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Green Technologies to Improve the Environment on Earth

Edited by Marquidia Pacheco

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Contributors
Ali Soofastaei, Tankiso Pitso, Xareni Pacheco, Joel Pacheco-Sotelo, Ricardo Valdivia-Barrientos, Marquidia Pacheco, Alfredo Santana, Zayre Ivonne González Acevedo, Marco Antonio García Zarate

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Meet the editor

Marquidia Pacheco received her Master's and PhD degrees in Physics and Plasma Engineering and a postdoctoral research on car exhaust treatment by plasma in France. Her research work has been published in two patents, two book chapters, one book, 43 indexed journals, and 126 congresses. She has organized four congresses and is director of 33 engineering and postgraduate theses. She obtained distinctions as the *Silver Medal in the Week of Science and Innovation 2009* in Mexico City and in the same year received an award granted by *AMC-UNESCO-L'OREAL 2009* for *Women in Science* for her trajectory on plasmas applied to environmental topics. She is cofounder of Sembrando ConCiencias, which involves children in science.

Contents

Preface

Environmental sustainability is vital to improve global equity, liberty and even security of entire nations. When the environment is compromised, lives are endangered and opportunities of people to access a better life are severely truncated.

Several efforts have been done worldwide, for example, in the 2017 report; the UN Environment described many activities realized against the alarming increase of pollution of air and water around the world. Additional subjects also treated as emblematic, are the climate change, wildlife crime, micro-plastic pollution and land degradation. The aim of this book is then to introduce some emergent technologies able to achieve some of the goals proposed by the United Nations.

IntechOpen itself achieved a second objective of this book, because they have supported women scientists worldwide with the edition of their books. This funding is very important; commonly in developing countries, the advance in science is very limited because economic resource destined to science and education is not enough. These restrictions are more marked if scientists are women. In order to develop science in poorest countries and to decrease the gender gap existing in scientific field, free access networks to scientific documents becomes essential. Free access to science could contribute to ameliorate life conditions, and from the personal point of view of this editor, it could make people more empathic of breaking barriers and get closer to peace.

Structure of the Book

This book contains enough information for beginners to start with, and also more detailed information for advanced readers. The book is divided into three main themes concerning some green technologies applied to diminish the atmospheric pollution, the global warming caused by greenhouse gases (GHG) and, as a final point, to enhance the preservation of endangered species.

In particular in Chapter 1, an introductory review briefly gives a background of environmental problems and some of emergent technologies used to reduce them.

Chapter 2 and Chapter 3 are about clean technologies to diminish gaseous pollutants emitted by coal and mining industries. Specifically, T. Pitso gives, in the chapter entitled "*Clean coal technologies adaptability and R&D support for efficiency and sustainability*", an overview of clean coal technologies and the principal challenges they face. A. Soofastaei, depicts the mitigation of mining industry by better managing the operations in "*The application of artificial intelligence to reduce greenhouse gas emissions in the mining industry*".

Several efforts have to been done by researchers in order to diminish GHG, by using, for example, alternative sources like geothermal energy as depicted in

Chapter 4 *entitled "Geothermal energy as alternative to reduce atmospheric emissions and supply green energy"* by Z. González and M. García. They show some results in a case study in Mexico.

Plasma technology is an affordable technique able to treat GHG and, at the same time, it is possible to obtain clean and energetic gases like hydrogen, at a relatively low power input. This specific technology is described by J. Pacheco, R. Valdivia and M. Pacheco in the chapter *"Greenhouse gases reforming and hydrogen upgrading by using warm plasma technology"*.

The automotive industry is also concerned with toxic gases attenuation, emphasizing its efforts on the CO_2 diminution. Electric vehicles (EV) are seen as a central alternative to diminish the negative impact on the environment; nevertheless, as it is noticed by A. Santana, their use in Latin American countries has to take additional considerations in order to cause a decrease in GHG. The discussion of these findings is addressed in *"EV in Latin American countries".*

An appropriate use of technology and a closer collaboration of different research fields can benefit the preservation of wildlife as depicted by X. Pacheco in Chapter 7 *"How technology can transform wildlife conservation"*.

Marquidia Josseline Pacheco Pacheco
Laboratorio de Aplicaciones de Plasmas,
Instituto Nacional de Investigaciones Nucleares,
Ocoyoacac, Mexico

Section 1

Introduction

Chapter 1

Introductory Chapter: Green Technologies to Improve the Environment on Earth

Marquidia Josseline Pacheco Pacheco

1. Introduction

Our planet Earth is suffering devastating effects mostly caused by human footprint. Development of sustainable technologies comes to be, then, vital and could have a positive impact on the environment if green technologies are accessible to everyone in the world.

Lessons learned from the past point out that the development in energy and technology has to consider aspects such as environmental protection, economic development, and equity [1]. Furthermore, the transition to green technologies needs immediate action due to the current urgency. This transition has to be equitable enough to diminish disproportionate negative effects on vulnerable communities.

Following the same logic, free access to scientific publications allows the poorest nations to know and apply green technologies; therefore, the possibilities to efficiently improving the environment on Earth increase.

2. Green technologies: the key of success

Furthermore, the success of green technologies lies on *humility*; Sheila Jasanoff describes those as *technologies of humility*. In her own words, this call for humility "is a prescription to supplement science with the analysis of those aspects of the human condition that science cannot easily illuminate" and also "Humility instructs us to think harder about how to reframe problems so that their ethical dimensions are brought to light" [2, 3].

Ergo, the aim of this book is to humbly compile some of the numerous technologies and techniques applied to improve the environment. Contributions, here presented, describe not only the benefits of technologies and techniques but also the drawbacks and the areas for improvement.

In recent years, the capitalism system has been viewed as a source of social and environmental problems. Companies are perceived to be flourishing at the expense of the broader community. A solution could be the creation of economic value in a way that also generates value for society by addressing its needs and challenges; this is called "shared value." This concept not necessarily means philanthropy not even sustainability; this is now seen as a new way to achieve economic success [4].

From this principle, the concept of *honest broker* makes sense. The honest broker mediates the interrelation between technologists and communities contributing to policymaking and a healthy democracy by using best science [5]. In other words, the honest broker could improve both, human well-being and environmental conditions, as is clearly depicted by P. Kumar, in the chapter "Role of Social Enterprises in Addressing Energy Poverty: Making the case for refined understanding through theory of Co-Production of Knowledge and theory of Social Capital." Furthermore, this chapter highlights the theory of social capital and its relation with social enterprises as a factor of change to motivate poor communities to adopt and use cleaner energy systems.

Regarding the impact of harmful human activities on soil contamination, there is still a lack of information; this phenomenon is more pronounced in poorest countries and is one of the world's biggest problems invisible to the international community [6]. From the soil pollutants, heavy metals are the most complex and persistent pollutants to remediate in nature; in particular cadmium and lead are the most toxic pollutants; they can affect the kidneys, liver, and lungs. Another harmful element that could be stored in those organs and has been defined as carcinogenic is the arsenic, while mercury can induce changes in human neural and gastric systems and can lead to death [7]. The chapter "Remediation for heavy metal pollution," by S. Gandimathi, explores the prediction of heaving metals using a Kriging model that is here presented.

It is undeniable that a transition to green technologies has to be done; however, mining industry and massive coal plants still exist, and their impact to environmental pollution is colossal. The development of coal industry has entered a high-carbon to low-carbon transitional period, and its direct use and the discharged pollutants will be significantly reduced. Unfortunately, coal used to produce electricity is still a dominant source around the world, and its use is still predicted beyond 2100 [8]. T. Soo Pitso gives, in the chapter entitled "Clean coal technologies adaptability and R&D support for efficiency and sustainability," an overview of clean coal technologies and the principal challenges they face.

Relating to the harmful impact of emissions produced by inherent activities of mining industry and its mitigation by better managing the operations, an interesting example, written by A. Soofastaei, can be read in "The application of artificial intelligence to reduce greenhouse gas emissions in the mining industry."

Likewise population growth, intensified agricultural practices and deforestation also have contributed to increase the concentration of greenhouse gases (GHG) in the atmosphere. An alarming data is reported by the WMO [9] about a record-breaking speed in 2016 of carbon dioxide (CO_2) concentration in the atmosphere; this concentration has attained its highest level in 800,000 years; it is nearly 100 times larger than that one at the end of the last ice age.

Several efforts have been done by researchers in order to diminish GHG, by using, for example, alternative sources like geothermal energy, as depicted by Z. González and A. García in the chapter "Geothermal energy as alternative to reduce atmospheric emissions and supply green energy." They show some results in a case study in Mexico.

Plasma technology is an affordable technique able to treat GHG, and, at the same time, it is possible to obtain clean and energetic gases like hydrogen, at a relatively low power input. This specific technology is described by J. Pacheco, R. Valdivia and M. Pacheco in the chapter "Greenhouse gases reforming and hydrogen upgrading by using warm plasma technology."

Automotive industry is also concerned on the toxic gases attenuation, emphasizing its efforts on the CO_2 diminution [10]. Electric vehicles (EV) are seen as a central alternative to diminish the negative impact on the environment; nevertheless, as it is noticed by A. Santana, their use in Latin American countries has to take additional considerations in order to really have a diminution of GHG. The discussion of these findings is addressed in "EV in Latin American countries."

Pollution deforestation and the climate change have also an immense impact on plant and animal life; in the next few decades, we will lose 20–50% of the earth's biota [11]; at present, enormous scale extinction of many animal species has been observed [12]. The appropriate use of technology and a closer collaboration of different research fields can benefit the preservation of wildlife as it is described by X. Pacheco in the chapter "How technology can transform wildlife conservation."

As a final point, we also aspire to transmit the idea that every action we take has an impact on the environment, so we must do all we can to prevent it, and most importantly, everything we do should be based on ethical principles. A Mayan greeting summarizes this idea in a few words:

In Lak'ech Ala K'in:

I am you and you are me

D&M.Pacheco, E.Santana

Kids' vision for: Science must signify Life

Author details

Marquidia Josseline Pacheco Pacheco
Laboratorio de Aplicaciones de Plasmas, Instituto Nacional de Investigaciones Nucleares, Ocoyoacac, Estado de México, Mexico

*Address all correspondence to: marquidia.pacheco@inin.gob.mx

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Section 2

Technologies Applied to Diminish Pollutants of Mining Industries and Coal Plants

Chapter 2

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].

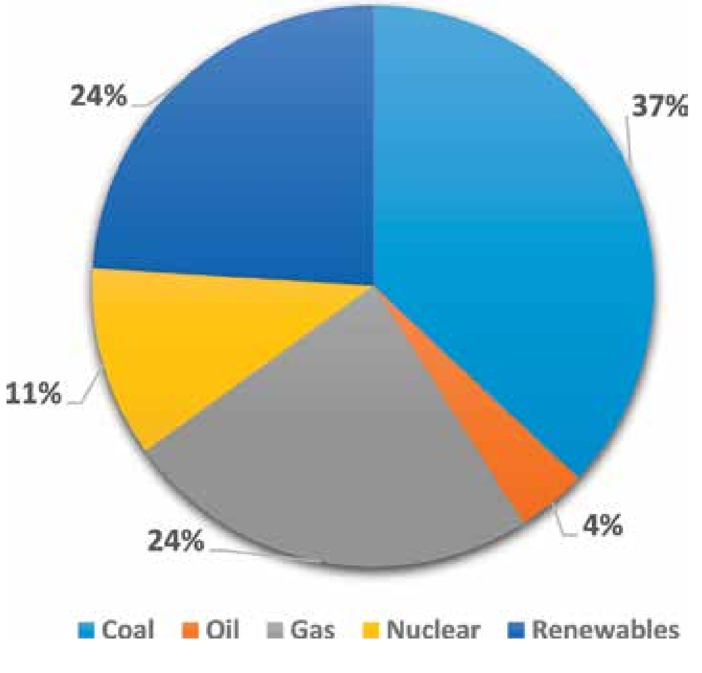

Figure 1.
World electricity mix. Source: International Energy Agency, World Energy Outlook [3].

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 super-critical (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.

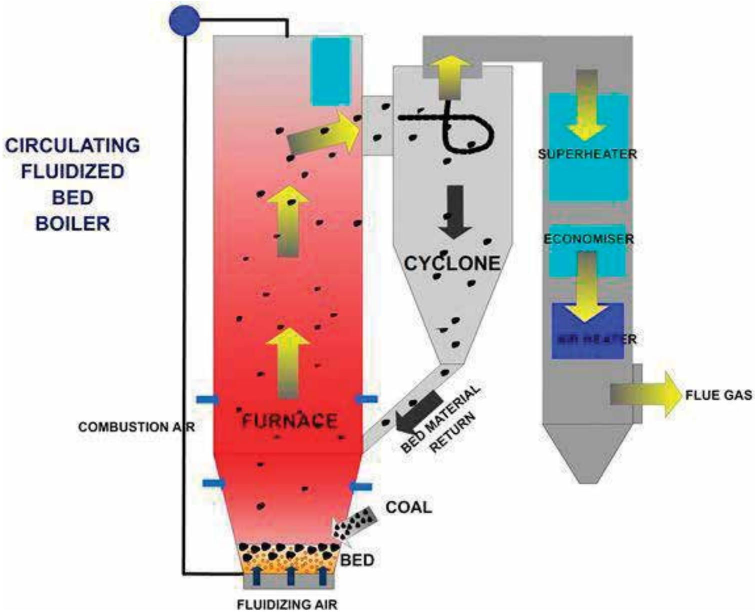

Figure 4.
Fluidised bed combustion (FBC). Image: Courtesy of Eskom fact sheet (2016).

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.

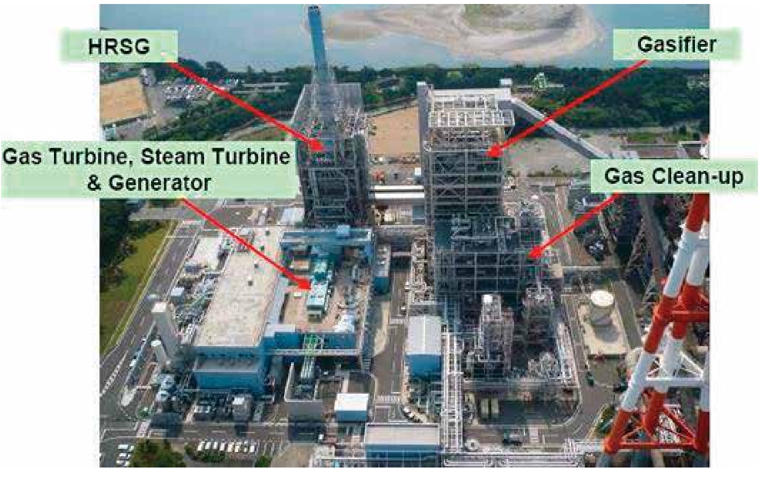

Figure 7.
View of the 250 MW IGCC demo plant at Nakoso, Japan. Source: Mitsubishi heavy industries, ltd.

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].

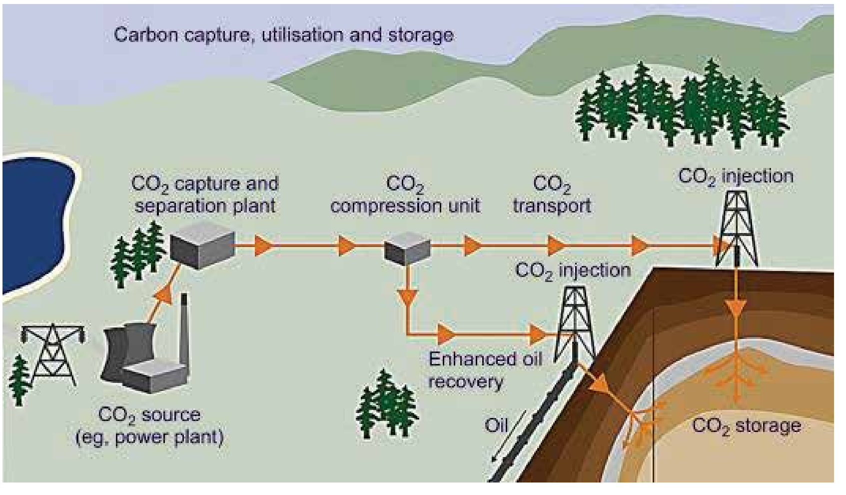

Figure 9.
Carbon mitigating technologies: Carbon capture and storage. Source: IEA, [3].

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.

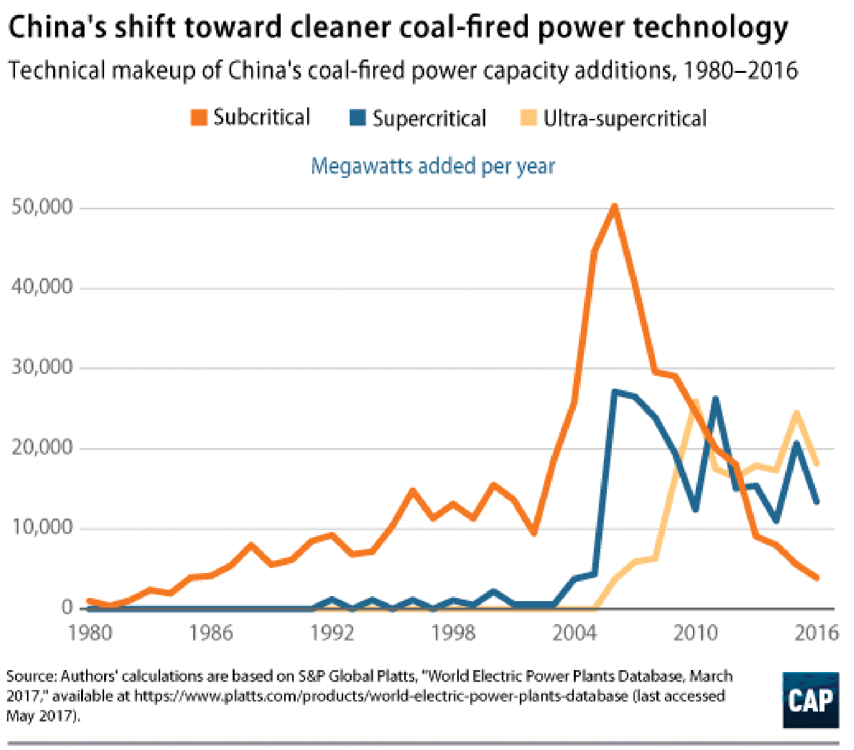

Figure 11.
China shifts to cleaner coal-fired power technology. Source: Center for American Progress (CAP, [25]).

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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Chapter 3

The Application of Artificial Intelligence to Reduce Greenhouse Gas Emissions in the Mining Industry

Ali Soofastaei

Abstract

Mining industry consumes a significant amount of energy and makes greenhouse gas emissions in various operations such as exploration, extraction, transportation and processing. A considerable amount of this energy and gas emissions can be reduced by better managing the operations. The mining method and equipment used mainly determine the type of energy source in any mining operation. In surface mining operations, mobile machines use diesel as a source of energy. These machines are haul trucks excavators, diggers and loaders, according to the production capacity and site layout and they use a considerable amount of fuel in surface mining operation; hence, the mining industry is encouraged to conduct some research projects on the energy efficiency of mobile equipment. Classical analytics methods that commonly used to improve energy efficiency and reduce gas emissions are not sufficient enough. The application of artificial intelligence and deep learning models are growing fast in different industries, and this is a new revolution in the mining industry. In this chapter, the application of artificial intelligence methods to reduce the gas emission in surface mines with some case studies will be explained.

