Chapter

Clean Coal Technology Adaptability and R and D Support for Efficiency and Sustainability

Tankiso Pitso

Abstract

The energy transition from fossil fuels to renewables will safeguard the environment. The energy production from coal-fired power station accounts to global greenhouse gas (GHG) emissions. It is urgent for the energy sector to become innovative to tackle climate change. The world coal reserves are paramount for energy security. Coal-generated electricity is still a dominant source of energy around the world, and it is believed that coal-generated energy will remain part of the global energy mix in the near future. In a short- and long-term, energy policy frameworks need to embrace and support clean coal technologies through expanded research and development investment primarily to mitigate climate change and guarantee environmental protection. This chapter explores green and emerging clean coal technologies (CCTs). It builds a case for investment in innovative green technologies to support cleaner environment. This study recommends a holistic approach; thus, while nations safeguard socioeconomic interests, economic competitiveness, investment in feasibility and adaptability of clean coal technologies should be gradually implemented. The commitment to climate change mitigation is paramount for sustainable growth and environmental preservation.

Keywords: clean coal technologies, greenhouse gas, research and development (R and D), climate change, environment, carbon capture and storage (CCS)

1. Introduction

This chapter focuses on clean coal technology adaptability and R and D support for efficiency and sustainability. It builds the analysis on the relevant, credible literature. In the context of climate change, there has been a need for complete overhaul of energy sources. Energy is fundamental for socioeconomic wellbeing of nations, so is the environment and ecosystems that sustain life. It is undoubted that energy is key for development. The modern way of life requires constant connection to reliable energy sources. Inability to supply people or industries with power means dire disappointment. People's devices, smartphones, laptops and all modern gadgets would not function without energy. The fundamental question is that where is this energy being sourced? Is it in harmony with the environment and all creatures living in it? There has been pressure on the planet earth. Human activities are rushing to achieve high levels of economic development at the expenses of environmental health. Now, humanity is all at the crossroads.

Conversely, it is an urgent duty to revise our behaviour towards nature. It is critical to respect and be responsive to symptoms from Mother Nature that there is a huge strain, temperatures are rising and massive destruction by wildfires and heavy storms and if these symptoms do not send a message to any human being alive on planet Earth, we shall all pay an even huge price. The human mind holds massive potential to develop most complex weapons and, possibly, mass destruction. It is time to develop technologies and systems that will help us save our environment through green technologies regardless or rather against our competing interests.

Climate change is the new threat. As plumes of smoke were billowing from chimneys of industries and massive coal plants over centuries, it was less significant to think deeper about the fact that things were getting worse and losing normalcy and that nature endured pressure from polluting gases. Coal was burnt for energy that was needed to supply heavy industries: manufacturing, mining and households. The more coal was burnt, the more carbon dioxide (CO_2) was produced, and this was a slow poison and affected the climate. Nevertheless, coal is still crucial for the world despite of it as the polluting energy source. The world is here now. Everyone needs to respond, and developing clean coal technologies will not be the only solution to saving environment, but as the world marches to a cleaner energy transition, extensive research suggests that coal cannot disappear in the energy mix, but it is feasible to strive towards deployment of clean coal technologies to allow necessary reductions on emissions.

It is evident that countries have committed to organising their efforts in reducing greenhouse gases (GHGs). Reliance on coal-fired power needs to be reduced, simply because coal is regarded as the culprit but needs to be seized as it is a major source of electricity due to polluting potential. Coal-fired plants (**Figure 1**) are currently supplying 37% of global electricity, and in some countries, coal supply has much higher percentage of power [1]. However, coal still dominates as the world's energy source. Coal is the most extensively accessible fossil fuel around the world, and it relies upon the energy security [2].

