions", Paris: IEA, 2019, p. 2.

[25] International Energy Agency (IEA), "The Role of Gas in Today's Energy Transitions", Paris: IEA, 2019, pp. 7-93.

[26] Green Building Council of South Africa, "The Green Building Handbook", South Africa, Volume 5. Cape Town: alive2green, 2012.

[27] Dodge Data and Analytics, "World green building trends 2018: developing markets accelerate global green growth", Design and Construction Intelligence SmartMarket Report, 2018.

[28] Green Building Council South Africa, The Green Building Handbook, South Africa, Volume 5. Cape Town: alive2green, 2012.

[29] Green Building Council of South Africa, Green Building in South Africa: Guide to Costs and Trends. Cape Town: alive2green 2019, p. 22.

[30] Business Energy Advisor: Manufacturing industries, https://snopud.bizenergyadvisor.com/article/manufacturing-facilities#toc-0, accessed 17 May 2020.

[31] South Africa Department of Energy, "The South African Energy Sector Report 2019", Pretoria: Government Printer, 2019.

[32] R. Milford, Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in South Africa. Nairobi: United Nations Environment Programme, 2009.

[33] Eskom, "Eskom Integrated Annual Report 2019". www.eskom.co.za., accessed 11 August 2020, March 2019.

[34] United Nations Industrial Development Organization (UNIDO), The UNIDO Programme on Energy Management System Implementation in Industry. Vienna: UNIDO, 2015.

[35] Rue du Can, S., Letschert, V., Leventis, G., et al., "Energy Efficiency Country Study: Republic of South Africa," LBNL Report 6365E. Berkeley, CA: Lawrence Berkeley National Laboratory, 2013.

[36] R. Spalding-Fecher, "Energy and energy policies in South Africa: an overview", NER Quarterly J., vol. 1, no. 1, p. 6, 2002.

[37] J. Wright, J.T. Bischof-Niemz, J. Calitz, and C. Mushwana, "Least-cost electricity mix for South Africa until 2040." Pretoria: CSIR Energy Centre, 2016.

[38] Alternative Information & Development Centre, Renewable-Energy-South-Africa-Electricity-Power-Plants, http://aidc.org.za/renewable-energy-south-africa-electricity-power-plants/, accessed 12 August 2020.

[39] Centre for Energy Economics Research and Policy, Heriot-Watt University, Statistical Review of World Energy 2020, 69th Edition, London: Pureprint Group, 2020.

[40] N. Stern, and M. Jacobs, Stern Review on the Economics of Climate Change. London: Government of the United Kingdom, 2006.

[41] F.L. Inambao and J.S. Joseph, "Sustainability: The big challenge," Int. J. Eng. Res. Technol., International Research Publication House. http://www.irphouse.com (Accepted for publication).