Keywords: artificial intelligence, deep learning, fuel consumption, gas emissions, mining operations, prediction models, optimization methods

1. Introduction

Energy consumption in mining is rising due to lower grade ores, located deeper underground [1]. Mining operations use a different type of energies in a variety of ways, including excavation, material handling and transferring, ventilation and dewatering [2]. Based on completed industrial projects, significant opportunities exist within the mining industry to reduce energy consumption [2]. The potential for energy used reduction has motivated both governments and the mining industry to research the decrease energy consumption [3].

The most usually used means of mining and hauling of materials is via a truck and shovel operation in surface mines [4, 5]. The trucking of overburden constitutes a significant portion of energy consumption [3]. The amount of energy consumption is a function of some parameters. The research presented by Carmichael et al. [6] is concerned with the effects of the density of the load, the geology of the site, road surfaces and gradients on the energy consumption of haul trucks. Cetin [7] examined the relationship between haul truck energy efficiency and loading rates, vehicle efficiency, and driving practices. Beatty and Arthur [4] investigated the effect of some overall factors, such as mine planning and cycle time, on the energy consumed by trucks. They determine the optimum values of these parameters to minimize fuel consumption in hauling operations. The study conducted by Coyle [8] is concerned with the effects of payload on truck fuel consumption. In this study, he shows the impact of load density variation based on the blasting procedures on fuel consumption by haul trucks. Soofastaei et al. completed many different projects in the field of haul truck energy efficiency in surface and underground mines [9–17].

To the authors' best knowledge, the investigations presented in the literature are based mostly on the theoretic methods used to estimate the fuel consumption of mine trucks. These models work based on the curves prepared by the truck manufacturer for the performance of haul mining trucks [5, 18–23].

In this chapter, the effects of the three main effective parameters on fuel consumption of haul trucks have been examined. These parameters are payload (P), truck speed (S) and total resistance (TR). On a real mine site, the correlation between fuel consumption and the parameters mentioned above is complex. Therefore, in this study, two artificial intelligence methods have been used to create a model to estimate and reduce fuel consumption. This model has been completed and tested in a surface coal mine in central Queensland, Australia. The developed model can predict the energy consumption of one type of truck in open-pit and open-cut mines using an artificial neural network (ANN) and can also find the optimum value of P, S and TR using a Genetic Algorithm (GA).

2. Calculation of haul truck fuel consumption

Fuel consumption by mine trucks is a function of some parameters (**Figure 1**). The most important of these parameters can be categorized into seven main groups including fleet management, mine planning, modern technology, haul road, design and manufacture, weather condition and fuel quality [9, 22].

In the present chapter, the effects of the P, S and TR on the fuel consumption of mine trucks were investigated. The total resistance is equivalent to the sum of the grade resistance (GR) and the rolling resistance (RR) [22].

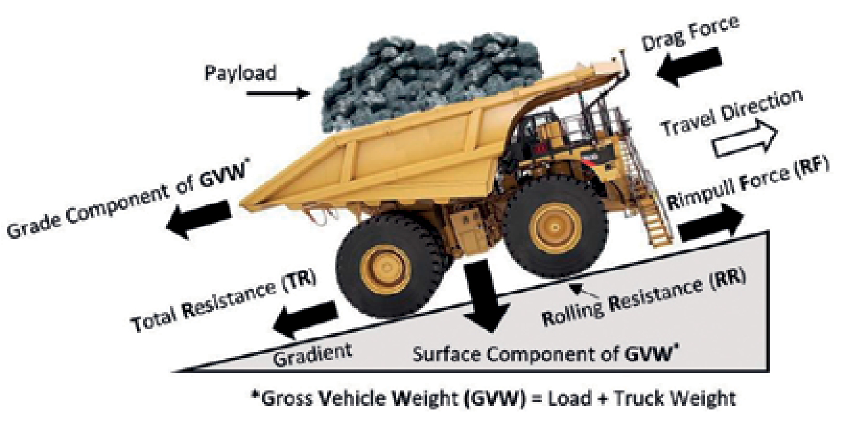

Figure 1.
Haul road and truck key parameters.

$$\mathrm{TR} = \mathrm{GR} + \mathrm{RR} \tag{1}$$

The rolling resistance depends on the tyre and road surface features and is applied to estimate the Rimpull force (RF), which is the force that resists motion as the truck tyre rolls on the haul road. The typical range of values for RR is between 1.5 and 4.0%. However, RR can be more than 10% in the mud-with soft spongy base for road condition [9].

The GR is the gradient of the road and is measured as a percentage and considered as the ratio between the horizontal and the length rise of the route [9, 24]. For example, a section of the haul road that rises at 15 m over 100 m has a GR of 15%. The GR can be positive or negative depends on a truck traveling up or down the ramp. The relationship between the above-mentioned parameters is illustrated by truck manufacture technical Rimpull-Speed-Grade ability Curve (**Figure 2**).

The truck fuel consumption (FC) can be calculated from Eq. (2) [24]:

$$\mathrm{FC} = (\mathrm{SFC} \times \mathrm{LF} \times \mathrm{P_o})/\mathrm{FD} \tag{2}$$

where SFC is the engine Specific Fuel burnt at full power (0.213–0.268 kg/(kW h)) and FD is the fuel density (0.85 kg/L of diesel). Eq. (3) illustrates the simplified version of Eq. (2) [25].

$$\mathrm{FC} = 0.3\,(\mathrm{LF} \times \mathrm{P_o}) \tag{3}$$

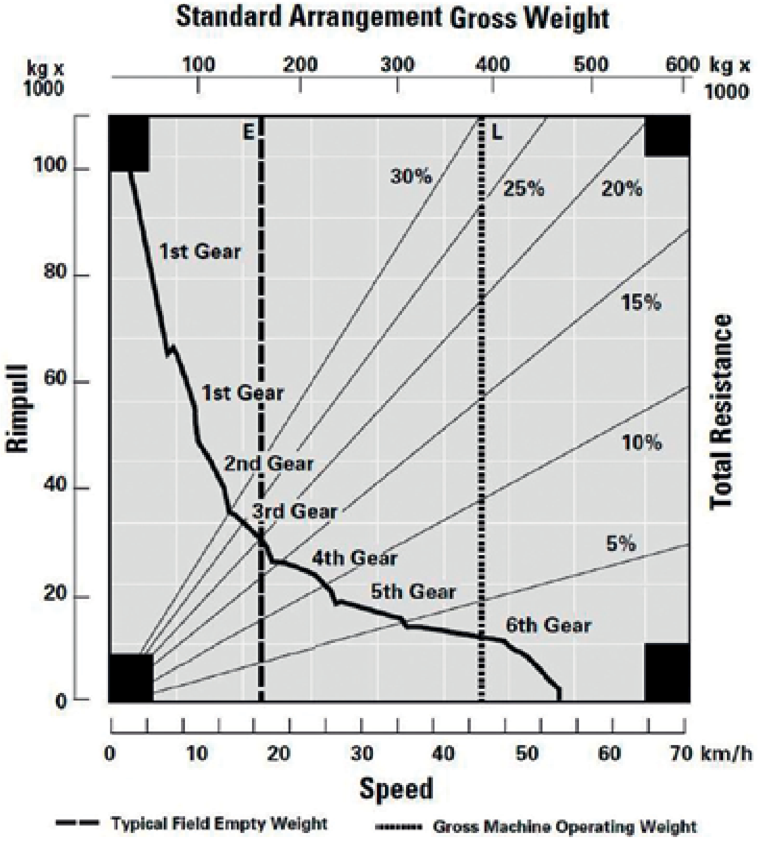

Figure 2.
Rimpull-Speed-Grade ability Curve for Haul Mine Truck (CAT 793D).

Operating conditions	LF (%)	Road condition
Low	20–30	Constant operation at a reasonable Gross Vehicle Weight less than suggested. There is not over payload
Average	30–40	Constant operation at a regular Gross Vehicle Weight suggested, minimum over payload
High	40–50	Continuous operation at or above the maximum suggested Gross Vehicle Weight

Table 1.
Typical values of load factors (LF) [22].

where LF is the engine load factor and is estimated as the percentage of normal load to the maximum payload in an operating cycle [26]. The typical values of LF are presented in **Table 1** [22]. P_o in Eq. (3) is the truck power (kW) and it is determined by:

$$P_o = (RF \times S)/3.6 \tag{4}$$

where the RF is calculated by the product of Rimpull (R) and the gravitational acceleration (g) and S is truck speed.

3. Greenhouse gas emissions

Diesel engines emit both Greenhouse Gases (GHG_S) and Non-Greenhouse Gases ($NGHG_S$) [27] into the environment. Total greenhouse gas emissions are calculated according to the Global Warming Potential (GWP) and expressed in CO_2 equivalent or CO_2-e [28, 29]. The following equation can be used to determine the haul truck diesel engine GHG_S emissions [28, 30].

$$GHG_{Emissions} = (CO_2\text{-e}) = FC \times EF \tag{5}$$

where FC is the quantity of fuel consumed (kL) and EF is the emission factor. EF for haul truck diesel engines is 2.7 t CO_2-e/kL.

4. Estimation of haul truck fuel consumption

The correlation between truck fuel burnt and nominated factors in this study (P, S and TR) is complicated and requires an artificial intelligence method to determine. The following subsection contains the details of an artificial neural network model that was settled to determine how the truck fuel consumption varies with the variation of these parameters.

4.1 Artificial neural network

Artificial neural networks (ANNs) are a standard synthetic intelligence method to simulate the effect of multiple variables on one primary factor by a fitness function. This model can be used to determine fuel consumption by taking into consideration some parameters which affect the fuel consumption of mine trucks. ANNs have been used in various engineering disciplines such as material [31–33], biochemical engineering [34], and mechanical engineering [35–37]. ANNs are required answers for multifaceted challenges as they can interpret the compound relationships between the multiple issues involved in a problem. One of the main benefits of ANN application is that they can simulate both nonlinear and linear correlation between factors, applying the data providing to learn the network. ANN, also known as parallel distributed processing, are the representation of models that the brain uses for learning [37]. They are a series of mathematical techniques which imitate some of the known characteristics of standard nerve arrangements and draw on the analogies of adaptive accepted learning. The critical section of an ANN paradigm could be the unusual arrangement of the information processing classification. An appropriate neuronal modeling is thus comprised of weighted connectors. ANNs are utilized in numerous computer applications to solve multifaceted problems.

In this chapter, an ANN was settled to make a Fuel Consumption Index (FC_{Index}) as a function of P, S and TR. This defined parameter shows how many liters of diesel is burnt to move one ton of mined material in one hour.

4.2 Developed model

The configuration of the created ANN algorithm for function estimate is a feed-forward, multi-layer perceptron NN with three input variables and one output (**Figure 3**). The activation functions in the hidden layer (f) are the continuous, differentiable nonlinear tangents sigmoid presented in Eq. (6).

$$f = \tan sig(E) = \frac{2}{1 + \exp(-2E)} - 1 \tag{6}$$

where E can be determined by Eq. (7).

$$E_k = \sum_{j=1}^{q} (w_{ijk} x_j + b_{ik}) \qquad k = 1, 2, \ldots, m \tag{7}$$

Where x is the normalized input variable, w is the weight of that variable, i is the input, b is the bias, q is the number of input variables, and k and m are the counter and number of neural network nodes, respectively, in the hidden layer.

Eq. (7) can be used as the activation function between the hidden and output layers (in this equation, F is the transfer function).

$$F_k = f(E_k) \tag{8}$$

The production layer calculates the weighted sum of the signals provided by the hidden layer and the associated coefficients. The network output can be assumed by Eq. (9).

$$Out = (\sum_{k=1}^{m} w_{ok} F_k) + b_c \tag{9}$$

4.3 Developed network application

The developed ANN algorithm can use to estimate the truck fuel consumption as a function of P, S, and TR, based on the following steps:

Step 1: Normalizing the input parameters between −1 and +1

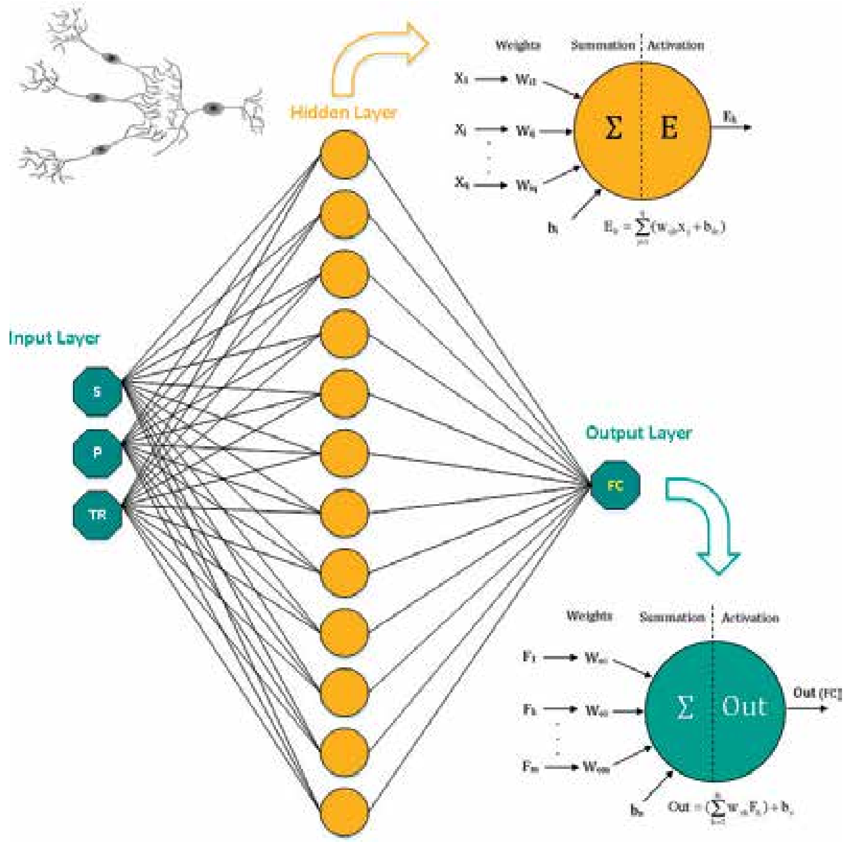

Figure 3.
The schematic structure of the designed ANN (sample).

$$x_n = \left(\frac{x - x_{min}}{x_{max} - x_{min}} \times 2 \right) - 1 \tag{10}$$

Step 2: Calculating the E parameter for each hidden node

$$E_k = \sum_{j=1}^{q} (w_{i,j,k} x_j + b_{i,k}) \qquad k = 1, 2, \ldots, 15 \tag{11}$$

Step 3: Calculating the F parameters

$$F_k = \frac{2}{1 + \exp(-2E_k)} - 1 \qquad k = 1, 2, \ldots, 15 \tag{12}$$

Step 4: Calculating Normalized Fuel Consumption Index ($FC_{Index(n)}$)

$$FC_{Index(n)} = (\sum_{k=1}^{15} w_{o,k} F_k) + b_c \tag{13}$$

Step 5: Denormalizing $FC_{Index(n)}$

$$FC_{Index} = 13.61 + \frac{(FC_n + 1)(237.92 - FC_n)}{2} \tag{14}$$

4.4 Applied model (case study)

Testing and validating phase of the developed model has been completed based on a few datasets collected by mine engineers in big surface mines in the center of Queensland Australia. Overall information about this mine has been tabulated in **Table 2**.

To train the developed ANN model, few pairing data were randomly selected from mine site collected real datasets (**Table 3**). To test the network accuracy and validate the model, independent samples were used. The results show acceptable agreement between the actual and estimated values of fuel consumption in all investigated mine site. The test results of the synthesized networks are shown in **Figure 4** where the horizontal, and vertical axes indicate the estimated fuel consumption values the actual fuel consumption values and by the model, respectively.

4.5 Developed model results

Figure 5 illustrates the correlation between P, S, TR and FC_{Index} created by the developed ANN model for a normal range of payloads for a specific type of trucks in the studied mine sit. The presented graphs show that there is a nonlinear correlation between FC_{Index} and Gross Vehicle Weight (GVW). GVW is the empty truck weight plus payload. The rate of energy consumption increases intensely with increasing total resistance. However, this energy consumption rate does not change suddenly with changing truck speed. The developed model also shows that the amount of FC_{Index} changes by variation of truck speed and payload. However, there is no clear correlation between all effective factors and energy consumption. As a result, completing another artificial intelligence model is needed to find the optimum value of the selected elements to minimize the mine truck fuel consumption.

The generated greenhouse gas emotions by haul trucks in surface mines can be estimated by predicted FC_{Index} by developed ANN model. **Table 4** shows the estimated $(CO_2\text{-e})_{Index}$ for CAT 793D in studied mine site in Australia. The presented indicator shows that how much CO_2-e will be made to move one ton of mine material in one hour.

The achieved results illustrate that there is a logical relationship between generated greenhouse gas emissions and truck operation parameters. Increasing the truck speed and total resistance will increase the gas emissions. The minimum amount of gas will be produced when the truck is moving with recommended payload by the manufacturer. Having overloaded trucks in the fleet can increase gas emissions dramatically.

Product	Location	Reserves	Fleet size	Truck type
Coking coal	Queensland, Australia	877 Mt	184 truck	CAT 793D

Table 2.
Studied mine sites (general information).

Used pairing data for training	Used pairing data for validation
1,500,000	2,000,000

Table 3.
Used data sets for model training and validation.

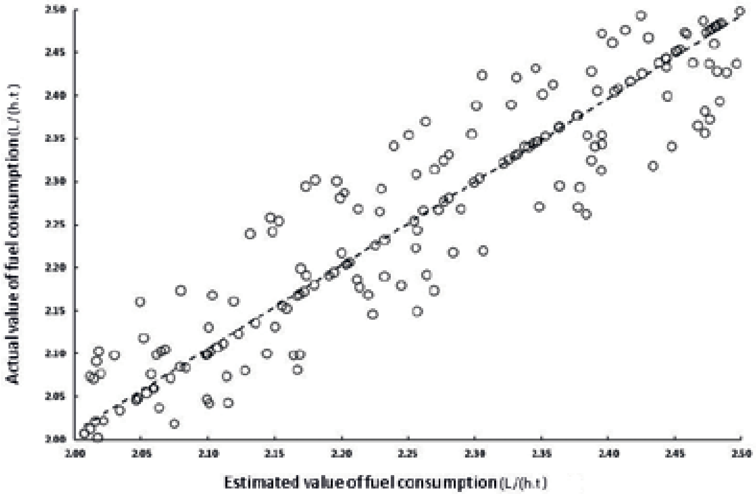

Figure 4.
Comparison of actual values with the estimated value of haul truck fuel consumption by developed ANN model.