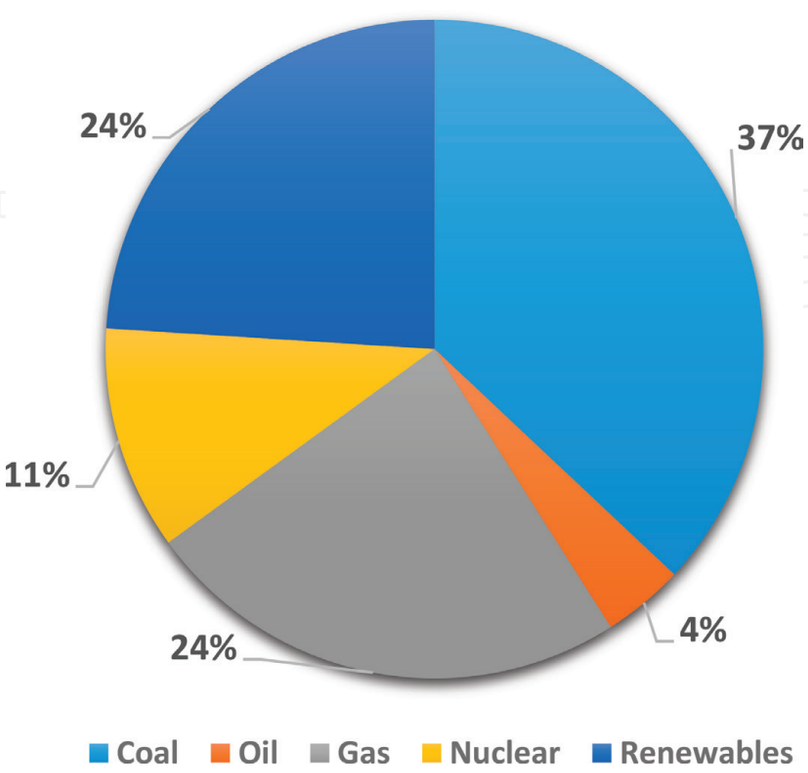

Figure 1.
World electricity mix. Source: International Energy Agency, World Energy Outlook [3].

The coal-fired power plants are under considerable configurations across the world to accommodate new certain innovative technologies. The clean coal technologies are a solution to the continual use of coal which has been regarded as the source of CO_2 which affects the environment. Coal-fired and coal-generated electricity is coming from burning of coal. There are gases that come from coal combustion which include carbon dioxide (CO_2) and nitrogen and sulphur oxides (respectively, NO_x and SO_x).These gases pollute the environment as such there has been an increased interest to develop technologies that will reduce CO_2 and other gases. The high efficiency, low emissions (HELE) technologies comprise of supercritical (SC), ultra-supercritical (USC) and advanced ultra-supercritical (AUSC) technologies [4].

The debate around energy security and climate change has attracted attention of policymakers and scholars in the energy sector across the world. To mitigate climate change, the world is committed to reducing the CO_2 emissions. There are opportunities and costs associated with this transition. However, in order to protect the environment, these emerging clean coal technologies are of paramount importance. It is in the interest of all nations to find ways to cut the pollution from coal-generated technologies. Conversely, these technologies are developed at a higher cost, and for developers of these technologies to continue in enhancing the efficiency, substantive investments need to be made in supporting further research to explore the following key areas:

- Adaptability of clean coal technologies to different contexts and environment.
- Further support for research and development (R and D) to develop and test these new technologies.
- The most important element is that further research will help enhance efficiency of these clean coal technologies and ensure sustainability.

1.1 Policy shifts

There have been international declarations aimed towards advancing green technologies through the UN Framework Convention on Climate Change, parties committed to technology development and transfer. Thus, nations decided to strengthen the Technology Mechanism and mandated Climate Technology Centre and Network in supporting the implementation of the Agreement, to undertake further work relating to, among others, technology research, development and demonstration and, secondly, to ensure the development and enhancement of endogenous capacities and technologies [5]. On the other hand, Omoju [6] asserts that overwhelming conviction of the important role of coal in the energy mix in the future has stimulated the increasing emphasis on the development of clean coal technologies in recent years [6].

Within the realm of climate change and emerging clean coal technologies, countries are propelled to integrate these technologies into coal energy systems. In most cases, the resource planning of every country takes into consideration the need to ensure efficiency in the use of energy resources and balanced energy policies to ensure energy security. The goal to high efficiency, low emissions (HELE) informs efforts around policy shifts and advanced technology options. WCA maintains that HELE technology suggests significant progress on the pathway towards carbon capture, usage and storage which is primarily vital to meeting global climate objectives [7]. A pathway to zero emissions is being paved, and moving to cleaner, green technologies is a drastic measure to saving the environment.