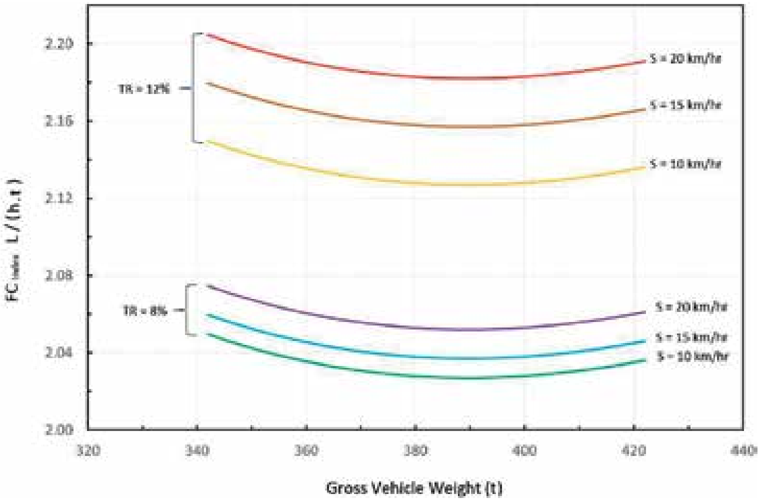

Figure 5.
Correlation between P, S, TR and FC_{Index} *estimated by ANN (CAT 793D).*

	$(CO_2\text{-e})_{Index}$ kg/(h t)					
GVW (t)	**Total resistance = 12%**			**Total resistance = 8%**		
	S = 20 km/h	**S = 15 km/h**	**S = 10 km/h**	**S = 20 km/h**	**S = 15 km/h**	**S = 10 km/h**
340	0.599	0.589	0.581	0.559	0.556	0.554
360	0.591	0.586	0.578	0.556	0.554	0.549
380	0.589	0.583	0.575	0.554	0.551	0.548
400	0.589	0.583	0.575	0.554	0.551	0.548
420	0.591	0.586	0.578	0.556	0.554	0.551

Table 4.
Estimated greenhouse gas emissions by ANN (CAT 793D).

5. Optimization of effective parameters on haul truck fuel consumption

5.1 Optimization

Optimization as a part of computational science is an actual way to discover the best quantifiable solution for problems. To solve the technical issues, it is essential to consider two components. The first one is the research area and the second one is an objective function. In the research area, all the potentials of the solution are considered, and the objective function is a mathematical function that connections each point in the answer area to an actual value, appropriate to assess all the members of the research area. Solving the multifaceted computational problems has been a persistent challenge in mining engineering. Traditional optimization models are characterized by the stiffness of its mathematical models that they are challenging to represent in real dynamic and complex situations. Presenting the optimization techniques based on Artificial Intelligence, as the heuristic search-based ones have reduced the problem of stiffness. Heuristic rules can be well-defined as applied rules, resulting from the experience and observation of behavior tendencies of the system in the analysis. They are suitable to solve all types of technical problems in engineering. Using equivalences with nature, some heuristic models were suggested during the 50s by trying to simulate biological phenomena in engineering. These models, named Natural Optimization Methods. One of the best benefits of applying the mentioned models is their random characteristic. By emerging the computers during the 80s, the use of these models for optimization of functions and processes became achievable, when traditional models were not successful in this field. During the 90s some novel heuristic models developed by the previously completed algorithms, as simulated annealing, swarm algorithms, ant colony optimization and genetic algorithms.

5.2 Genetic algorithms

Genetic algorithms (GAs) were proposed by Holland (1975) as an abstraction of biological evolution, drawing on ideas from natural evolution and genetics for the design and implementation of robust adaptive systems [38]. The new generation of GAs is moderately recent optimization models. They do not use any data of derivate. So, they have good chances of escape from a local minimum. Their application in related engineering problems brings to global optimal, or, at least, to solutions more acceptable than those obtained by other traditional mathematical models. They apply a straight analogy of the evolution phenomena in nature. The individuals are randomly nominated from the research area. The fitness of the answers, which is the result of the parameter that is to be optimized, is determined consequently by the fitness function. The individual that creates the best fitness within the population has the maximum chance to go into the next generation, with the opportunity to replicate by crossover, with another individual, creating decedents with both characteristics. If a GA is adequately developed, the population (a group of possible solutions) will converge to an optimal answer for the defined problem. The procedures that have more involvement in the evolution are the crossover, based on the assortment, reproduction and the mutation. Genetic algorithms have been used in a diverse range of engineering, scientific, and economic problems [36, 38–41] due to their potential as optimization methods for multifaceted functions. There are four significant benefits when using GAs for optimization problems. Firstly, genetic algorithms do not have numerous mathematical requirements regarding optimization problems. Secondly, genetic algorithms can handle some types of objective functions and restrictions defined in discrete, continuous or mixed research areas. Thirdly, the periodicity of evolution operators makes genetic algorithms very useful for performing global searches. Lastly, genetic algorithms provide us with significant flexibility to hybridize with domain-dependent heuristics to allow an efficient implementation of a problem. Besides of genetic operators, it is also essential to analyze the influence of some variables in the behavior and the performance of the GA, to find them according to the problem requirements and the available properties. The impact of each factor in the algorithm performance depends on the class of issues that are being treated. Therefore, the determination of an optimized group of values to these factors will depend on a significant number of experiments and tests. There are many primary parameters in the GA method. Details of these critical parameters are tabulated in **Table 5**.

The primary GA parameters are the size of the population that affects the total performance and the efficiency of the GA, the mutation rate that avoids that a given position remains standing in value, or that the search becomes fundamentally random.

5.3 Developed GA model

In this chapter, the GA model is introduced to improve three effective critical parameters on the energy consumption of haul trucks in studied mine site. The genetic algorithm was selected as an optimization strategy mainly due to its capacity of providing diverse solutions and its parallelization power in the searching process. Those characteristics go hand in hand with the primary goal for this optimization process, which is offering a set of P, S and TR values for the final user that would yield a minimum FC_{Index}. This range of values it is significant in real applications, for instance, the truck drivers cannot reach an exact point of speed or even an average during a whole cycle period. This fact is the reason why gradient-based optimization algorithms were not evaluated, such as making the same ANN trained dream of inputs that minimize the FC_{Index}.

A vital point for using the GA as the optimization process is controlling the feasibility of population. All the individuals must be checked throughout generations if they are in the same distribution (i.e. maximum and minimum values) in which the ANN was trained for mainly two reasons. First, the ANN only mapped the relationship among P, S, TR and FC_{Index} based on the data provided during the training phase and the predictions results or the fitness values are reliable only in this distribution. Second, the values of each attribute must reflect the reality of mine sites and trucks operation limitations to provide feasible solutions.

GA parameter	Details
Fitness function	The primary function of the optimization
Individuals	An individual is any parameter to apply to the fitness function
Populations and generations	A population is an array of individuals. At each iteration, the GA performs a series of computations on the current population to produce a new generation
Fitness value	The fitness value of the individual is the value of the fitness function for each
Children and parents	To make the next generation, the genetic algorithm chooses certain individuals in the existing population, called parents, and uses them to develop individuals in the next generation, called children

Table 5.
Genetic algorithm parameters.

In the developed model payload, truck speed and total resistance are the individuals and the primary function of optimization is mine truck fuel consumption. In this model, the fitness function was created by the ANN algorithm. All GA processes in the developed model are illustrated in **Figure 6**.

In this model, seven main processes were defined. These procedures are initialization, encoding, crossover, mutation, decoding, selection, and replacement. The details of the procedures mentioned above are presented in **Table 6**.

In this developed model, the key factors applied to control the algorithms were R^2 and MSE. Technical details of the developed models for the studied mine site are presented in **Table 7**.

In this study, the developed ANN and GA models were completed by writing computer code in Python. Payload, truck speed and total resistance are input parameters of the algorithm in the first step. The completed model creates the fitness function based on the completed ANN model. This function is a relationship between mine truck fuel consumption and inputs. In the second step, the developed function goes to the genetic algorithm (optimization) phase of the computer code as an input. The finalized codes start all GA procedures under stopping criteria well-defined by the model (MSE and R^2).

Finally, the optimized parameters (P, S and TR) will be presented by the algorithm. These improved factors can be used to minimize the haul truck fuel

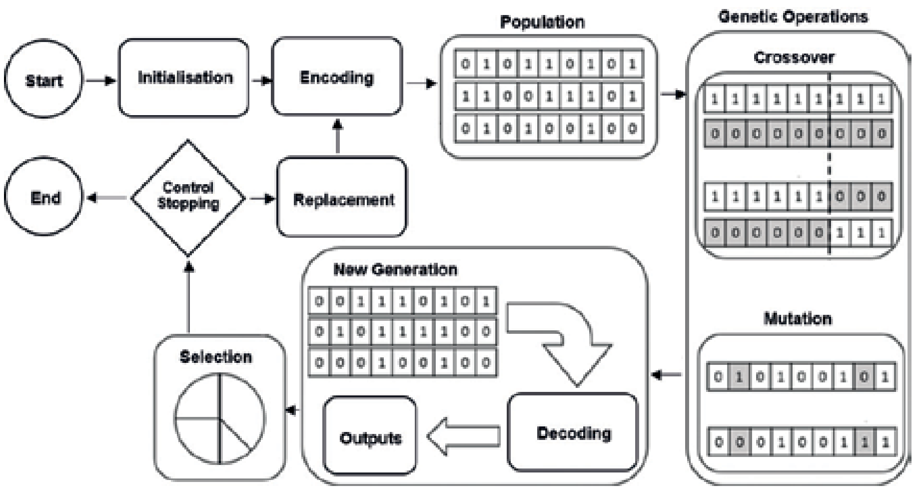

Figure 6.
Genetic algorithm processes (developed model).

Procedure	Details
Initialization	Produce original population of candidate solutions
Encoding	Digitalize original population value
Crossover	Combine parts of two or more parental answers to make a new one
Mutation	Deviation process. It is intended to infrequently break one or more participants of a population out of minimum local space and potentially discover a better answer.
Decoding	Change the digitalized format of a new generation to the original one
Replacement	Replace the individuals with better fitness values as parents

Table 6.
Genetic algorithm procedures.

Parameters	Details
Population type	Double vector
Population size	20
Creation function	Uniform
Scaling function	Rank
Selection function	Stochastic uniform
Elite count for reproduction	2
Crossover fraction	0.8
Mutation function	Uniform
Rate of mutation	0.01
Crossover function	Scattered
Migration direction	Forward
Migration fraction	0.2
Migration interval	20
Constraint parameters (initial penalty)	10
Constraint parameters (penalty factor)	100
Stopping criteria	MSE and R^2

Table 7.
Technical details of genetic algorithm developed model.

consumption. All procedures in the developed models work based on the existing dataset collected from a big surface mine in Australia, but the completed methods can be prepared for other surface mines by replacing the data.

5.4 Results

The first step of applying the developed optimization model is defining the range (minimum and maximum values) of all variables (individuals). This variable range is estimated based on the collected datasets in the established model. The parameters used to control the generated models are R^2 and MSE. **Figure 7** demonstrates the variation of these parameters in generations in studied mine site.

In the studied mine site, the value of R^2 was about 0.98, and the value MSE was 0, of after the 47th generation. These values were not changed until the genetic algorithm was stopped in the 53rd generation. Correspondingly, the values of control factors were constant after the 47th generation, but the algorithm continued all procedures until the 53rd. That is because a confidence interval was defined for the algorithm to catch dependable results. The value of the fitness function (FC_{Index}) in all generations has been illustrated in **Figure 8**. The simulated value of mine truck fuel consumption is different between 0.03 and 0.13 (L/(h t)). The mean of the estimated results is 0.076 (L/(h t)), and more than 45% of results are located above the average line. The presented model could find some local minimized fuel consumption, but the acceptable results can be found after the 47th generation. **Figure 8** also shows that the FC_{Index} is about 0.04 (L/(h t)), which lies in the acceptable area. It means that by improving the payload, truck speed and total resistance in the studied mine site, the minimum FCIndex for the CAT 793D is about 0.04 (L/(h t)).

The optimum range of variables to minimize fuel consumption by the selected haul truck in these case studies (all mine sites) are tabulated in **Table 8**.

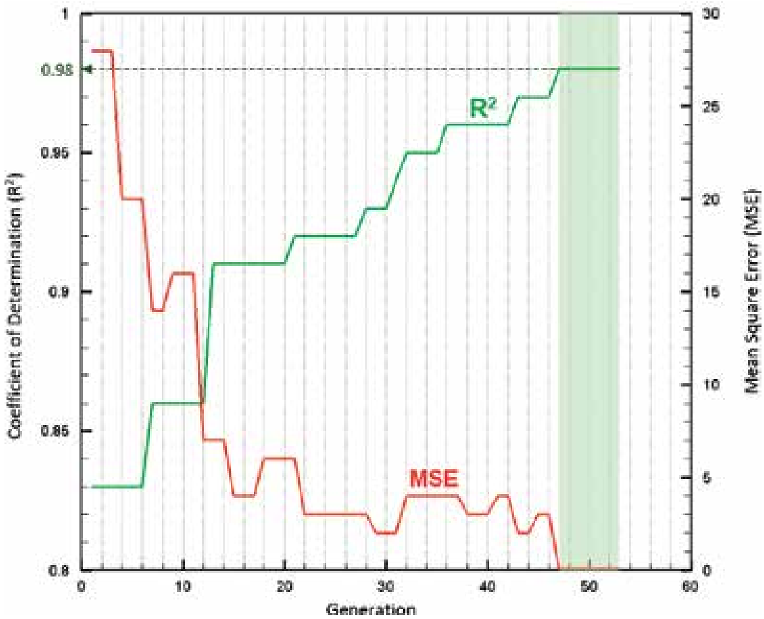

Figure 7.
The coefficient of determination and mean square error for all generations.

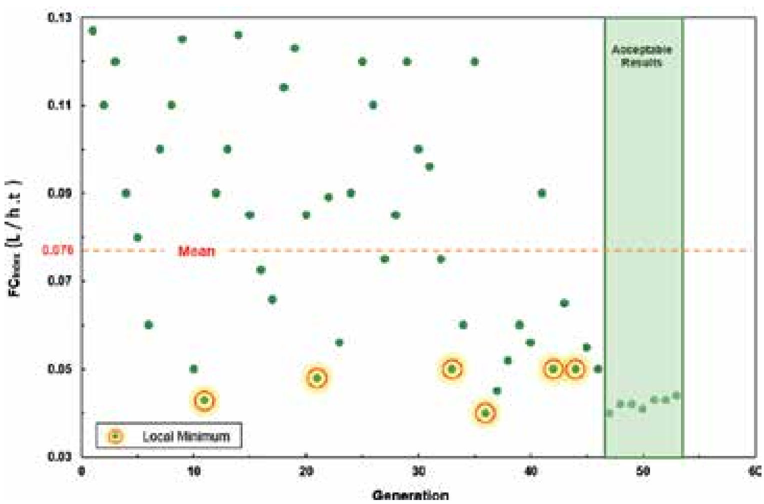

Figure 8.
Fuel consumption (fitness value) in all generations (studied mine site).

Truck	Variables	Normal		Optimized	
		Min	Max	Min	Max
CAT 793D	Gross Vehicle Weight (t)	150	380	330	370
	Total resistance (%)	8	20	8	9
	Truck speed (km/h)	5	25	10	15

Table 8.
Optimization model recommendations to maximize energy efficiency gains.

As a final result of using suggested optimization model in studied mine site, mine managers approved that they had 9% fuel consumption reduction and related Greenhouse gas emissions by using the developed application in mine for 6 months. Five per cent productivity improvement was also announced by the operation team in the application testing period.

6. Conclusion

The purpose of these presented methods and algorithms was to improve mine truck fuel consumption and reduce greenhouse gas emissions based on the correlations between payload, truck speed and haul road total resistance by investigating on real datasets. These correlations were complicated and required artificial intelligence methods to create a consistent algorithm to tackle this challenge. In the first section of this chapter, an ANN algorithm was explained to find a relationship between investigated parameters. The results illustrated that fuel consumption has a nonlinear correlation with the studied parameters. The ANN was learned and validated using the gathered real mine sites datasets as an example. The achievements presented that there was good agreement between the estimated and actual values of haul truck fuel consumption. In the second section of this chapter, to minimize the fuel consumption in haulage operations, a genetic algorithm was developed. The results showed that by applying this method, optimization of the effective factors on energy consumption is possible. The established algorithm could find the local minimums for the fitness function. The offered GA model highlighted the satisfactory results to minimize the rate of fuel burnt in surface mines. The range of all investigated effective parameters on haul trucks fuel consumption was optimized, and the best values of payload, truck speed and haul road total resistance to minimize FC_{Index} were highlighted. There are some possibilities to improve the presented models in this chapter by increasing the number of input parameters. Selected parameters are controllable in real mine sites. However, changing the total resistance and control the payload variance are a little difficult by using current technologies. There are other manageable parameters such as idle time, queuing time etc. that can potentially replace with modeled parameters in the presented algorithms in this chapter.

Nomenclature

ANN	artificial neural network
b	bias
E	summation function
f	activation function
F	transfer function
FC	truck fuel consumption (L/h)
FD	fuel density (kg/L)
GA	genetic algorithm
GR	grade resistance (%)
GVW	Gross Vehicle Weight (t)
LF	engine load factor (%)
m	number of neural network nodes in the hidden layer
MSE	mean square error
Out	final output
p	number of neural network outputs

P	truck payload (t)
P_o	truck power (kW)
q	number of input variables
r	truck wheel radius (m)
R	Rimpull (t)
RF	Rimpull force (KN)
RMSE	root mean square error
RR	rolling resistance (%)
R^2	correlation coefficient
S	truck speed (km/h)
SFC	engine specific fuel consumption (kg/kW h)
T	torque (kN m)
TP	truck power (kW)
TR	haul road total resistance (%)
VIMS	vehicle information management system
w	the weight of the variables
x	input variable
y	target (real) output
z	estimated output

Subscripts

i	input
j	the counter of input variables
k	the counter of a neural network node in the hidden layer
max	maximum
n	normalized
o	output
r	the counter of network outputs

Author details

Ali Soofastaei
The University of Queensland, Brisbane, Australia

*Address all correspondence to: ali@soofastaei.net

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Section 3

Technologies to Diminish Greenhouse Gases

Chapter 4

Geothermal Energy as an Alternative to Reduce Atmospheric Emissions and Provide Green Energy

Zayre I. González-Acevedo and Marco A. García-Zarate

Abstract

Recently, there has been a worldwide rise of concern regarding the increasing emissions of air pollutants and global climate change. In contrast, there are also concerns about the growing energy consumption and how to guarantee its supply. Renewable energies can help minimize the use of fossil fuels, this being a high priority on the political agenda of countries around the world. Within renewable energies, geothermal energy is one of the oldest and most well-known sources of energy to generate electricity. Its use started in 1904 in Italy, but it needs a high initial investment. Depending on the geothermal reservoir, fluids drawn from the deep Earth could liberate a mixture of gases such as carbon dioxide, hydrogen sulfide, methane, and ammonia. The aim of this work is to compare gas emission of renewable, clean, and conventional sources of energy to be able to elucidate if geothermal energy could be a suitable green energy to minimize gas emissions to the atmosphere.

Keywords: life-cycle assessment, gas emissions, geothermal energy, sustainability, renewable

1. Introduction

In recent years, the topic of energy has been present in environmental debates, as well as many national and international forums with a focus in creating agreements and action in preserving the environment. As mentioned in the Intergovernmental Panel on Climate Change or IPCC, some major effects have been shown in water pollution, soil acidification [1], greenhouse gas emissions, air pollution, and the damages these have brought onto human health [2–4]. These changes seek to incorporate relevant topics such as climate change, water scarcity, and residue management to energy planning [5]. In this context, some renewable energy sources such as biomass, hydraulic, Aeolic, solar, marine, and geothermal are being considered. The production of these types of energy is considered inexhaustible as opposed to fossil fuels, which run out in a considerably short period of time [6, 7].

Mainly from a political and economic point of view, many countries already promote and use renewable energy sources because they recognize the need to change current energy-related patterns and must protect the environment, which is why these are considered green energy. This concept covers not only the protection of the environment but also sustainability. This was defined at the end of the 1980s in the Brundtland's reunion as "meeting the needs of the present generation while not compromising the ability of future generations to meet their needs" [8].

Therefore, it is a great global concern these days with the decrease in fossil fuel reserves and the increase in the demand for energy [9]. Geothermal energy has then been identified as an important aspect in transitioning to sustainable energy systems for its reliability [10] and flexibility [11]. Research indicates that geothermal energy could provide around 3.5% of the world's population energy by 2050. Among the main geothermal energy producers are Japan and Iceland. The USA had the greatest installed capacity to create geothermal energy with 3450 MW by 2015. Iceland took the seventh place with 665 MW and Japan with a 519 MW capacity [12].

Sustainability evaluations of energy technologies often do not consider the social and cultural impacts along with the long-term repercussions of developing certain energy systems. Even though the economic and ecologic evaluations of energy systems may be hard to define [13], they are not any less important [14].

For geothermal energy, the term renewable corresponds to a property in the source of energy, while sustainable refers to the way the resource is used. Therefore, geothermal energy is sustainable as long as the steam extraction does not exceed the water supply. It is also renewable as long as the deposit continues to produce the same amount of electric energy for more than 100 years.

It involves damages on different scales; the development and frequent use of energy can have sustainable and significant implications on a multidimensional level [15, 16]. It is renewable because most of the time, the regeneration rate is faster than extraction. This clearly shows that we must control the extraction rate so that it is sustainable.

2. Geothermal energy

Geothermal studies cover the variations in temperature in the Earth's crust and the phenomenon that influences the distribution of internal heat in our planet. This study is made through exploration, evaluation, and exploitation of this type of energy. This type of energy manifests on the surface in the form of volcanoes, geysers, fumaroles, hot springs, etc. (**Figure 1**).

The Earth's thermal energy is vast, and only a small fraction has been used due to the limitations set by geological conditions (e.g., permeability) which impair the transportation of water in liquid or steam phase. The geothermal gradients reflect the movement of heat from deep areas toward the outer crust, which produces different changes in temperature at a different depth [17–19].

The geothermal resource has multiple applications according to the temperature and the enthalpy it represents. The temperatures of the fluid that vary in intervals of 100°C per kilometer are called systems of medium or low enthalpy. These resources are used directly or to create electricity with binary systems. When the temperature is higher than 180°C per kilometer, it is considered a system of high enthalpy. This enormous heat wave can usually heat great extensions of rock in deep settings where hydrothermal deposits or systems of hot dry rock form [20]. Hydrothermal formations rarely produce dry steam, which is ideal to produce electricity. They mostly have wet steam or geothermal corrosive brine with a high content of dissolved and suspended salts (**Figure 2**).

In the case of the hot dry rock formation, geothermal energy is used because they are generally free of fluids. A fluid is introduced in a well where the formation

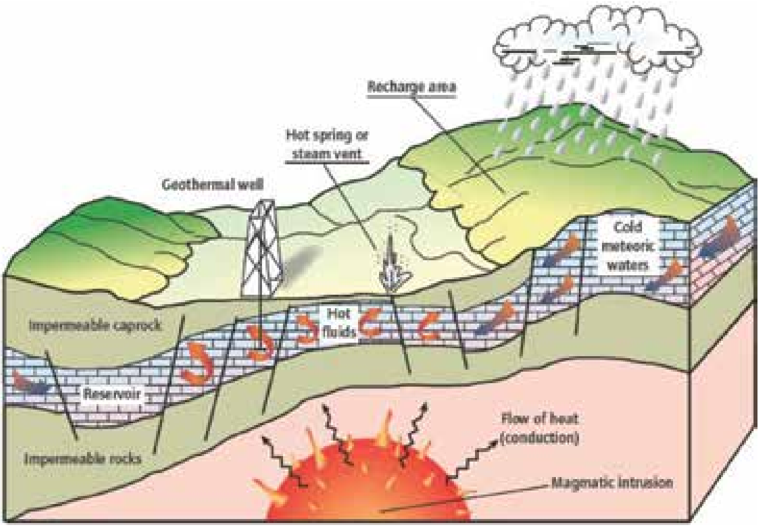

Figure 1.
Geothermal steamfield with its elements: recharge area, impermeable cover, reservoir, and heat source [17].

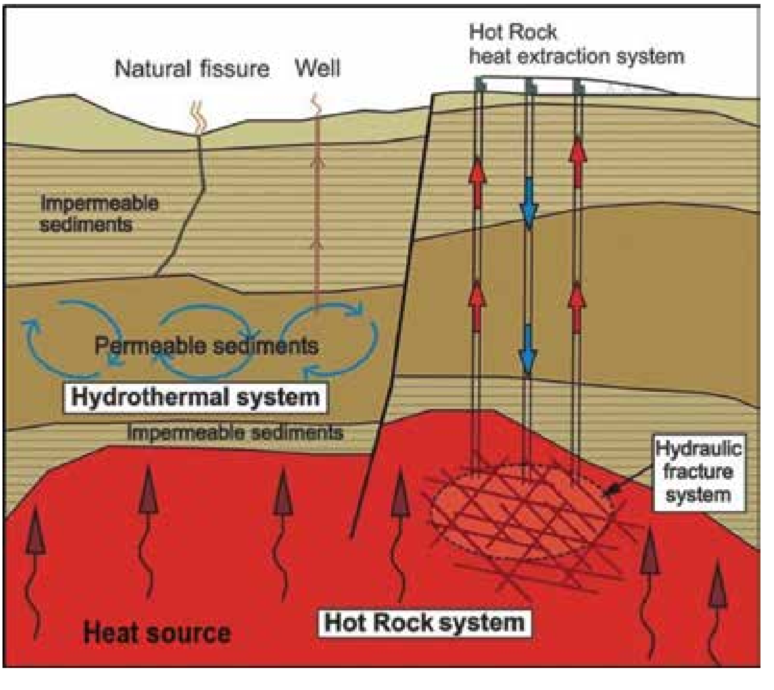

Figure 2.
Geological settings of hydrothermal and hot rock geothermal systems (modified from [21]).

vaporizes it creating a hot fluid that is collected to create electric energy. This is made through a binary conversion. For this type of formation, the limiting factors are its low permeability and low thermal conductivity that makes the exchange of heat difficult. Hydraulic fracturing has been proposed in this case to increase the superficial area available. These types of deposits are called enhanced or engineered geothermal systems (EGS) (**Figure 2**).

The different geothermal systems can be found in regions with a normal lightly superior geothermal gradient especially in places surrounding the plaque margins where the geothermal gradient can be significantly higher than average. This is the origin of geothermal resources.

Aside from a few setbacks, there are reasons to affirm that geothermal energy has a great advantage over other types of energy. For example, for its independence from climate and natural elements, it is available 24 hours a day 365 days a year, it is unmoved by the change of stations, the production area of 25 MW maximum is 1 acre, and geothermal stations are safe.

Also, it is important to point out that geothermal stations are reliable and work around 95% of the time, some even more than 99%. This can be compared to the 60%—70% for carbon-based and nuclear stations [22–24].

Geothermal energy is known as a renewable, immense, and practically inexhaustible source with a technological maturity that is solid, clean, versatile, and useful to generate electricity, among other applications [16, 25]. The use of geothermal resources has shown technical and economic viability to produce energy with a sustainable conscience, and in this context, it has been considered that the energy extracted from this system can be recuperated in a time scale similar to the process of its extraction [26]. In studies on the life-cycle analysis, it has been shown that the production of electricity affects the environment very mildly since its discharge is mainly wet steam and low gas emissions [27]. This makes it environmentally conscious.

3. Mexican case

The geothermal energy development in Mexico has been concentrating on producing energy in five geothermal electrical fields distributed around the country (**Figure 3**), from which the first four have been operated by the Federal Electricity Commission (CFE in Spanish), generating unit VI. Grupo Dragón owns the fifth field.

(a) Cerro Prieto, BC. It is the main and largest geothermal water field, and it is located in Baja California, a semiarid region, in the northwest of Mexico in the border with the USA (**Figure 4**). This geothermal field is located in a separable basin produced between the Cerro Prieto and the imperial active landslide faults

Figure 3.
Geothermal electrical fields in Mexico (modified from [28]). The fields in orange are operated by CFE, and the field in yellow is operated by Grupo Dragón.

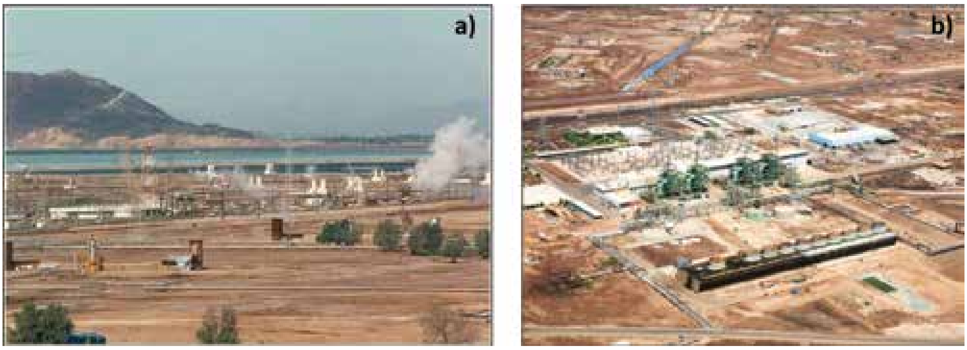

Figure 4.
(a) Cerro Prieto Geothermal Power Plant, evaporation pool, and Cerro Prieto Volcano (courtesy of CFE) and (b) Cerro Prieto geothermal power plant (courtesy of CFE).

that belong to the San Andreas Fault system. The heat source of the geothermal system is a thermal anomaly produced by a thinning of the continental crust in the basin. The geothermal fluids are contained in sedimentary rocks, mainly sandstones intercalated in a series of shales with a mean thickness of 2400 m [29].

This field is also the oldest in the country. It began working on April of 1973. By 2016, it had 150 producing wells and 30 reinjection wells. The capacity was of 570 MW made up of four flash evaporation units of 110 MW each, a low-pressure condensation unit of 30 MW, and four flash evaporation units of 25 MW each [30].

(b) Los Azufres, Mich. This geothermal field began operating in 1982. The producing rocks are of volcanic origin, typical of the Mexican Volcanic Belt which is a region covered by Pliocene-Quaternary volcanoes crossing from the Pacific Ocean to the Gulf of Mexico [31]. The field is located in a forest of pines, oyamels, and oaks, with subhumid temperate climate and semi-cold climate with summer rains (**Figure 5**).

By 2016 it had 44 producing wells and 6 reinjection wells. It is located in central Mexico, near the volcanic belt, with a capacity of 247.8 MW made up of six flash evaporation units (53.4 MW, 50 MW, and four of 26.6 MW each); it also has seven units of back pressure of 5 MW each and two units of binary cycle of 1.5 MW each. The operating capacity is 224.8 MW, since four of the back pressure units and two of the binary cycles are out of service [30].

(c) Los Humeros, Pue. This field began operating in 1990 and is located in central Mexico. This geothermal system is contained within volcanic rocks. The field lies in a Quaternary caldera. The geothermal fluids are hosted by tertiary

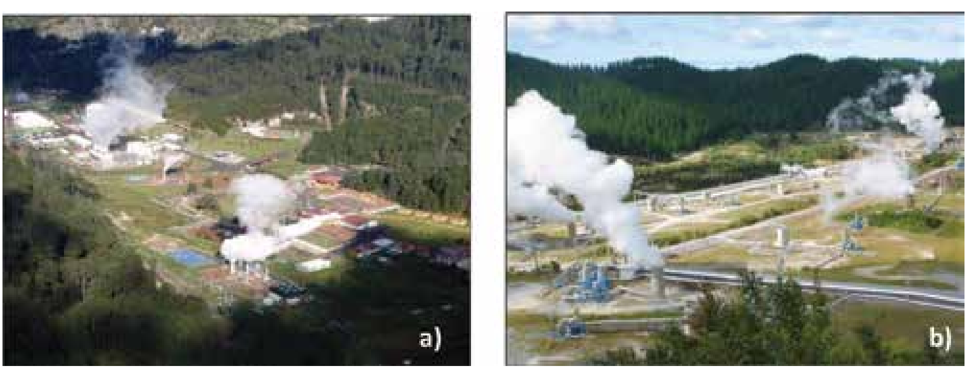

Figure 5.
(a) Los Azufres Geothermal Power Plant (courtesy of CFE) and (b) Los Azufres geothermal power plant (courtesy of CFE).

andesites, and the heat source is a magma chamber. This reservoir presents lower permeability than Los Azufres, but the temperature is up to 400°C in some wells, which is the highest, recorded in Mexican reservoirs [31]. The wells in Los Humeros produce usually low brine that is returned to the reservoir by injection wells [29]. In **Figure 6**, there are two pictures showing two different units of the geothermal power plant, some producing wells.

The power plant by 2016 had a capacity of 93.6 MW, with 23 producing wells and 2 of reinjection. It is made up of eight back pressure units of 5 MW each. The operating capacity is of 68.6 MW, since five of the back pressure units are out of service [30].

(d) Las Tres Vírgenes, BCS. This field is located in the north of Baja California Sur, in the Vizcaino Biosphere Reserve, and began operating in 2002. Las Tres Vírgenes is inside a Quaternary volcanic complex composed of three N-S aligned volcanoes. The heat source is related to the magma chamber of the La Virgen volcano, the youngest and southern of the volcanic complex. The geothermal fluids are hosted by intrusive rocks [29], with a low secondary permeability. These rocks are part of the regional intrusive basement and are overlain by volcano-sedimentary rocks [31].

By 2016, it had three producing wells and two reinjection wells with a capacity of 10 MW. It has two flash evaporation units of 5 MW each and a binary cycle of 2 MW to be built in the future [30]. In **Figure 7**, there are two pictures showing one unit of the geothermal power plant and a panoramic view.

Figure 6.
(a) Los Humeros Geothermal Power Plant (CFE courtesy) and (b) Los Humeros geothermal power plant [32].

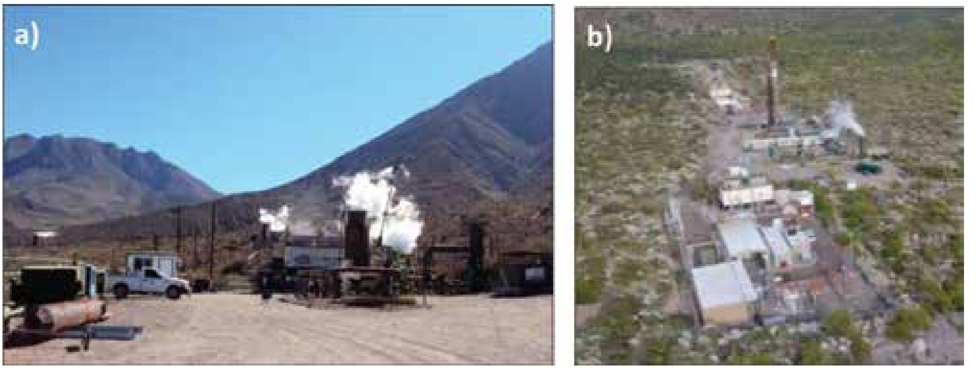

Figure 7.
(a) Las Tres Vírgenes geothermal power plant [33] and (b) Las Tres Vírgenes geothermal power plant [34].

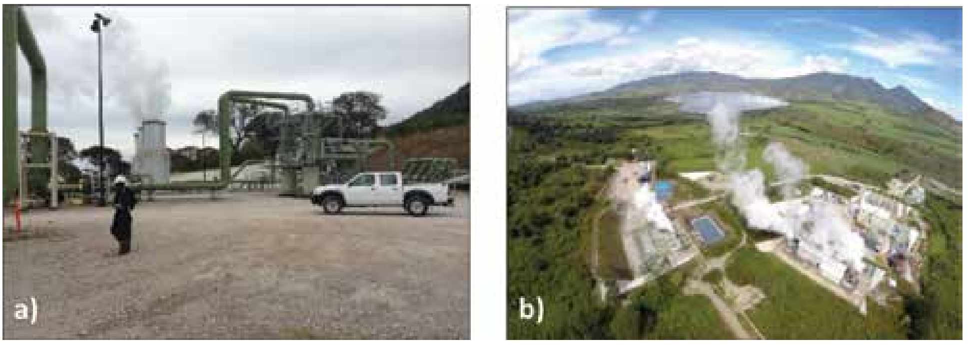

Figure 8.
(a) El Domo de San Pedro geothermal power plant [35] and (b) El Domo de San Pedro geothermal power plant (courtesy of Grupo Dragón).

(e) Domo de San Pedro, Nay. It is the most recent geothermal electrical field and started its operations in February 2015. It is the first geothermal field operated by a private producer Grupo Dragón. The field is currently operated for self-consumption, meaning that the energy is consumed by the entity that owns the plant, although not necessarily in the same location [35]. By 2016, it had a capacity of 35.5 MW, with four producing wells and three reinjection wells. It is made up of a flash evaporation unit of 25.5 MW and two inverse pressures of 5 MW each [30]. (**Figure 8**).

4. Gas emissions

Gas concentrations in the geothermal fluid vary according to the characteristics of the deposit that runs through the conventional geothermal cycle in energy stations. It has a certain amount of non-condensable gases (NCG) (CO_2, H_2S, NH_3, N_2, CH_4, etc.). These gases represent approximately 95% and the 1–2% maximum of the NCG content on geothermal fluids, respectively. The NH_3 and H_3BO_3 gases, which are water soluble, are mainly found in the aqueous phase, are transported to the atmosphere through the air separation (NH_3), and derive (NH_3 and H_3BO_3) from the cooling towers [36, 37].

The quantity and type of hydrogen sulfide reduction required in a geothermal energy plant vary considerably depending on the characteristics of the reservoirs and the design of the geothermal energy plant. The corresponding concentration of H_2S can vary dramatically from one reservoir to another and from one well to another within the same reservoir [38, 39]. The amount of H_2S that must be eliminated will depend on the specific environmental, health, and security requirements from the area in which the geothermal energy plant is located. The environmental regulations in the USA and Europe are very demanding since H_2S has a very low odor range and is very toxic in small concentrations 10–500 ppb [40]. Therefore, since the escape points of these devices are not generally high, it is conceivable to have odor or even lethal concentrations on the ground level [41–44].

In Mexico, there are no regulations for H_2S emissions in the geothermal industry. However, there is one for occupational exposure, which is of 15,000 $\mu g\ m^{-3}$ within 8 h [45], in contrast to what the World Health Organization recommends which is 150 $\mu g\ m^{-3}$ within 24 h [41].

The results of the H_2S emissions from the geothermal electrical fields from the Pollutant Release and Transfer Register (PRTR) of 2006 are shown in **Table 1**. From this table we can see that the geothermal electrical field with the highest H_2S

Site	ton H_2S /y	GWh/y	KWh/y	ton H_2S /KWh	g H_2S /KWh	g eq SO_2 /KWh*
Cerro Prieto	7136	3670.36	3,670,360,000	1.9442E-06	1.9442	3.65
Los Azufres	4588	1801.13	1,801,130,000	2.5472E-06	2.5473	4.78
Humeros	1570	507.66	507,660,000	3.0922E-06	3.0922	5.81
Tres Vírgenes	61	53.63	53,630,000	1.1392E-06	1.1393	2.14

**Acidification potential equivalent factor 1 g H_2S = 1.88 g eq SO_2 [53].*
Data reported by [52].

Table 1.
Calculations of H_2S emissions in 2016 of geothermal energy in Mexico.

emissions is Cerro Prieto. However, when the emissions are measured in KWh, the highest is Los Humeros, Pue. In addition, when calculating the acidification potential equivalent factor, which gives an overview of the possibility of causing acid rain in the area where the H_2S emissions are, the Los Humeros field is the one with the most potential for acidification, followed by Los Azufres, Cerro Prieto, and Las Tres Vírgenes. In the bibliography, the range of potential is located between 0.2 and 0.7 g eq SO_2 KWh-1 [46], but the reports come from enhanced or engineered geothermal systems (EGS) and geothermal life-cycle analysis normally coming from binary stations, which in theory should not have emissions to the atmosphere [47]. Even though the results shown in **Table 1** are emissions from the operation of geothermal electrical stations in 1 year, it is the first time they have been shown for this type of deposit. Aside from operation, the only stage where this type of gas is emitted is during perforations for the geothermal wells. These results evidently show that new technologies to lower H_2S emissions are needed [48–50] even if there are no any strict regulations like in other countries.