There are concrete plans around clean coal technologies that are being drafted across the world. For instance, China's National Energy Administration (CNEA) developed an 'Action Plan for Clean and Efficient Use of Coal (2015–2020)' as the guiding principles for China's clean coal policy [8]. South Africa's National Development Plan (NDP) (2030) also recognises a need to implement the advanced clean coal technologies to reduce emissions and address the climate change issue. Retrofitting the existing coal plants with CCS or other clean coal technologies is vitally important [9].

1.2 Evolution of clean coal technologies

CCS technology has been around since the 1980s [10]. According to WNA, '**clean coal**' **technologies** have a variety of **evolving** responses to the late twentieth-century environmental concerns, including that of global warming due to carbon dioxide releases to the atmosphere [11]. The major factors that influence the selection of energy sources and clean energy technologies are energy availability, environment and economics [12]. The Global CCS Institute maintains that there are currently 21 CCS projects in operation or construction around the world [13].

2. Clean coal technologies as climate mitigation effort

The world is at crossroads in terms of energy needs and responding to climate change. Over the last few years, there has been an ambition to develop technologies that will help us cut greenhouse gases which are believed to be contributing to global warming which in turn affect the planet we live in. Clean energy is the way to go not only as an effort to mitigate climate change but also meeting sustainable development goals which highlight environmental health and resource management. Bringing clean coal technologies is a noble step in ensuring that while the world meets its energy security, the environmental health is not compromised. Coal cannot be rendered as obsolete natural resource, but clean coal technologies will reduce environmental impact on coal-fired power stations across the globe. In addition, emerging coal technology has the potential to balance environmental and economic concerns while continuing to satisfy our growing world with energy output [14].

To address climate change, it is paramount to deploy clean coal technologies that will reduce the GHG and in the process helps the world to attain energy security while balancing the economic and environmental priorities (**Figure 2**). CCTs serve as important factor CO_2 abatement. Therefore, all coal-producing countries which rely heavily on coal-generated energy might be content with the status quo which simply guarantees energy security and low energy tariffs. However, it cannot be a business as usual; there is a need to deploy CCTs not mainly to comply with international commitments but to be ethical in saving the environment.

2.1 Available clean coal technologies

The coal power plants are considered clean when fitted with advanced technologies that reduce CO_2 from polluting the environment. These technologies can be classified into supercritical and ultra-supercritical steam cycle, circulating fluidised bed combustion (CFBC) and integrated gasification combined cycle (IGCC) [15]. These are some of the advanced coal technologies installed in different countries around the world. Regardless of cost as a major barrier, some countries see it fit to invest in these technologies because the benefits will be much

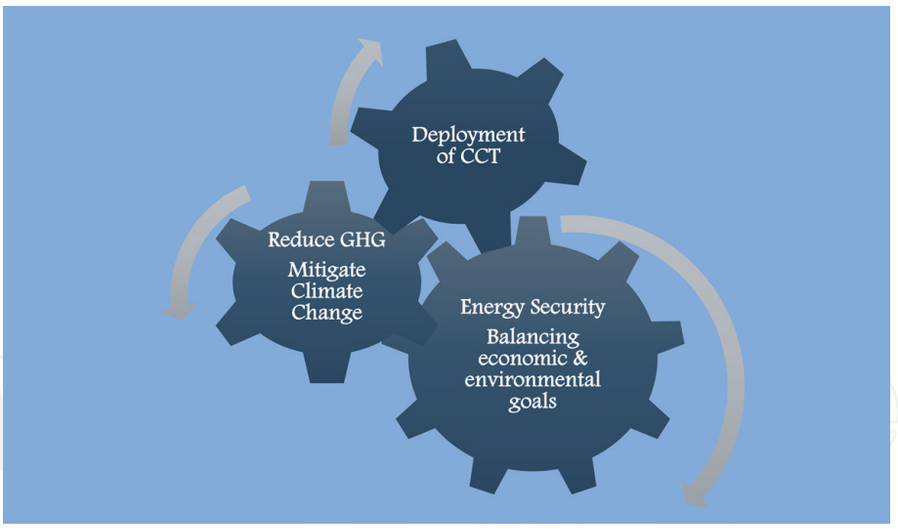

Figure 2.
Interlocking clean coal technologies ideals and impact. Adapted from Giglio [14].