For example, H_2S emission control systems have been developed in Iceland, since its regulation is of 50 μg m^{-3} average in 24 h [51].

CO_2 emissions occurring during operation in geothermal electrical fields in Mexico in comparison to fossil fuel energy stations are presented in **Table 2**. On this table, it is shown that the plant with the highest CO_2 emissions per KWh is Los Azufres in contrast to other three geothermal electrical fields in Mexico. These values will include the emissions from natural gas-fueled stations; therefore, both technologies can be considered clean. In comparison to the carbon- or petroleum-fueled stations, the CO_2 emissions are lower.

Site/energy type	Tons CO_2/y	GWh/y	KWh/y	ton CO_2/KWh	g CO_2/KWh
Cerro Prieto	242,417	3670.36	3,670,360,000	6.6047E-05	66.05
Los Azufres	332,771	1801.13	1,801,130,000	1.8475E-04	184.76
Humeros	29553.857	507.66	507,660,000	5.8215E-05	58.22
Las Tres Vírgenes	1509	53.63	53,630,000	2.8137E-05	28.14
Geothermal (average)	606250.857	6032.78	6,032,780,000	1.0049E-04	84.29
Coal (a)					315
Oil (a)					260
Natural gas (a)					182

(Data reported by [54]): (a) [55].

Table 2.
Calculations of CO_2 emissions of renewable energies in Mexico.

The spread of the gas emissions depends on the meteorological conditions, the orography, the altitude of the emission points, and the gas temperature. Non-condensable gases are mainly emitted from the condenser after the reduction and the cooling towers' exit. If the recollection system is not efficient enough in redirecting the geothermal fluid from one plant to another, emissions might happen during the well drilling (discharge and degasification) and the plant's closing (free steam discharge). For this reason, it is required to make an environmental evaluation that would result in the start of an environmental project to predict and evaluate the consequences that might come from it and measure the possible damage caused around the area to dictate correcting measures or minimize the effects and impact [56].

A summary of the potential factors of climate change is shown in **Table 3**, based on the evaluation of the life cycle of renewable energies around the world. In this table, we can observe that the hydrothermal systems have more CO_2 emissions than the EGS. Within the EGS, the cogeneration and hot dry rock systems are the ones with less CO_2 emissions from all renewable energies, according to this table. In comparison to nuclear energy, binary stations emanate approximately the same emissions even though the hydrothermal systems emit a greater quantity of CO_2 per

Energy type	Conversion efficiency (%)	GWP g CO_2eq/KWh	Country	References
Geothermal energy				
Hydrothermal systems	n.r.	50–70	USA	[47]
Enhanced geothermal system (base case)	12 (ORC)	36.7	France	[58]
Binary plant	n.r. (ORC)	24.73–35.99	France	[59]
	9.7	42–62	Germany	[60]
Cogeneration plant	n.r. (ORC)	3.57–3.39	France	[59]
Hot dry rock	n.r.	3.39–3.57	France	[59]
Nuclear energy				
Fission power generation	33	22.25	Singapore	[61]
Solar panels				
Monocrystalline silicona	13.8	44.7	Italy	[62]
Polycrystalline silicona	13	72.4	USA	[63]
	14.4	8.74	Italy	[64]
	12.5	63	Germany	[65]
Amorphous silicon	6.3	34.3	USA	[63]
Wind turbines				
Onshore	90	7	Denmark	[66]
Horizontal axis	n.r.	12	Thailand	[67]
		179	New Zealand	[68]
Vertical axis	n.r.	46	France	[69]
Offshore	85	11	Denmark	[66]

Organic Rankine cycle (ORC); n.r., not reported.

Table 3.
Global warming potential (GWP) of life-cycle assessment for different renewable energies worldwide.

KWh in the production of electric energy. In the case of solar panels and wind turbines, while operating, there are evidently no gas emissions to the atmosphere. However, emissions occur during manufacture, transportation, installation, and disposing of the technology. When evaluating the life cycle of these technologies with a given life span of 25–30 years, then we can say that there are emissions of CO_2 per KWh in the production of electric energy. Some solar panels are even above the GWP reported for some binary geothermal stations or hydrothermal geothermal systems. This is the case for wind energy as well.

Now, in the matter of the efficiency of the technologies to convert to electric energy, it is seen that wind turbines are very efficient in comparison to the rest of the reported technologies. In the case of binary thermal stations, it varies in relation to the enthalpy of geothermal water and the external temperatures that can affect the energy necessary for cooling [57].

5. Environmental impact

The first formal lines to define the environmental characteristics related to geothermal development were published in 2016. There, the best practices to follow in the most important phases of a geothermal project were given, particularly in relation to creating electric energy and what is required for deep well drilling [70]. The development of sustainable energy is an emerging paradigm that implies the reduction of negative environmental impact and the efficient use of geothermal resources for long periods of time [71].

This emphasizes the need to establish new guidelines in public policy to include a simulation of the efficiency in energy production to ensure a reliable supply, security and energy diversity, economic efficiency, research development aid, and the development of improved technologies. Thereon, the term "renewable" is given to the resource, as well as the type of energy, and it implies a rhythm in which the system naturally rebuilds itself. The scale of time in which a natural geothermal system recharges is the main criteria to evaluate if the resource and geothermal energy are considered renewable; if the extracted geothermal energy is naturally substituted by an additional quantity of energy and this process takes place in a time period similar to the extraction time, then it will be renewable [72].

However, it is important to highlight that the use of geothermal energy does not only imply maintaining the production of each geothermal system individually. This is because sustainable development must incorporate all the aspects of human necessities and activities. Actually, sustainable usage implies an economic, social, and environmental integral development, just like the battle against climate change. Even then, the level of sustainable production of a geothermal resource increases with time as the knowledge on the resource also increases with technological advances. This means that, with exploration and continued monitoring, new exploration methods with innovative drilling technologies and efficiency may traduce in the increment of the production capacity of a geothermal well [73].

6. Challenges

The challenges in converting to sustainable energies are focused on providing access, particularly increasing the efficiency, minimizing the environmental impact, and promoting social acceptance and security. Although geothermal projects have a disadvantage in the long wait for development and high initial costs, this source of energy has a great increase in potential in the upcoming decades, and it is important to promote energy independence and reduce the use of fossil fuel by-products. Since geothermal energy is typically considered renewable, these resources must be ensured for future generations. This means that they must be renewed in time lapses acceptable for human societies. Thereon, the premature exhaustion of geothermal resources and the life span of a geothermal resource refer to the amount of time a geothermal resource can be exploited to produce electricity commercially. This brings up the matters of sustainability and energy security.

7. Conclusions

In a world that has shown great concern for the environment, there is also a greater attention to consider clean and sustainable sources of energy, such as geothermal. However, different technologies used in the production of geothermal energy result in different types of emission values to the atmosphere. The environmental effects of developing geothermal energy are linked to how geothermal energy stations operate. For example, the liberation of non-condensable gas is a problem in intermittent steam energy stations but not in binary fluid stations because it is not expected to have non-condensable gas as long as the geothermal fluids are pressurized. One of the disadvantages of the binary fluid stations is the need of external sources of refrigeration water.

Geothermal resources can be considered renewable as long as the system maintains a balance in regain with the help of cold or warm reinjection of the geothermal brine. Generally, the environmental impact from creating electric energy from geothermal resources is far less than other types of renewable, clean energies. One of the emissions that must be looked after is hydrogen sulfide, which is contained in most geothermal steam sources, as well as carbon dioxide, which have an impact on natural vegetation, habitants, and crops near the geothermal central at an approximately 5 km radius.

Due to the likelihood of expansion in geothermal energy in the further years, it will be needed to standardize the compliance of different environmental laws by incorporating environmental regulation guidelines in the process of policies and decision-making to create strategies to guide the geothermal development and ensure sustainable development and to also accept the need to conceptualize the relationship between economic development and natural and preservation of energy resources by providing a foundation to write legislations on geothermal resources around the world, from geothermal development and exploration to abandoning deposits.

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Author details

Zayre I. González-Acevedo[1]* and Marco A. García-Zarate[2]

1 Center for Scientific Research and Higher Education at Ensenada, B.C. Geology Department, Ensenada, Baja California, Mexico

2 Applied Physics Department, Ensenada, Baja California, Mexico

*Address all correspondence to: zgonzale@cicese.edu.mx

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Chapter 5

Greenhouse Gases Reforming and Hydrogen Upgrading by Using Warm Plasma Technology

Joel O. Pacheco-Sotelo, Ricardo Valdivia-Barrientos and Marquidia Pacheco-Pacheco

Abstract

Global warming is an alarming problem with adverse impact on climate change. Carbon dioxide (CO_2) and methane (CH_4) have been identified as the most significant greenhouse gases (GHG) normally arising from anthropogenic activities; therefore, promising treatment technologies are developing all over the world to resolve this problem. The warm plasma is an emergent process with low specific energy requirement capable to reach high temperature to produce excited species and support subsequent chemical reactions. Consequently, warm plasma reactors can be accomplished with simple structure reactors having high gas flow rates and treatment capacity. Plasma interaction with GHG leads into a molecular dissociation, mainly forming CO and H_2, also known as syngas, which represents an alternative energy source with innovative applications in microturbines and fuel cells, among other emerging applications. The process here explained assures a significant reduction in CO_2 emission and H_2 yield upgrading. The reforming experimental results by using two warm plasma reactors are connected in series to improve the syngas yield. This alternative represents a great possibility for CO_2 conversion.

Keywords: warm plasma reforming, overall energy, H_2 upgrading

1. Introduction

Fossil fuels present a serious dilemma to humanity; around 86% of the world energy demand emanates from this source, having strong implications for global climate change. During the combustion of a ton of coal, more than 3.5 ton of CO_2 is released, which means an accumulation of 10^{12} tons in the atmosphere [1]. An important parameter that determines the progress level of a country is the Human Development Index (HDI) [2], which considers the energy consumption expressed in kg oil equivalent per capita. This index is also used to establish the quality of life in a country, but this is paradoxical because to achieve a good standard of living, an immoderate consumption of energy is required; an inhabitant of the USA spends up to ten times more energy than another of Ethiopia; it means that this devastating energy consumption will revert in short term toward a poor quality of life.

The concentration of CO_2 has dramatically increased over the past 1000 years and can be explained by the industrialization and urbanization, as well as the indiscriminate use of fossil fuels and the consequent deterioration of natural resources, representing a serious environmental, social, and economic problem [3, 4]. The average temperature on Earth's surface has also increased since the industrial revolution, notably in the last 50 years, and especially in recent decades, a significant increase in GHG concentration has been identified. Particularly in May 2013, the Mauna Loa Observatory (US NOAA) detected an alarming amount surpassing 400 ppm of CO_2. This disquieting growth marked in just a few decades exceeds what has been accumulated in the atmosphere for over the last half million years, affecting the increasing average temperature of the planet [5]. Continuing in this way, the environmental consequences will have an irreparable cost and will probably reach a point where any living being will face serious problems.

GHG are the major cause of global warming; their average concentration is shown in **Table 1**. CO_2 has also has a long life in the atmosphere (between 5 and 200 years).

To find a new and better technology for CO_2 conversion, it is necessary to contemplate the energy cost and its impact on the environment. The reduced energy content in CO_2 represents the main limitation for a posterior reuse, demanding additional energy, which eventually impacts on new CO_2 emissions. Consequently, the energetic cost involved in its reuse must consume less energy than that obtained at the termination of the process. The most effective and cost-free way to collect and transform CO_2 is provided by nature itself through the well-known process of photosynthesis [7]; however, human being has not been capable to adapt this process to a feasible technology, except by providing extra energy of the order of 191 MJ/kg to obtain H_2 having an energy value of 120 MJ/kg; to be specific, a deficiency still remains in the energy cost.

Concerning wind energy, it is characterized by the complete absence of GHG emissions being one of its main advantages; nevertheless, it is a variable energy source with a stochastic pattern that is difficult to predict, which implies adding storage services and requiring installed in spaces close to the coast or on maritime platforms. The requirement of storage units leads to a temporary inertia in the loading and unloading, so it may not always be available for transitory energy demands.

Regarding the energy derived from biomass (referred as bioenergy), it still has numerous challenges: natural vegetation has to be sacrificed with a massive deforestation to produce crop-based biofuels to make available their growing demand [8].

Nuclear energy is also another primary source of energy that can be considered clean in terms of CO_2 emissions, which currently produces 17% of world consumption (2700 TWh). A global plan in the medium or long term consists in the

Constituent	Concentration
CH_4	55–70% vol
CO_2	30–45% vol
N_2	0–2% vol
COV	0% vol
H_2S	>500 ppm
NH_3	~100 ppm
CO	~100 ppm
Siloxanes	~100 ppm
Lower heating value (LHV)	~22.5 MJ/m^3

Table 1.
GHG average concentration [6].

transition from thermal power plants to nuclear power plants, since a significant reduction in GHG emissions, notably CO_2, is ensured. In Europe, the total electricity produced by the nuclear route reaches 80% in France, 60% in Belgium, and 43% in Sweden. Therefore the transition to this alternative could occur in short term taking advantage of the GHG energy capacity.

An additional energy source is hydrogen. Hydrogen is considered as the fuel of the stars, because in our Sun, every second 600 million tons of hydrogen are converted into helium only by nuclear fusion, releasing enormous amounts of energy, providing also the light and heat which makes life on Earth possible.

It is imperative to ask if it is reasonable to use fossil fuels to generate electricity and then use the electricity to generate hydrogen. Each transformation involves energy losses, thus the overall efficiency becomes lower and, furthermore, CO_2 would be emitted to the atmosphere. In order to be sustainable and environmentally friendly in the long term, electricity for water electrolysis must be derived from renewable or nuclear energy sources which do not emit CO_2 and air pollutants, such as SO_2 and NO_x. Hydrogen is also very attractive as a fuel or additive for internal combustion engines, because it can considerably reduce air pollution; however, using H_2 as a fuel for vehicles requires large high-pressure containers or cryogenic vessels if it is compressed as liquid. This problem can be eliminated by installing on board a plasma reactor to produce hydrogen-rich gas. Gaseous or liquid hydrocarbon fuels are converted by plasma reactor producing hydrogen-rich gas. The efficiency of the overall system is attained by an energy balance when a mixture of hydrocarbon fuel combined with hydrogen-rich gas is injected into the engine.

The energy emitted by the Sun is the most abundant primary source, providing 10,000 times more energy than the total consumption in the world, the terrestrial atmosphere receives a power density of 1370 W m^{-2}, the direct transformation to electrical energy is achieved through solar cells, which are noiseless, do not generate emissions, do not consume fuel, have simple installation, do not have moving parts, and are easy to maintain. However, the main challenge is its temporary storage dependence of energy to supply the variations (or absence) of solar radiation, which increases its operating cost at an order of magnitude higher than generation by natural gas.

In recent years the carbon capture and conversion (3C) technology has been emerging with a greater scope, which, unlike the carbon capture and storage (CCS), does not treat CO_2 as a waste, but on the contrary, promotes its conversion to industrial uses.

Natural gas or biogas reforming are considered cleaner than coal gasification in most countries but is facing technological challenges because the catalysts are inclined to deactivation by soot deposition and sulfur poisoning. In mitigation of these issues, plasma-based CO_2 dissociation technologies could probably offer a new alternative for syngas production.

In recent times many topics are conveniently changing from "control" to "utilization"—using CO_2 and other greenhouse gas for new applications; for existent conditions it is difficult to control or prevent new CO_2 emissions, searching its utilization as raw gas in obtaining further substances is much easier under special conditions. Then, CO_2 becomes a useful gas rather than only a GHG.

Actually, the syngas reforming into methanol or other liquid fuels use the well-known Fischer-Tropsch (FT) processes normally assisted by catalysts; however, this leads to the following disadvantages:

a. Several compressors are required to achieve a pressure of 20–80 bar is required to realize diffusion through the membranes or to attain the operating ranges in the FT process.

b. Temperatures between 200°C and 500°C are needed in syngas reforming. At these temperatures large amounts of steam are generated, which subsequently limit the catalyst activity and deposit carbon layers on its surface reducing its lifetime and dipping its conversion capacity.

c. Catalysts are vulnerable to sulfur compounds and therefore require regeneration or replacement cycles. The catalyst depends on the specific surface area, being the most commercial and accessible catalysts of those made of CuO and Al_2O_3. The Pd catalysts present better performance but have higher economic cost.

d. Contact time between catalysts is crucial to obtain liquid fuels; consequently it is necessary to limit the gas flow at reduced ranges, which leads to high residence times.

e. H_2/CO_2 and CO/CO_2 ratios are optimum when they approach to 2; steam is generated at higher ratios. By exceeding these optimal relations, steam is generated, and excessive water could deactivate the catalyst action, and a reverse reaction also occurs (WSR).

In the case of conventional steam reforming of CH_4 or natural gas, it requires 4.5 kg of H_2O for each kg of H_2 produced, but 5.5 kg of CO_2 is released. When using the reformed coal, 3 kg are required for every 9 kg of water and 11 kg of CO_2 are released, so the latter is considered the most polluting of the processes.

Once H_2 is generated by different processes, it is important to consider its compression, liquefaction, transport, and storage, taking into account its physical properties (ρ_{gas} = 0.088 kg/m^3, ρ_{liquid} = 70 kg/m^3), and boiling point of 20.3 K. So the energy needed to produce, compress, liquefy, transport, transfer, and store H_2 plus the losses in each conversion added to the process of reconversion to electrical energy (through a fuel cell with 50% conversion) in each of the stages can reach to consume more energy than that it will provide or recover from H_2. In addition to the energy cost, another factor to consider is the economic factor: each GJ of H_2 costs $5.6 when it is obtained from natural gas, goes up to $10.30 when using coal, and costs $20.10 with water electrolysis; in this last the consumption of electricity represents 79% of the deliverable energy cost of H_2 (140 MJ/kg) [9].

A short-term alternative is to use a primary source of energy, in this case GHGs or biogas resulting from biodigester and its treatment with plasma to obtain syngas. The provisional storage of this chemical energy contained in the syngas represents a viable alternative either for its "a posteriori" reconversion or for its direct reconversion "in situ" to electrical energy using fuel cells.

2. General plasma characteristics

A fundamental principle differentiating the plasma's behavior from other fluids is that each charged particle simultaneously reacts with a considerable number of charged particles, thus producing an important collective effect. The range of temperatures comprised by laboratory plasmas ranges from room temperature to temperatures comparable to those found inside stars, while density range expands from 10^{12} to 10^{25} m^{-3}; it should be noted that plasmas of industrial interest have kinetic temperature range comprised from 1 up to 20 eV.

Plasma gas discharges are characterized by its chemical activity convenient to induce chemical reaction even without catalyst requirement, that is, plasma

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discharges act as a thermochemical rector overcoming many particular problems in catalytic reformers such as short lifetime, expansive costs, and slow-moving time response. Plasma gas discharges are divided into two types according to its temperature and electron density: nonlocal thermodynamic equilibrium and local thermodynamic equilibrium. In the first case, the degree of particle ionization is very weak, and the temperature of electrons is much higher than heavy particles, so the ion temperature is low and is recognized as cold plasma. Crown plasma dielectric barrier discharges are examples of this category of plasmas where reactions with radicals are common. In the second case, a higher degree of particle ionization, higher electron density, and comparable temperatures in heavy particles and electrons are characterized. This kind of plasma is produced by transferred electric arcs, plasma torches, and high-intensity radio frequency discharges.

A third category or a category having conventional thermal plasma and nonequilibrium plasma conditions is the warm plasma. The warm plasma is a transitional discharge able to work under moderate power density at enough high gas temperature to produce molecule dissociation and excited species, supporting the subsequent chemical reactions. Such plasma discharges have significant advantages: The reactor has simple assembly and do not require extra cooling systems, since they work with reduced electric currents and high voltages; consequently the electrode erosion is notably diminished. Warm plasmas are also characterized by high chemical selectivity and have found applications in fuel conversion to syngas production, hydrogen sulfide dissociation, and CO_2 dissociation. Gliding arc plasma discharge or jet atmospheric pressure plasmas are examples of warm plasma discharges.

Therefore, the use of warm plasma is considered more appropriate to treat GHG because the syngas gas formed by H_2 and CO molecules still exists in temperature range 900 up to 3500 K, just for our application interest (see **Figure 1**). The cold plasma having a lower range of temperatures also reaches the dissociation of GHG but does not subsist stable when relatively high GHG flows rates are treated.

The ionization process in warm plasma discharges are induced by a strong electric field, producing relatively high-energy particles, leading in selective chemical transitions in a very effective manner, and subsequently, the energy necessary to support the electric discharge is reduced, since the electrical conductivity σ(T) has a stepwise behavior and the internal wall temperature of the reactor is kept high reducing the radiation losses.

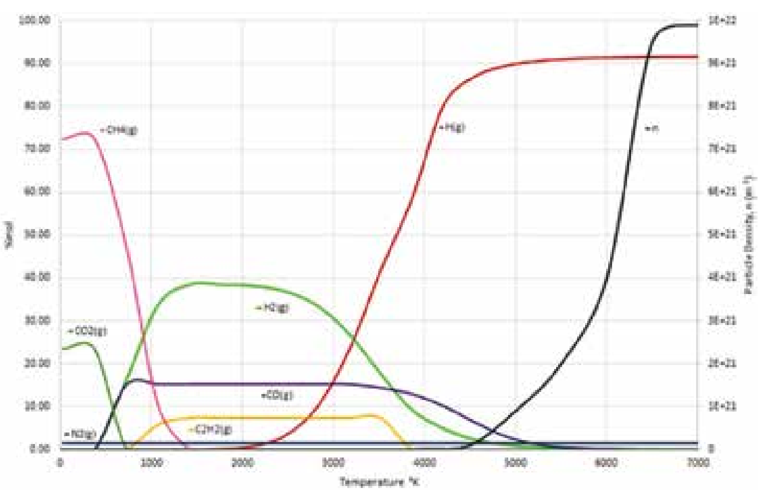

Figure 1.
GHG concentration variation in function of temperature.

Because of its high power density, this plasma reactors can be designed for small- and large-scale applications, these types of reactors can also work in portable or onboard processes [10]. In summary, the use of warm plasma is more adequate for our purposes.

The HSC software [11] combines chemical and thermodynamic features enabling calculations in standard computer to visualize conversion and yielding data in function of temperature or other input variables. So the prediction of important results and confirmation of experimental ones can be attained. With regards to biogas concentrations shown in **Table 1**, the HSC was used to simulate and find the evolution of the participating species (reactants and by-products) that are carried out in a temperature range of 300–7000 K. **Figure 3** shows a maximum H_2 yield in the temperature range 1200–2600 K. Another diatomic species is C_2H_2 whose concentration begins to increase at 1000 K, remains at a constant maximum value up to 3000 K, and then decays and dissociates to monatomic species. Other species not marked in **Figure 3** are the radicals N^+, OH, C^+, as well as the concentration of electrons, which begin to increase considerably from 4000 K. Enough information on this monoatomic or radical species can be found in Ref. [12]. Regarding the electron density n_e, it has a significant increase beyond 5000 K, consequently corresponding to thermal plasmas discharges.

Additionally, warm plasma discharges are characterized by a good energy efficiency transfer principally because an efficient vibrational excitation of the molecules can be reached, and this leads in a better molecule splitting with less energy insertion. The selective excitation of vibrational modes enhances the chemical selectivity, because it requires a low amount of electron energy to increase the lowest vibrational level, and by interchanging this energy with other vibration levels (VL) this leads in a concentration increase of the higher levels to finally get the vibrational-vibration relaxation (V-V) up to reach a dissociation level, allowing as a result, reduced energies, diminishing from 10 to only 5.5 eV. The selective mechanism consists in sending electrical impulses into the plasma discharge, and once the dissociation has been achieved, the reactions can be sustained by applying a lower energy of around 1 eV/mol [13, 14]. As a consequence the chemical reaction is carried out in a shorter time and with reduced energy cost, specifically if a vibrational excitation is promoted.

The most important characteristic of CO_2 is its high specific heat at lower temperatures that significantly increases the enthalpy; therefore, a more constricted arc is produced, and as a consequence a higher current density is produced, hence a higher magnetic pinch pressure and a higher plasma flow velocity are manifested.

Compared to traditional catalytic reforming processes with high capital costs, high temperature requirements, large equipment size, and rapid loss of catalyst activity [15, 16], warm plasma reforming (WPR) would provide an attractive route for methanol reforming, because the gas temperature can be low, while the electrons are highly energetic to sustain the chemical reactions.

2.1 High-frequency operation effect

The importance of high-frequency (HF) plasma discharge and its effect in V-I relationship behavior is presented in this section, indicating a more stable discharge once higher frequency is applied into discharges.

Since the warm plasma discharge is a complex physical concept, the mathematical equations describing an exact physical behavior would be very difficult to obtain and even more difficult to solve; so an approximate and manageable model of the plasma discharge derived from the well-known Elenbaas-Heller equation, considering constant pressure and others simplifications as was explained elsewhere

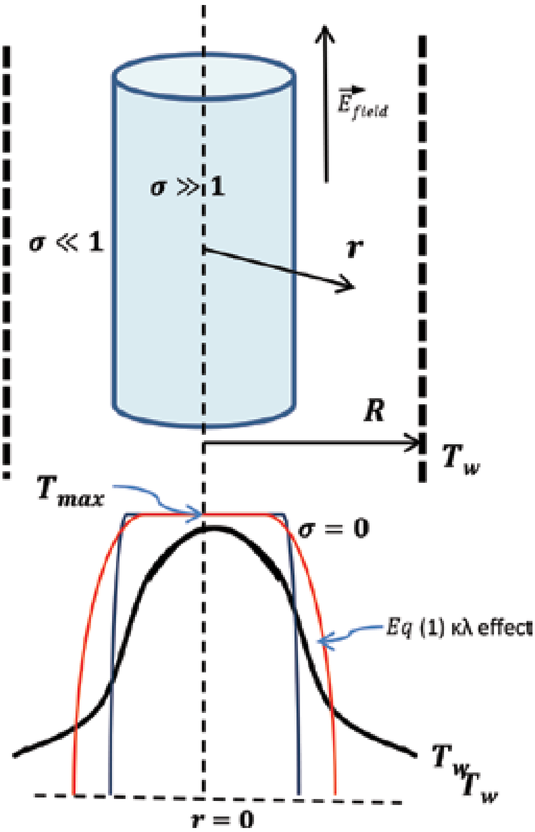

Figure 2.
Temperature profile according electrical conductivity.

[17, 18], is expressed in Eq. (1); this model is taken up again to demonstrate the effects of the frequency on the discharge stability.

The electric field applied (E_{field}) in the discharge column (see **Figure 2**) gives the power transmitted to the electrons and then transferred to the gas atoms via elastic and inelastic collisions among electrons, atoms, and other species participating in the discharge. Consequently, the gas is heated up, and the thermal energy is removed by thermal conduction, radiation, convection, and diffusion.

In warm plasma, the radiation and convection losses are neglected because no intense current participates in discharge, so Eq. (2) is obtained:

$$\rho C_p \frac{dT}{dt} = \sigma E^2 + \frac{1}{r}\frac{d}{dr}\left(\frac{\kappa dT}{dr}\right) \tag{1}$$

$$\frac{dT}{dt} = \frac{\frac{I_{disch}^2}{S\ \sigma(T)} - [P_{loss}]}{S\rho(T)C_p(T)} \tag{2}$$

This algorithm uses an initial temperature value to calculate the Joule power loss P_{loss}, and the specific heat $C_p(T)$, the density $\rho(T)$, and the discharge electrical conductivity $\sigma(T)$ are obtained from a database for a given constant pressure [19]. S represents the transversal section of the column discharge. Once these coefficients have been determined, it is possible to solve this equation by using a SIMULINK tool and presenting the discharge as a two-terminal electrical device. This model accomplishes a good agreement between analytical and experimental values at low and high frequencies, moreover it allows us to find the characteristic discharge time and temperatures of plasma (see Section 2.2).

The manner in which the discharge impedance responds as a component of the circuit is a key element that describes the discharge behavior, and its interaction with the power supply, subsequently, is a very useful tool to design an efficient converter-discharge system. The model also shows that the temperature modulation in the discharge decreases considerably according to the relaxation time and predicts the discharge electrical behavior, considering different power requirements at high and low frequencies.

2.2 Relaxation time and frequency effect

When the source of energy in (1) is extinguished, the right first term equals zero (E = 0); in consequence the temperature begins to decay, resulting in a simple Eq. (3), leading an expression for the relaxation time τ_{rel} (4):

$$\rho C_p \frac{dT_0}{dt} + 4\left(\frac{\kappa T_0}{r^2}\right) = 0 \Rightarrow \frac{dT_0}{dt} + \frac{4\kappa T_0}{\rho C_p r^2} = 0 \tag{3}$$

$$\Rightarrow T_0(t) = T_i e^{-t/\tau_{rel}} \begin{cases} T_i = \dfrac{EI}{4\pi\kappa} \\ \tau_{rel} = \dfrac{\rho C_p}{\kappa} \dfrac{\pi r^2}{4\pi} \end{cases} \tag{4}$$

Thus, the dynamic behavior is similar to a first-order circuit. The relaxation time depends inversely on the thermal conductivity κ and directly on the density ρ and specific heat C_p, as well as on the radius of the discharge, which for practical purposes has been considered to be 0.4 mm. In this manner, the family of curves expressed in **Figure 3** can be obtained.

It is obvious that CO_2 has the highest relaxation times (~200 ms) and H_2 presents the lowest conductivity times (~200 μs) as a consequence of its remarkable

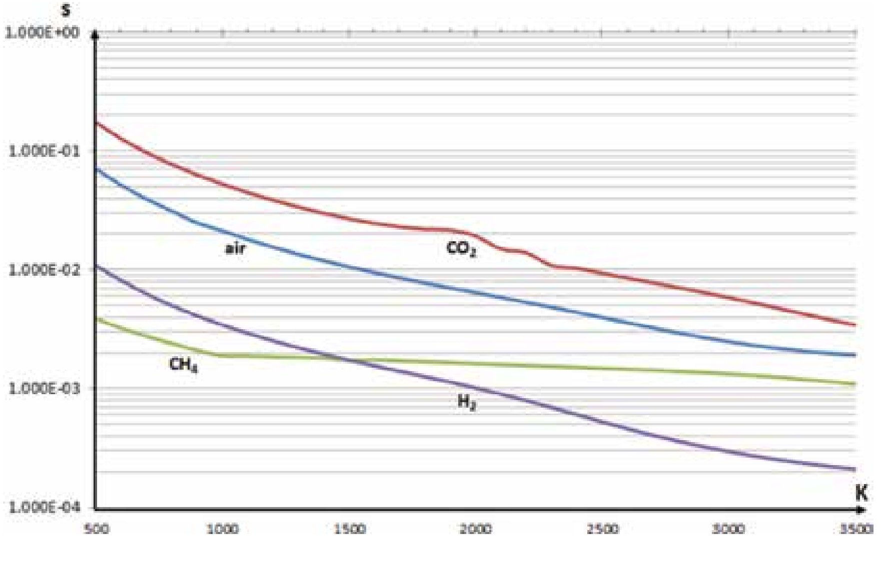

Figure 3.
Discharge plasma relaxation time.

thermal conductivity. Above 1500 K, H_2 has a shorter relaxation time, which means that heating and cooling time is less than the rest of the gases in the plasma discharge, so it is convenient to apply a discharge frequency greater than 10 kHz, as a consequence the temperature variations will be reduced, as shown in thermal stress simulation at different frequency operations in **Figure 4**.

Another useful parameter is the temperature modulation of the plasma which relates the temperature variations of a discharge respect its average temperature as a function of the frequency of operation $[(\Delta T/T_{av})_f]$; [20] defines temperature variations and average temperature as

$$\Delta T = \frac{T_{max} - T_{min}}{2} \tag{5}$$

and

$$T_{av} = \frac{T_{max} + T_{min}}{2} \tag{6}$$

The temperature variations and average temperature in function of frequency were determined from Eqs. (5) and (6), and its results are depicted in **Figure 4**. At frequencies beyond 5 kHz, the temperature variation is approximately 1% around a temperature value of 3900 K, while for a low frequency such as 50 Hz, the temperature variation corresponds to almost 1500 K. Therefore the influence of the frequency respect to the supply current in plasma discharge is closely connected with the relaxation time τ_{rel} during plasma freshening [21, 22]. In conclusion, if the waveform signal period exceeds this relaxation time, the plasma temperature will be modulated (50 Hz case in **Figure 4**). In the opposite case, when the period is much lower than τ_{rel} as in the case of HF (>5 kHz), the plasma temperature will be nearly constant. A free decay temperature arises when the plasma discharge is turned off, indicative of the thermal discharge response to changes in waveform signal source.

By using the same model, the V-I relationship of an electrical discharge can be obtained and represented as a Lissajous curve presented in **Figure 5**. Simulations were performed at different frequency values, starting at 50 Hz up to 5 kHz. When

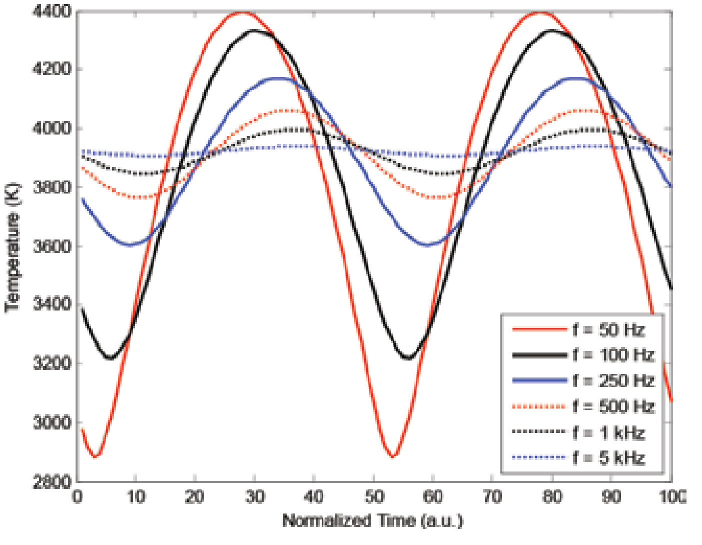

Figure 4.
Thermal stress at different frequency operation.

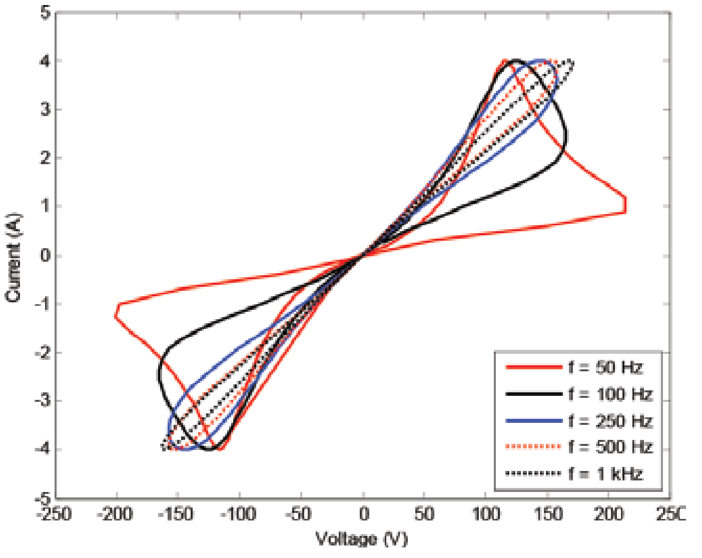

Figure 5.
V-I relationship and its frequency effect.

the excitation frequency becomes relatively high (>5 kHz), the discharge characteristic V-I behavior inclines to be completely linear, comparable to a purely resistance charge; otherwise, if the frequency is reduced (<100 Hz), the discharge is nonlinear; for some points where the voltage is not large enough, at that time the discharge current will be extinguished and must wait for the next period to reach a voltage level high enough to ionize and restart the discharge, thus succeeding with high current impulsions, producing a noisy spectrum. In the case of direct current operation, the V-I operating area shows a static path having a slope $\Delta V/\Delta I < 0$ so the behavior is very unstable, and to overcome this problem, a high series resistance must be included in the trajectory discharge, increasing the power loss and diminishing the efficiency.

2.3 Important parameters in reforming processes

There are numerous methods to generate syngas (H_2 + CO) [23, 24]. These methods include steam reforming (SR), partial oxidation (POX), and dry reforming (DR), as shown in Eqs. (7)–(9):

$$\text{SR} : CH_4 + H_2O \rightarrow 3H_2 + CO; \Delta H = 206 \text{ kJ mol}^{-1} \tag{7}$$

$$\text{POX} : CH_4 + 0.5\, O_2 \rightarrow 2H_2 + CO; \Delta H = -36 \text{ kJ mol}^{-1} \tag{8}$$

$$\text{DR} : CH_4 + CO_2 \rightarrow 2H_2 + 2CO; \Delta H = 247 \text{ kJ mol}^{-1} \tag{9}$$

The advantages of dry reforming (9), compared with the other procedures, include the use of CO_2 and CH_4 as reactants mixture; as is well known, this mixture represents 94% of the GHGs. The focus of this work includes the research of the warm plasma discharge, applied for GHG reforming; in addition the electrical energy cost is optimized to produce higher GHG conversion and to obtain a high yield and selectivity rates of H_2. However, H_2 as a fuel has significant drawbacks, especially those related with its storage. Even though hydrogen has a high mass heating value (120 MJ kg^{-1}), it has a very low volumetric heating value (11 kJ l^{-1}), compared for instance to 16,000 kJ l^{-1} for methanol. The ideal scenarios where DR might be considered are anywhere the supply of CH_4 is linked with CO_2.

The general idea about DR technique consists in using the GHG into plasma discharge to produce higher energetic synthetic by-products (H_2 + CO).