Figure 3.
The Łagisza power plant, Poland. Image: Jänttiet al. [16].

better than ignoring the pollution from coal-fired plants. Investment in low-carbon energy technologies should be every country's responsibility.

Subsequently, clean coal technologies have been existing for a couple of years now. The Łagisza Power Plant is hailed as the world's first supercritical CFB technology (**Figure 3**). This is regarded as a success story in clean coal technologies. This plant began commercial operations in late June 2009, and it marked a new era in the evolution of circulating fluidised bed (CFB) technology. Since its commercialisation, the operation experience of the Łagisza boiler is said to been excellent. Since its operation period, the load range, the boiler has been performing as designed, and the plant operation has been stable and easily controllable [16] (**Figures 4** and **5**).

The WFGD plant is expected to be the cleanest coal-fired power plant in Eskom's fleet. During its performance tests, Kusile's WFGD plant has exceeded original performance commitments as it achieved 93% removal efficiency rate, to deliver more value to Eskom and the local communities [17]. The WFGD system at Kusile is the most advanced environmental control technology to significantly reduce SO_2 emissions. GE's WFGD system guarantees cleaner air for the environment and the inhabitants of the Mpumalanga area. South Africa has a relatively high carbon footprint per capita [17]. Consequently, WFGD offers an important means to limit CO_2 emissions.

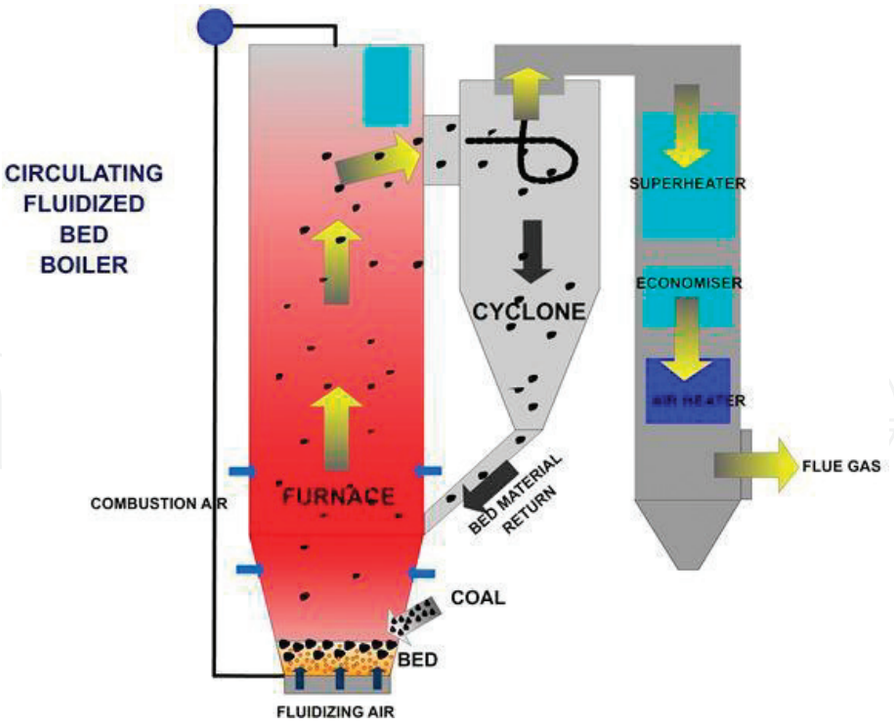

Figure 4.
Fluidised bed combustion (FBC). Image: Courtesy of Eskom fact sheet (2016).

Figure 5.
Eskom's Kusile wet flue gas desulphurisation plant (South Africa). Image: Biznis Africa (2018).

Figure 6 shows the installed Tanjung Bin 4 ultra-supercritical technology. This is regarded to be the most efficient coal combustion technology on the market today. The supercritical power plants are said to operate at a higher temperature and pressure than regular coal-fired power plants. As such, these more stringent steam parameters improve their efficiency, increasing the amount of power output and decreasing fuel consumption and emissions, particularly CO_2 per unit of fuel burnt [18].

Key figures of the technology as per GE POWER description. The technology has:

- 7.5 GW installed by GE in the country
- 1000 MW additional output with Tanjung Bin
- Energy for 1,400,000 people in Malaysia
- 5400 employees on-site at its peak

Figure 6.
Tanjung bin 4 ultra-supercritical technology. Image: Courtesy of GE POWER.

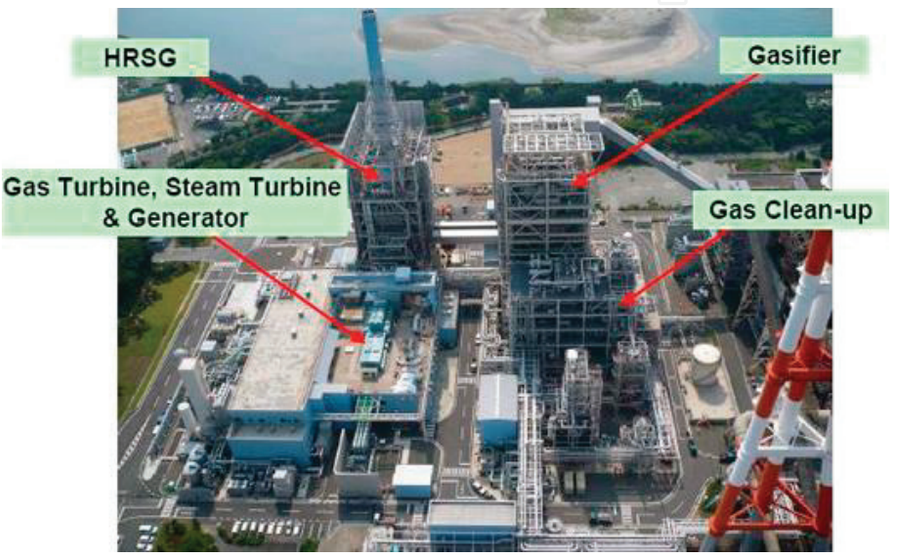

Figure 7.
View of the 250 MW IGCC demo plant at Nakoso, Japan. Source: Mitsubishi heavy industries, ltd.

This technology offers a potential for high efficiency with very low emissions [19] (**Figure 7**).

This technology is amongst the world's most advanced clean coal technologies. This CFB commercial operation began in 2015. Accordingly, this power station is hailed to be meeting the stringent emission values as stated below [20].

Fuel, Indonesian coal and biomass.
Boilers, 4 × 550 MWe CFB.
Net plant efficiency (LHV), 42.4%.
Steam flow (SH/RH), 1573/1282 t/h.
Steam pressure (SH/RH), 257/53.
Bar (g) steam temperature (SH/RH), 603/603°C.
Feed water temperature, 297°C.

Figure 8 demonstrates the power plant with an advanced technology. This technology is ranked among the high-efficiency supercritical circulating fluidised bed (CFB) technology. It offers excellent solutions for high-efficiency electricity production and CO_2 reduction. The first high-efficiency CFB power plants to utilise the supercritical steam parameters in coal firing with once-thought steam cycle technology are Łagisza, 460MWe in Poland; Novocherkasskaya, 330MWe in Russia; and Samcheok Green Power, 4 x 550MWe [16].

Figure 9 demonstrates the process of carbon capture, utilisation and storage of CO_2. From the power plant, CO_2 is captured at separation plant. Then, the CO_2

Figure 8.
Samcheok green 550 MWe power plant, South Korea. Image source: powermag.com 2018 [24].