Usually in literature, two important parameters are utilized as good indicators for describing plasma dry reforming process efficiency. These parameters are specific energy (SE) and energy efficiency conversion (ECE).

SE represents the energy needed to produce a mole of syngas, according to Eq. (10):

$$SE = \frac{P_{el} t_{exp}}{mol(H_2 + CO)_{produced}} \tag{10}$$

where P_{el} represents the discharge power applied for a time t_{exp}; consequently it represents the energy applied and expressed in (kJ), and the denominator $mol(H_2 + CO)_{produced}$ denotes the syngas produced. The reformation process will have a better performance, whereas this rapport inclines to slight values of SE.

ECE signifies the proportion of energy contained in syngas obtained in relation to the input energy, which is the sum of the energy applied in the plasma ($P_{el}t_{exp}$) and the energy during the CH_4 conversion. ECE is defined by Eq. (11). The most desirable ECE value must be close to 100%:

$$ECE = \frac{\left[\left(\text{mol } H_{2\ \text{produced}}\right)\left(LHV_{H2}\right) + \left(\text{mol } CO_{\text{produced}}\right)\left(LHV_{CO}\right)\right]}{P_{el} t_{exp} + \left[\left(\text{mol } CH_{4\ \text{converted}}\right)\left(LHV_{CH4}\right)\right]} \times 100 \tag{11}$$

In order to calculate the ECE the LHV utilized are reported in **Table 2**.

Once the reaction takes place, in addition to SE and ECE, it is of great interest to know the reactants conversion, which is attained by using Eqs. (12) and (13), indicating the amount of CH_4 and CO_2 that are converted during the reaction:

$$CH_4 \text{ conversion}(\%) = \frac{\text{mol}CH_{4\ \text{converted}}}{\text{mol}CH_{4\ \text{feed}}} \times 100 \tag{12}$$

$$CO_2 \text{ conversion}(\%) = \frac{\text{mol}CO_{2\ \text{converted}}}{\text{mol}CO_{2\ \text{feed}}} \times 100 \tag{13}$$

The principal reaction by-products are H_2 and CO; the conventional manner to evaluate them is by using Eqs. (14) and (15). The H_2 yield is defined as the ratio of H_2 produced during the reaction in relation to the input CH_4 multiplied by two, because each mole of CH_4 produces 2 moles of H_2. Whereas CO yield is defined as the ratio of CO produced during the reforming in relation to the input of CH_4 plus CO_2:

$$H_2 \text{ yield } (\%) = \frac{\text{mol } H_{2\ \text{produced}}}{2 \times \text{mol } CH_{4\ \text{feed}}} \times 100 \tag{14}$$

Molecule	LHV (kJ mol^{-1}) @ 298.16 K
H_2	242.056
CO	283.179
CH_4	802.933
C_2H_2	376.5

Table 2.
LHV for different gases [25, 26].

$$\text{CO yield } (\%) = \frac{\text{mol } CO_{\text{produced}}}{\text{mol } CH_{4 \text{ feed}} + \text{mol } CO_{2 \text{ feed}}} \times 100 \tag{15}$$

Similarly, according to Ref. [25] the acetylene produced is given by

$$C_2H_2 \text{ yield } (\%) = \frac{2\text{xmol } C_2H_{2\text{produced}}}{\text{mol } CH_{4 \text{ feed}}} \times 100 \tag{16}$$

In the same way, the selectivity of these three products are defined by Eqs. (17)–(19):

$$H_2 \text{ selectivity } (\%) = \frac{\text{mol } H_{2 \text{ produced}}}{2 \times \text{mol } CH_{4 \text{ converted}}} \times 100 \tag{17}$$

$$\text{CO selectivity } (\%) = \frac{\text{mol } CO_{\text{produced}}}{\text{mol } CH_{4 \text{ converted}} + \text{mol } CO_{2 \text{ converted}}} \times 100 \tag{18}$$

$$C_2H_2 \text{ yield } (\%) = \frac{2\text{xmol } C_2H_{2\text{produced}}}{\text{mol } CH_{4 \text{ converted}}} \times 100 \tag{19}$$

Finally, the syngas relationship H_2/CO is determined by (20), this important parameter indicates the content of H_2 in the syngas, and it could define the conversion processes in which it can be used to obtain successive by-products:

$$H_2/CO \text{ (u.a.)} = \frac{\text{mol } H_{2 \text{ produced}}}{\text{mol } CO_{\text{produced}}} \tag{20}$$

In the dry reforming technique, an ideal H_2/CO ratio close to 1 must be obtained, and this ratio can be easily modified by controlling the concentration of reactants at the inlet supply. Therefore, the syngas obtained from the dry reforming can be used in the synthesis of a variety of chemicals in much more extensive manners than in the other reforming processes. Another advantage of dry reforming is that CO_2 content can be exploited in natural gas sources, biogases, coal-methane, and organic waste.

An alternative way to promote CO_2 conversion is to mix this molecule with another substance, which usually has a higher Gibbs energy, such as H_2 or CH_4, because it provides energy-carrying radicals that come from H_2. For instance, the reaction $CO_2 + H_2 \rightarrow CO + H_2O$ (ΔH_0 = +51 kJ mol^{-1}) requires almost six times less energy to promote the conversion of CO_2 than that obtained when it is unmixed $CO_2 \rightarrow CO + (0.5)O_2$ (ΔH_0 = + 293 kJ mol^{-1}). The vibrational energy is lower than that of electronic excitation, for example, for the H_2, 4.4 eV is required and for its electronic excitation the double of energy (8.8 eV).

Since biogas also contains unfavorable impurities (H_2S, NH_3, chlorine, and siloxane compounds), a cleaning process is generally required for previous transportation or conversion. Commonly zeolite and carbon nanomaterial are used as adsorbents due to their excellent thermal stability, low cost, large specific area, and pore volume [27]. Noble metals working at high pressures like Pt, Pd, and Ru are also used, particularly because they are less sensitive to carbon deposition, but they are rather expensive in industrial high flow rate applications.

3. Experimental setup and warm plasma reactor features

The warm plasma reactor is constructed in a copper segmented configuration; the mixture gas enters tangentially into the reactor, as is depicted in **Figure 6**

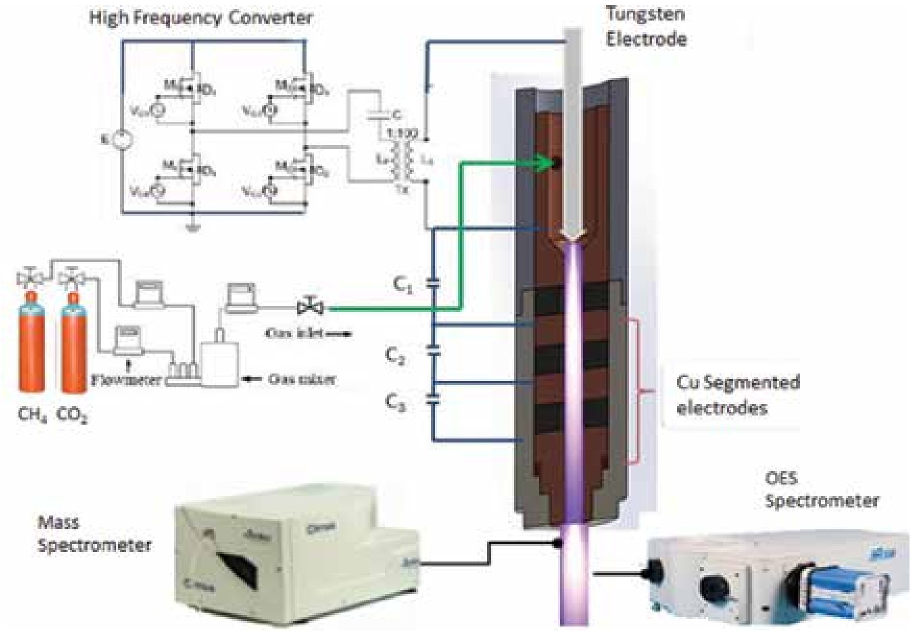

Figure 6.
Segmented plasma torch for GHG reforming.

looking to preserve a stable temperature along the jet length and at the same time to preheat the GHG before entering to plasma discharge and thereby achieving a faster ionization. The plasma discharge is generated between an external electrode and a central tungsten electrode. Due to the different physical properties between central electrode (tungsten) and external electrode (copper), the role of cathode and anode is periodically alternating; as a result the current passes twice zero during a period of the supply voltage.

The flux moving through the segmented electrodes elongates the plasma jet with a large volume. The arc discharge continues the spiral motion descending along the chamber reactor increasing the column length, and also a swirl effect is formed enhancing the reaction time in the central part of the discharge. The whole plasma is confined to a post-chamber 1 cm in diameter and 12 cm in length. The voltage needed to initiate the discharge ranges from 8 up to 10 kV; once the plasma is started, the voltage automatically drops to a lower level (around $2kV_{pp}$). The arc column length is a function of power applied to the discharge, reactor geometry, and nature of the gas to be treated.

Optimal experimental conditions were found to be 8–14 LPM, the power input for a stable discharge is in the 300–700 W depending on the gas to be treated. By adding nitrogen gas and increasing the power up to 500 W, the gas ionization through the entire length of the reactor is assured. N_2 addition in GHG's treatment leads to a better dissociation creating active species being dispersed homogeneously in the plasma reactor by causing the dissociation of the initial molecules by third body impact. Besides a third participant gas, N_2 promotes the dissociation of CH_4 by creating the radicals CN, C_2, and CH, very useful for the route toward methanol synthesis [28].

The power source consists of a high-frequency full bridge converter constituted by one ferrite core setup transformer to provide up to 10 kV at high frequencies. The power supply handles a wide-frequency range operation (5–200 kHz). The duty cycle in each phase is adjusted to 50% providing a soft start in the MOS avoiding redundant power consumption in the plasma discharge as it was explained in detail elsewhere [29]. The HF transformer transfers the maximum energy toward the plasma discharge; in addition, it also functions as a stabilizer, because a natural negative feedback controls the impedance plasma discharge; when the impedance charge goes down, the voltage is automatically adjusted to sustain a stable plasma discharge; and consequently a lower electrical field of about 3 kV/mm is applied between electrodes; as a result, a low-current discharge streaks between the electrodes' closest points and pre-ionizes the gas gap, causing the formation of a stronger current to sustain the warm plasma discharge in the GHG.

By working at HF, the fitting transformer size and weight are reduced as well for the other passive components becoming competitive in energetic and price terms. The transformer contains a ferrite core EI-shaped type, naturally protected against short circuit on the secondary coil because of the important leakage magnetic flux which allows obtaining an automatic impedance control. The simplified block diagram of the proposed converter (HF converter) is shown in **Figure 6**, which is a symbolic illustration of the internal modules and its connection with the plasma reactor.

4. Experimental results

Some samples were taken directly from a biodigester. To achieve this sampling, a special compressor was used, to store the gas in a container through a pressure up to 300 kg cm^{-2} (see **Figure 7**). The diagnosis reveals that some impurities such as H_2O, H_2S, H_2O, air, etc. where counted in in the biogas, being the principal components CH_4 as is exposed in **Table 3**.

Preserving the concentrations obtained in the biogas characterization, the mixture of these gases was injected in the experimental arrangement shown in **Figure 6**, with an applied power of 461 W throughout 143 s of experiment duration,

Figure 7.
Biogas sampling.

Specie	Concentration (% vol)
CH_4	55.7200
CO_2	13.4900
Air	28.2200
H_2S* 236 ppm	* 0.0236
H_2O	1.3480
Other species	1.1984

Table 3.
Biogas mixture concentration.

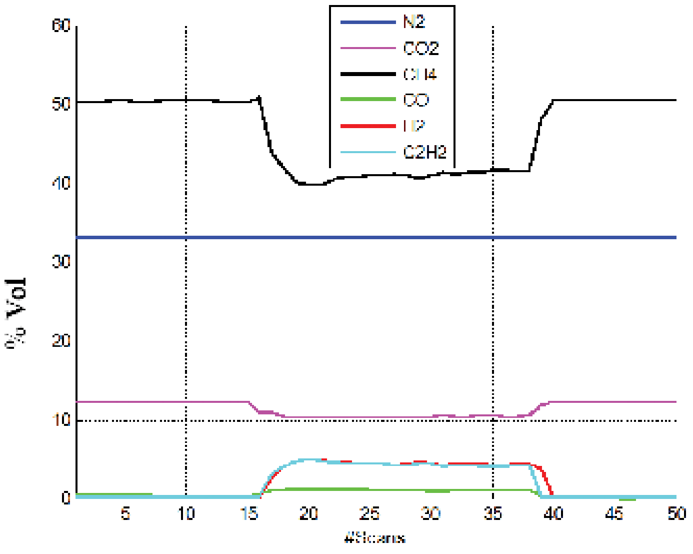

Figure 8.
Evolution concentration obtained by mass spectrometer.

Flow Rate LPM	Ein kJ	Conversion (%)		Yield/Selectivity (%)			SE (kJ/mol)	ECE (%)	Ref.
		CH_4	CO_2	H_2	CO	C_2H_2			
2.52	72.57	90.20	77.11	17.27/ 19.20	60.25/ 75.72	19.13/ 21.32	1386	19.49	(a) This work
12	65.89	34.13	31.34	5.98/ 17.55	2.25/ 7.75	22.58/ 68.78	380.23	21.87	(b) This work
10	39.60	40.35	34.99	6.38/ 15.95	7.75/ 32.12	68.78/ 48.57	287.42	26.31	(c) This work
1.5	(270 W)	45	33	.../60	.../90	–/40	~600	~28	[31]
73.3	(18 kW)	78.71	64.80	.../82.85	.../96.8	///	///	57.22	[32]
4	(1.05 kW)	62.2	61.5	.../81.2	.../79.9	///	537	74.63	[33]
7.2	(400 W)	58.3	35.2	.../88.1	.../96.0	///	174	90.2	[34]

Table 4.
Operational conditions and numerical results in GEI treatment.

that is, 65.89 kJ. The result of the evolution of the concentration of the input and output species is shown in **Figure 8** with the corresponding numerical values expressed in **Table 4**, by using Eqs. (10)–(20). Real-time GHG study was carried out before and after the biogas by mass spectrometry by using a Cirrus 320 mass spectrometer.

A worth sub-product obtained is acetylene gas C_2H_2, normally obtained during methane pyrolysis at a temperature around 2150 K; thermodynamically this molecule is unstable relative to most other hydrocarbons at lower temperatures, but above 1500 K acetylene is more stable than other hydrocarbons, the reason why it is very used in high-quality welding applications. The most probable reforming path reaction for acetylene is described by the next reaction (21):

$$(1-X)CH_4 \overset{k1}{\rightarrow} C_2H_6 \overset{k2}{\rightarrow} C_2H_4 \overset{k3}{\rightarrow} C_2H_2 \overset{k4}{\rightarrow} 2C + H_2 \quad (21)$$

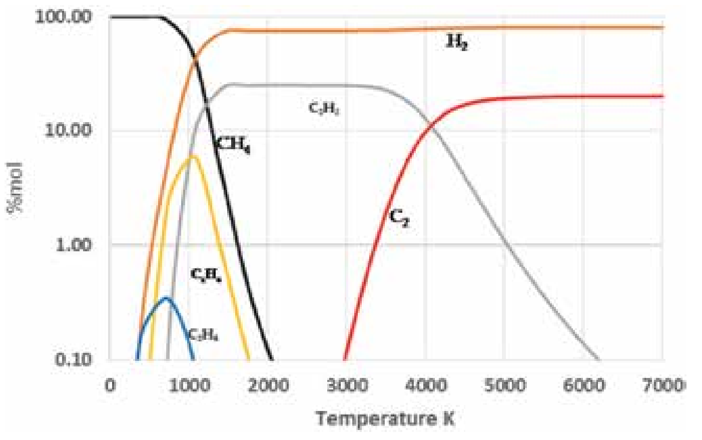

Figure 9.
Yield of acetylene in methane plasma reforming.

being (1-X) CH_4 the unconverted methane during GEI plasma reforming in (9). At high temperature, ethane (C_2H_6) and ethylene (C_2H_4) are very short-lived, being k_1, k_2, and k_3 rates constant with reaction times smaller than 10^{-4} s [25, 26]; normally k_4 is a rate constant with longer reaction time leading to C_2 and H_2 formation. Methane dissociation starts in warmer plasma zone, and the C–H bond breaks with simultaneous formation of H_3, CH_2, CH, H, C_2, and C; the recombination of these radicals leads to the formation of acetylene through reactions (18) and (19).

Figure 9 shows reaction (21) and its evolution concentration against temperature. The concentration level (% mol) is exposed in logarithmic scale to appreciate the ethane and ethylene concentration evolution which are much lower than that of acetylene, this previous being stable and remaining at a constant concentration up to 3500 K; beyond this temperature, acetylene is decayed into H_2 and C_2. In warm plasma discharge, this average temperature is rarely attained, so the final by-products obtained are H_2, C_2H_2, and CO.

The plasma dry reforming (DR) is not only described by Eq. (9); a complementary reaction succeeds and corresponds to a reaction occurring during CO_2 + CH_4 reforming for methane that has not yet been converted into syngas. In this way, methane to acetylene reforming (MAR) in Eq. (22) can be established:

$$(MAR) : (1 - X)\ 2CH_4 \rightarrow (1 - X)\ (C_2H_2 + 3H_2);\ \Delta H_{298} = 376.5\ kJ\ mol^{-1} \qquad (22)$$

5. Conclusions

The aim of this work was focused in the GHG dissociation effectiveness by using a simple design of a warm plasma reactor applied for CH_4 + CO_2 reforming obtaining competitive results, because dry reforming process efficiency possess very low SE and a relatively high ECE.

The warm plasma reactor has a compact size, faster response and reaction times, and cheaper than conventional gasification process because it requires no external ignition and neither cooling mechanism. Working at atmospheric pressure eliminates the operational and maintenance costs of vacuum equipment.

Concerning discharge stability and its frequency effect, a simple model based in an integro-differential equation in which the gas properties are all highly nonlinear function of temperature and pressure and its solution was resolved on the basis of simplifying assumptions.

Besides the syngas ($CO + H_2$) a substantial formation of acetylene (C_2H_2) is also obtained; therefore by-products with high energetic value are obtained.

The principal drawbacks were overcome using a special HF converter to get stable discharge and V-I linear behavior.

The plasma systems here proposed can be justified since it converts CO_2 into harmless gases instead of storing CO_2 in geological locations; it also has good energy conversions, with good treatment capacity and without generation of unwanted species. If the dissociation products can be used to produce a usable final product, such as syngas or other fuel gas, the technology becomes economically appealing.

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Author details

Joel O. Pacheco-Sotelo, Ricardo Valdivia-Barrientos* and
Marquidia Pacheco-Pacheco
National Institute of Nuclear Research, Ocoyoacac, Mexico

*Address all correspondence to: ricardo.valdivia@inin.gob.mx

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Chapter 6

Electric Vehicles Are a Zero-Emission Technology?

Alfredo Santana-Diaz

Abstract

Electric vehicles (EVs) are advertised as a zero-emission solution and as an alternative to the mobility problems of persons and goods in large cities. This chapter analyzes if these vehicles are really an option that would favor the green policies and environment of Latin American cities. The elements analyzed are the specific driving cycles for Latin American cities as well as geographical conditions, the access to technology, economic costs, and the infrastructure required to adapt EVs. These elements are are compared with the case of the countries of Northern Europe, where a greater circulation of these vehicles currently exists. The impact of transferring EV technology from one country to another, without considering specific situations, is also analyzed and, finally, some clues to be taken into account are stressed in order to determine if EVs in Latin America could be considered as green technologies.