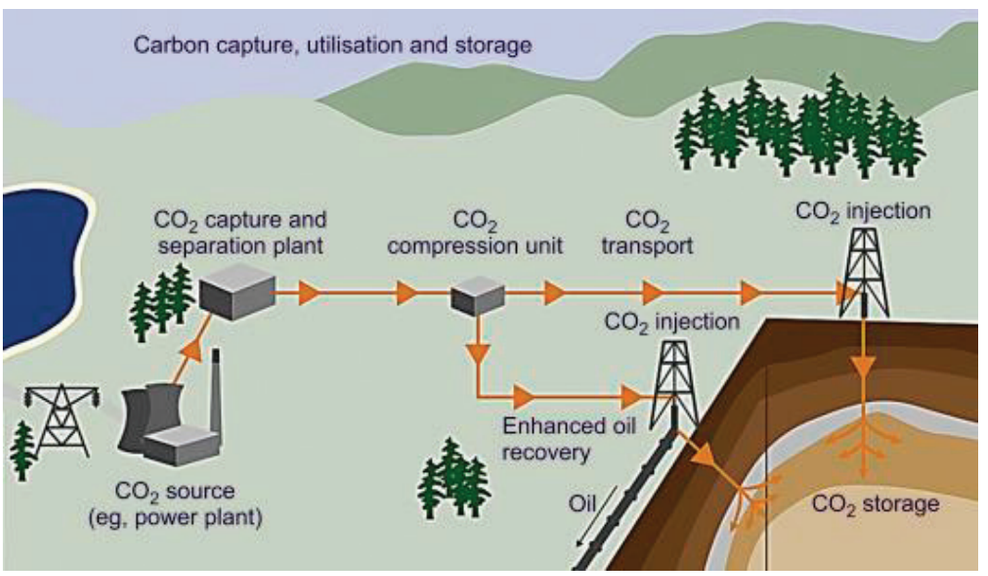

Figure 9.
Carbon mitigating technologies: Carbon capture and storage. Source: IEA, [3].

compression unit is transported and pumped into CO_2 storage beneath the earth surface. The CO_2 can also be injected for usage in forestation [21].

It is a further step towards lessening the CO_2 emissions by the Canada's government. It is believed that this CCS plant is said to have a capacity to cut carbon dioxide emissions by 90% by trapping CO_2 and the CO_2 should be stored underground [22]. As shown in **Figure 10**, this is a great project in ensuring that drastic cut on emissions is realised and achieves the low-carbon power generation. It is a sign that when there is political will, these technologies can be slowly deployed and assist the world to realise low-carbon economies. Canada has achieved a great milestone. Many nations considering installation of CCS technology will take this project as a case study.

2.2 Circulating fluidised bed combustion power generation (CFBC)

Circulating fluidised bed combustion power generation (CFBC) is considered to be one of the most sustainable clean coal technology solutions for the following reasons: most efficient method to address escalating environmental constraints tolerates wide fuel flexibility and quality variation [20]. CFBC is highly successful internationally, and it is found in the EU, the USA, India, China and many Far Eastern countries.

Figure 10.
Commercialised completed boundary dam CCS power plant in Canada. Photograph: SaskPower CCS.

Accordingly, optimization of old coal-power plants is seen as the 'low-hanging fruit' by utilising technologies, since it makes the best possible use of what is already available. With reference to the USA, it is asserted that optimisation includes using sophisticated software to help plants reduce emissions, increase efficiency, lower costs and improve reliability. There is an integrated online optimisation system at a coal-fired plant located in Baldwin, Illinois, which led to a 12–14% reduction in nitrogen oxide (NO_x) emissions, reduction of ammonia consumption by 15–20%, increase in fuel efficiency and available megawatt hours and reduction in GHGs, mercury and particulates [14].

China has 1.3 billion of inhabitants; as such, it needs an electricity system that is much larger. Electricity system is not enough to substitute coal in the near to medium term. To bridge the gap, China is said to have been rolling out new technologies to drastically reduce local air pollution and climate emissions from the nation's remaining coal plants [23].

China has been adjusting the coal-fired power stations to be fitted with cleaner technologies (CAP, 2017). There has been transition from subcritical and supercritical and to advance ultra-supercritical. China shows its commitment to cutting the emissions and achieves the greener coal power plants (**Figure 11**) [23].

2.3 What are the challenges for implementing clean coal technologies?

Quality of coal is no longer the same; as such tons of coal maybe required to be burnt to produce the required energy output. The affordability and political and policy support towards development and implementation of these technologies are prerequisites. CCTs are criticised to be costly, and as such advocacy for renewables believes that fossil fuels should slowly be strapped of the energy sources. Brewing argument is that there is evident slow rate in the deployment of the clean coal technologies and slow change in policy environment. As such it may not be possible to achieve emission reduction goals. There is lack of consistent policy and political support and that affect the progress [24]. IEA suggests that 'CCS is advancing slowly, due to high costs and lack of political and financial commitment' [21].

2.4 Feasibility and adaptability of clean energy technologies

Will clean coal technologies be feasible for developing economies? There is a sceptic view that these technologies will be costly for developing economies.

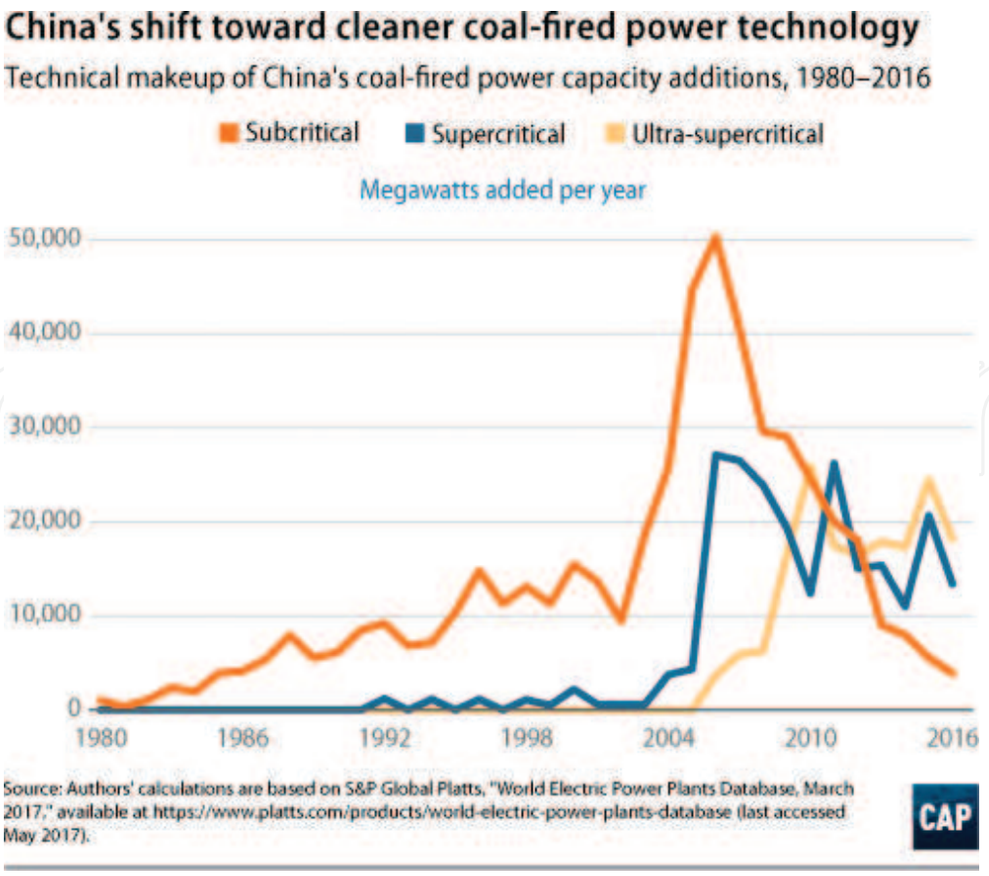

Figure 11.
China shifts to cleaner coal-fired power technology. Source: Center for American Progress (CAP, [25]).

However, these technologies are feasible and can assist developing economies to also meet the CO_2 reduction goals. Examples of two clean coal technologies suitable for adaptation to Southern Africa include circulating fluidised bed combustion power generation and ultra-supercritical power generation [20].

In the United Nations Framework Convention on Climate Change (UNFCCC), the parties commit to investigate the high-efficiency, high-capacity coal-fired power generation technology. The allocation of financial resources in support of development and adaptation of high efficiency, low emissions technologies is the task that needs to be pursued with prudence [5]. Countries need to allocate certain portion of national budgets towards these new processes of ensuring energy security while addressing climate change. Participating in clean coal research will allow nations to share information and forge international partnerships to advance research and find the working processes at affordable range. The government subsidies will be beneficial to support the large-scale implementation of CCTs.

CCS technology is regarded to be appropriate for countries with access to the sea where carbon dioxide is stored permanently under the sea. Countries, where their coal-fired power plants are inland, need to commission feasibility studies to ensure if such technology is adaptable or alternative technologies may be installed. Funding numerous research projects is the best way to determine which high efficiency, low emissions technologies are implementable. Not only the US Department of Energy (DOE) has pledged to work towards advancing clean coal technologies, but also energy authorities from advanced and emerging economies have realised a need to cofinance initiatives aimed at delivering clean coal technologies [26, 27].

The recent study suggests that there are 1.1 billion people across the world who are currently living without access to electricity [7]. Coal will therefore remain part of energy mix to support the baseload and meet rising energy demands across the

world. As such, supporting innovation should be part of every government's priority especially countries that still or will still rely on coal-fired electricity. Keeping the coal clean technology is a key step to meeting zero emission economies.

The study by IEACCC affirms that HELE technology coal-fired plants in Bangladesh, Indonesia, the Philippines, Thailand, Malaysia and Vietnam will play a vital role in reducing emissions of CO_2 but not only these countries are ready for these technologies. What the study put forwards is that 'not all countries have opted to use the best available HELE technology for new and planned capacity and if significant tranches of the less efficient technologies are installed now and in the near future, they become "locked in" to the coal fleet for decades. Given the importance of using HELE technologies for continuing coal use, it is vital to continue to press the case for their uptake to ensure that such outcomes are minimised [4]'. It is a concern, though noticeable, that not all countries have a financial capacity to instal advanced clean coal technologies with immediate effect.

In meeting sustainable development goals, coal should of course provide the growing energy demand. The low-emission technologies are existing, and they cannot be ignored by those with authority and powers to implement. This process should not happen overnight, but proper gradual steps in implementation are key. Countries have their own key priorities, but allocating financial resources towards CCTs will be a fruitful endeavour in meeting the climate change objectives.

3. Conclusion and policy recommendation

The development and adaptation of clean coal technologies will be a key policy area for various economies. It is a fundamental task for each and every nation to support deployment of clean coal technologies. Coal is an abundant resource and cannot be abandoned, while ultra-supercritical and supercritical units can be developed to cut the GHG and help us meet the growing energy demand across the world. It is notable that these CCTs are not panacea to cutting CO_2. Other alternative green technologies need to be developed and implemented in driving low-carbon future. It has not emerged that coal can also be co-fired with biomass such that there is efficiency in cutting pollutants. There has been extensive research that has been done and proves that modern technologies when fitted to these coal-fired power plants have an enormous potential to cut GHG. These emerging technologies hold a larger beneficial advantage in saving the environment.

Holistic approach: It is clear and proven across the world that coal will continue to play an indispensable role in meeting many country's growing energy needs especially countries endowed with considerable coal reserves. Research must be financed to advance technologies towards improving efficiency and reduction of emission.

Political will is critical. The leaders across the world need to allocate certain amount of national budgets on the adaptation and feasibility projects for acquiring these new coal technologies. In the short- and long-term, energy policymakers need to be actively involved and acquaint themselves with knowledge of new emerging clean coal technologies to save the environment. The following policy recommendations are made for coal-using countries:

- Every government is responsible for promoting the development and utilisation of clean coal technologies and saving the environment.

- Global cooperation and knowledge sharing are critical to help other countries to understand efficiency of these technologies in reducing emissions and addressing environmental concerns.

- It is the duty of not only the governments but the private sectors to forge partnerships in sharing the costs of implementing clean coal technologies.
- Integrating clean coal technologies into coal-fired power generation will ensure energy security while ensuring the environmental health.
- Coal is a very important fossil fuel, and it is of abundance and will remain part of the future energy mix for a number of nations. As such, clean coal technologies are not just concept ideas but a need to be implemented at a global scale. It is important to introduce these technologies at a gradual pace.
- Support for energy policy research to augment clean coal and to achieve HELE mandate.

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Abbreviations and acronyms

CAP	Center for American Progress
CFBC	circulating fluidised bed combustion
CNEA	China's National Energy Administration
CCT	clean coal technologies
CCS	carbon capture and storage
FBC	fluidised bed combustion
GHG	greenhouse gas
HELE	high efficiency, low emissions
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
NDP	National Development Plan
R and D	Research and Development
UNFCCC	United Nations Framework Convention of Climate Change
UPSC	ultra-supercritical steam cycle
WCA	World Coal Association
WFGD	wet flue gas desulphurisation
WNA	World Nuclear Association

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Author details

Tankiso Pitso
University of Johannesburg, Sam Tambani Research Institute, Johannesburg, South Africa

*Address all correspondence to: tankiso.pitso@yahoo.com

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