Keywords: electric vehicles, driving cycles, mobility, zero-emission, transfer technology

1. Introduction

Global EV sales are increasing; annually, these global vehicle unit sales reached approximately 100,000 in 2012, 200,000 in 2013, and 300,000 in 2014, being the most important market in the USA, followed by Japan, Europe, and China [1]. Several automotive companies have wide programs to manufacture and sell electric vehicles; additionally, media reflects that the government, industries, as well as non-governmental organizations are pushing to have policies and benefits to adopt electric vehicle as a symbol of an eco-friendly transport technology. In particular, the actions of the governments of China, France, Germany, Japan, the Netherlands, Norway, the UK, and the USA are leading with policy incentives and infrastructure investments, and these countries make up over 90% of the world's electric vehicle market [1].

Countries of Northern Europe show important advances in spreading the use of electric vehicles. Countries with potential bigger markets as France, the UK, Japan, and the USA are developing consumer incentives and charging infrastructure support to increase the numbers of EVs in the cities.

India, China, and Latin American countries are rapidly changing to EV production and, in less proportion, to their use, as a result of two motivations: they are low-cost manufacturing countries and their hungriness to have access to the newest technologies. But, it is possible that the current state of this technology is not suitable for those countries, especially for Latin American ones.

In this chapter, the influence of geographic, economic, and social conditions is taken into account to determine the performance of EVs in Latin American countries; a case study of their behavior in Mexico City is also discussed.

Finally, a different scenario of their use and benefits is concluded; at this moment, the use of actual EVs conceived for different geographic, economic, and social conditions is not the best solution to really impact on the environment in Latin American countries.

2. Energy consumption in electric vehicles

To quantify the energy consumption in a vehicle, it is important to know three sets of key data:

- Vehicle dynamic characteristics
- Driving cycle
- Geo-environmental conditions

In particular, it is very important to also take into account the interconnected geographic and environmental conditions because, under real-driving conditions, EVs seem to be much more dependent on environmental conditions than fuel vehicles, especially in urban areas [2]. In those areas, the conditions of traffic obligate, sometimes, to make use of ventilation and air conditioning units; these conditions have an impact of approximately 10% of the fuel consumption on conventional vehicles [3], whereas it can be responsible of a range drop up to 40% for EVs [4]. Finally, the altitude of cities over the sea level and even the pavement deterioration are additional conditions that directly impact on the EV performance.

To ensure a good knowledge of energetic requirements of EVs, it is important to assume the range autonomy according to the purpose and the mobility needs of users. A utility vehicle will have a very different energy demand compared with a personal vehicle. Even for the same purpose, the traffic conditions shape different energy configurations.

2.1 Vehicle dynamic model

A classic vehicle dynamic model is shown in **Figure 1**, where acceleration force (Fa), drag force (Fd), roll force (Fr), mechanic force (Fm), and gravity force (Fg) are represented under an inclination θ (θ is the measured angle over the road).

The mechanical power needed at the tire of the vehicle is the product of the speed (v) and the mechanic force. The expression that describes the power consumption is given by the following Eq. (1) [5]:

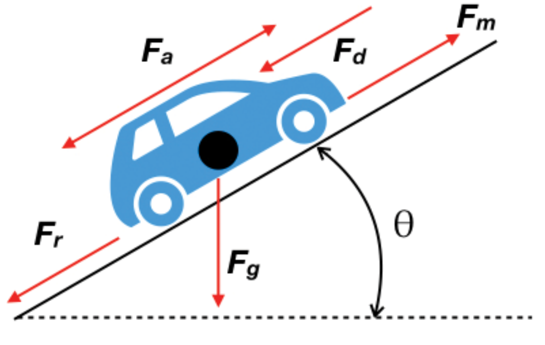

Figure 1.
Vehicle force diagram.

$$P_m = v\,F_m = v\left(F_a + F_d + F_r + F_g\right) \tag{1}$$

From Eq. (1), it is seen that the mechanic force required moving the vehicle is the sum of the acceleration force, the drag force, the roll force, and the gravity force; these forces are, respectively, depicted by Eqs. (2)–(5) as follows:

$$F_a = m_v \frac{dv}{dt} \tag{2}$$

$$F_d = \frac{1}{2}\rho_a A_f c_d v^2 \tag{3}$$

$$F_r = m_v c_r g \cdot cos\theta \tag{4}$$

$$F_g = m_v g \cdot sen\theta \tag{5}$$

where m_v is the vehicle mass, dv/dt is the longitudinal acceleration, A_f is the vehicle frontal area, c_d is the vehicle drag coefficient, ρ_a is the mass density of air, v^2 is the square of the speed, c_r is the tire's rolling coefficient, and g is the gravity force constant.

From Eqs. (1)–(5), it can be seen that the mass and the speed are the most important variables in the calculation of mechanic power for the vehicle. However, looking into each equation, there are other important parameters that usually influence consumption, for instance, the acceleration and the inclination of the road.

2.2 Driving cycle

An additional parameter that needs to be taken into account for the determination of the energy consumption is the driving cycle; in a few words, it is a data set showing the speed profile in function of driving.

In the driving cycles known as "New" European Driving Cycle (NEDC), the speed variations are considerably reduced [6]. Therefore, under this supposition, the driving cycle does not represent the real driving conditions in real-world vehicle usage as depicted in [7], and therefore the toxic emissions and fuel consumption of the vehicles are underestimated [8].

For this driving cycle, the influence of Eq. (2) over Eq. (1) is underestimated [9, 10]. An example of the NEDC results can be appreciated in **Figure 2**.

The driving cycle called the World-wide harmonized Light duty driving Test Cycle (WLTC) is a random cycle that proportionates nearest results to real driving conditions compared with those obtained in the driving cycle NEDC.

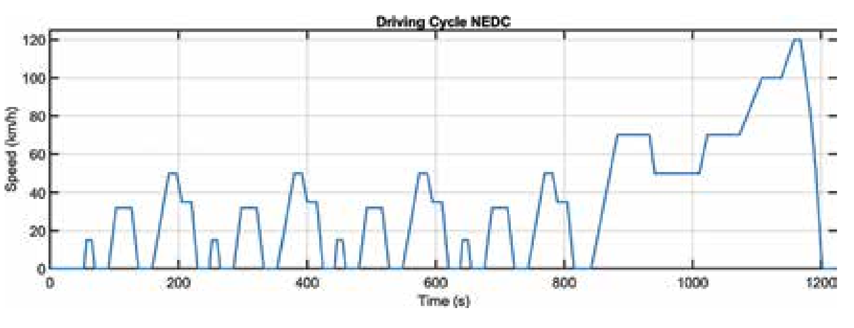

Figure 2.
Driving cycle NEDC.

Figure 3.
Driving cycle WLTC.

Several works [11, 12] have shown closer results to real conditions using the WLTC because the consideration of the changes in accelerations and the different speed phases has a wide-range operation of vehicle. This year, WLTC becomes accepted as a better driving cycle [13]. As can be seen in **Figure 3**, the driving cycle WLTC provides more detailed information than driving cycle NEDC (**Figure 2**).

2.3 Geo-environmental conditions

Geo-environmental conditions are not, so often, taken into account on consumption analysis. This analysis is strongly influenced by the θ angle, because the elevation could dramatically change during the displacements, but in many cases, the angle is simplified to zero; then the force of gravity (Eq. (5)) is not more taken into account to calculate the power consumption (Eq. (1)). In the next section, the importance of this contribution would be emphasized.

2.4 Computing energy requirements

By integrating the power consumption (Eq. (1)), the required energy could be determined; during the cycle, it is possible to determine the maximum, the average, and the required power at each point.

After obtaining energy requirements, another parameter could be also determined, for example, the net energy required on the system during the cycle, the energy required per kilometer traveled, the energy recovered by regenerative brakes during the cycle, and the number of batteries.

A second iteration has to be done considering the new weight of the vehicle with the inclusion of the number of batteries calculated in the initial step. From these results, the real autonomy expected for the driving cycle is determined.

3. Main characteristics of commercial electric vehicles

The commercial electric cars have been designed to operate with NEDC driving cycles in the best geographical environmental conditions, ergo low traffic and without altitude changes (θ angle considered as zero) in order to facilitate comparisons between different vehicle companies.

The electric motors of vehicles have around 60 kW of power. The battery stack installed is about 24kWh. The automotive companies try to give to the consumer at least the same characteristic of performance of a combustion engine car, see **Table 1**.

The marketing of electric cars uses the traditional features of conventional gasoline cars. These accessories allow maximum comfort, such as air conditioning

	Car model	Company	Capacity (kWh)
1	Leaf	Nissan	24
2	iMiEV	Mitsubishi	16
3	E6	BYD	75
4	Tesla model S	Tesla	85
5	Chevrolet spark	GM	21
6	Fiat 500e	Chrysler	24
7	BMW i3	BMW	33
8	Focus	Ford	33

Table 1.
Commercial battery electric vehicles [14–16].

and electric screens for handling; however, in an electric car, this represents an additional spending of energy and bigger weight of the vehicle, so a greater number of batteries are necessary, and the cost of the vehicle substantially augments.

From these facts, Are then all these features necessary? Maybe EVs must be designed differently.

4. Environment conditions in different metropolises

Latin American cities have different conditions compared with cities of Europe or the USA, first of all, the traffic and road conditions, the elevation of a geographic location in cities, and finally the economic and social aspects of populations of these cities.

	Metropolitan Area	Population	Country	GDP (in billions USD)	Altitude Capital (m)	Difference (m)
1	São Paulo	21090792	Brazil	430.5	760	140
2	Mexico City	20892724	Mexico	403.6	2216	300
3	Buenos Aires	13693657	Argentina	315.9	10	74
4	Rio de Janeiro	12280702	Brazil	176.6	19	969
5	Lima	9904727	Peru	176.5	107	868
6	Bogotá	9286225	Colombia	159.9	2619	1141
7	Santiago	6683852	Chile	171.4	521	1783
8	Belo Horizonte	5829923	Brazil	84.7	877	684
9	Caracas	5322310	Venezuela	51.8	909	2506
10	Guadalajara	4796603	Mexico	80.7	1516	887
11	Porto Alegre	4258926	Brazil	62.1	1	301
12	Brasília	4201737	Brazil	141.9	1092	220
13	Fortaleza	3985297	Brazil	35.2	21	80
14	Salvador	3953290	Brazil	38.5	1	116
15	Recife	3914397	Brazil	40.5	1	116
16	Medellín	3777009	Colombia	43.5	1568	1737
17	Santo Domingo	3658648	Dominican Republic		42	145
18	Curitiba	3502804	Brazil	57.7	913	178
19	Campinas	3094181	Brazil	59.3	670	1372
20	Guayaquil	2952159	Ecuador		47	485
21	Puebla–Tlaxcala	2941988	Mexico	38.1	2175	422
22	Cali	2911278	Colombia		758	1209
23	Guatemala City	2749161	Guatemala		1529	866
24	Quito	2653330	Ecuador		2850	2396

Table 2.
Latin American metropolitan areas.

	City	Population	Country	Gross Domestic Product ($BN)	Altitude Difference (m)
1	London	8136000	UK	879.5	142
2	Berlin	3470000	Germany	215.2	71
3	Madrid	2824000	Spain	225.9	148
4	Roma	2649000	Italy	166.8	92
5	Paris	2244000	France	850	160
6	Hamburg	1705000	Germany	120.1	58
7	Barcelona	1455000	Spain	167.8	137
8	Milan	1306000	Italy	214.5	69
9	Munich	1195000	Germany	190	52
10	Birmingham	1021000	UK	81.8	87
11	Stockholm	952058	Sweden	180	105
12	Turin	921000	Italy	76.9	146
13	Frankfurt	717624	Germany	230	61
14	Oslo	634293	Norvege	74	369
15	Helsinki	629512	Finland	90.8	114
16	Copenhagen	583525	Denmark	134.3	53
17	Dublin	527612	Ireland	127.8	101
18	Edinburgh	482005	UK	41.8	112

Table 3.
European cities.

In **Table 2**, main Latin American metropolises are listed in function of their population; also the gross domestic product and the elevation in the cities are shown [17].

As it can be seen in **Table 2**, last column, several Latin American metropolises have considerable elevation differences on the same city; in these cases, the vehicles are confronted to important slopes, where the θ angle is not negligible affecting then the autonomy of electric vehicles.

By the other side, as it can be seen in **Table 2**, the big populations in these metropolises are related with high traffic density, and then, the average speed is lower, and acceleration changes could be important.

Comparing data reported in **Table 2** with European cities as reported in **Table 3** [17], it can immediately be remarked that elevation differences in European cities are lower than Latin American ones, considering the population density is also lower in European cities. The energy requirements are then different for the same category and use of vehicles in European or Latin American countries.

Besides these geographic and social differences shown in **Tables 2** and **3**, another notorious difference is the gross domestic product (GDP) between countries; in general, GDP are lower in Latin American cities.

Therefore, the electric vehicles in Latin American cities must have different characteristics making them more expensive. Then, the overcrowding of EVs in Latin American cities could be farther than European cities for economic factors. Since the EV market is smaller in Latin American cities, the infrastructure to have cleaner electric energy is also poorest.

5. Case study in Mexico City

Mexico City's government through Science and Innovation Development Agency (SECITI) sponsored the development of an electric taxi for the city in order to reduce pollution emissions. The group developing the cab for Mexico City was formed by the companies Moldex, Giant Motors, and the Research Center in Mechatronic Automotive from Tecnológico de Monterrey.

In the frame of this project, during 2016 and 2017, several tests under real driving conditions were running to design a specific electric taxi for Mexico City, taking into account the traffic, slopes, and operation conditions for the main commercial and residential areas.

Table 4 shows some results from these tests. First, it is clear that at a determined cycle, when slopes are not considered, the energy consumption is underestimated of around 16%. Then, the range autonomy will be shorter than that expected if the geographic data is not considered.

The energy consumption was also determined from the study of the same car in a chassis dynamometer under different driving cycles (see **Table 5**). The real driving cycle, shown in **Table 4**, has an energy consumption value similar to that obtained from WLTC 3 (**Table 4**), but concerning parameters as speed average and maximum speed, the values from real driving cycle are nearest to WLTC 2; then the traffic conditions (see **Figure 3**) shape the energy requirements in an important way. Limiting speed (60–100 km/h) allows energy savings of around 32%.

Concerning the energy consumption obtained from NEDC, and reported in **Table 5**, a difference of 17% with WLTC 3 results was founded, indicating that energy consumption is underestimated with NEDC cycles.From **Tables 4** and **5**, it could be perceived that the quantity of batteries, calculated from NEDC driving cycle, is underestimated, 16% caused by slopes and 17% caused by speed and acceleration.

In general, several commercial vehicles have been modeled using the NEDC driving cycle. Its performance would be far away from the published standards of operation.

5.1 Electric energy for electric vehicles

In Mexico, the main electric energy comes from thermal methods, then electric vehicles do not considerably reduce the pollutions caused by fossil fuels, and the emissions are only moved from cars to electric production centers.

From the analyses of electric taxi project in Mexico City, photovoltaic solar panel with battery support was not an economically feasible solution because the initial investment is very expensive; from additional calculations it was found that more than 7 years of daily use of vehicle is necessary to equal the electric cost offered by the

	Speed average (km/h)	**Maximum speed (km/h)**	**Maximum acceleration (m/s^2)**	**Energy consumption (kWh/km)**	**Difference between energy consumption (%)**
Real cycle (reference)	30.57	95.10	2.2	186	
Real cycle without slopes	30.57	95.10	2.2	156	−16%

Table 4.
Real driving conditions.

	Speed average (km/h)	Maximum speed (km/h)	Maximum acceleration (m/s^2)	Energy consumption (kWh/km)	Difference between energy consumption (%)
WLTC 3 without slopes	49.34	139.18	2.38	196	
NEDC (without slope)	32	120	1.04	163	−17%
WLTC 2 without slope	35.69	85.2	1	133	−32%

WLTC 3 was analyzed at maximum speed superior than 100km/h, and WLTC 2 at maximum speeds comprised between 60 and 100km/h.

Table 5.
Driving conditions in a dynamometer.

electric company. The hypothetical electric energy requirements of an important number of EVs (1000 or more) cannot be assured with the actual capacity in Mexico City.

Finally, when the price of electric vehicle for personal use is compared versus engine vehicles, they are three times more expensive.

6. Conclusions

If the automotive companies kept betting on personal EVs for Latin American cities, then those cars would require more energy (between 16 and 33%) than European ones, and therefore they would be more expensive or with a reduced autonomy. In order to adapt the EVs, they would have to be designed to be smaller and lighter.

Therefore, EVs for Latin American metropolis have to follow a different strategy from Europe looking in order to really obtain an environmental purpose.

The following declarations are proposed as recommendations to be implemented in Latin American cities:

First, EV manufactures have to determine the real cycle for these cities in order to keep the ethical use of the vehicle.

Second, the EVs for personal utilization are not suitable at that moment due to the current state of technology. The utility cars and the public transport could represent a better solution to the EV market, and the green effects could be more important.

Third, more efforts in research to enhance energy systems shall be done with an ecological approach instead of the economic motivation.

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Notes

Moldex Company

Moldex is a Mexican company manufacturing electric vehicles for utility purposes (http://moldexmexico.com/en/vehiculos-electricos/).

Giant Motors Company

Giant Motors is a Mexican company assembly light trucks (http://www.fawtrucks.mx/).

Research Center in Automotive Mechatronics (CIMA), Instituto Tecnológico de Monterrey

CIMA is a research center in automotive mechatronics from Tecnológico de Monterrey located in Toluca that focus in forming engineers and applied research for design, manufacturing, and energy issues for automotive industries (http://cima.tol.itesm.mx/).

Author details

Alfredo Santana-Diaz
Instituto Tecnológico de Monterrey, Research Center in Automobile Mechatronics, Toluca, México

*Address all correspondence to: asantana@itesm.mx

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Section 4

Technologies in Wildlife Preservation

Chapter 7

How Technology Can Transform Wildlife Conservation

Xareni P. Pacheco

Abstract

Wildlife is under threat from various kinds of human activities, such as habitat destruction, illegal wildlife trade, spread of invasive species and diseases, and from the human impact on the Earth's climate, which is changing the nature of wild habitats. Advances in technology give conservationists, scientists, and the general public the advantage to better understand the animals, their habitats, and the threats they can face. In this chapter, I provide a review of the benefits of the use of technology to animal ecology and conservation. Two major approaches are being recognized to conserve threatened and endangered wildlife species. The first encompasses protecting the species within their habitat, and the second involves breeding and caring individual species ex situ. The use of technological applications in captivity, such as satellite imaging and assisted breeding technologies, is focused to enhance animal welfare and to influence zoo visitors' awareness of conservation-related behavior. Given the increasing demands on protecting wildlife, it seems a fair time for us to pause and ask what could be the best way to use technological innovations and to stimulate a closer collaboration among conservation practitioners, animal behaviorists, biologists, computer and system scientists, and engineers, to mention but a few.

Keywords: technology, animal conservation, animal tracking, interactive technology, animal welfare

1. Introduction

The earth is gifted with an enormous diversity of natural ecosystems comprising a vast range of wild flora and faunal species. Nonetheless, global environmental changes such as climate change, deforestation, desertification, and land use impact negatively on plant and animal life. In the present day, the animal world is under severe attack; more than 1210 species of mammals, 1469 of birds, 2100 reptilians, and 2385 species of fish are threatened [1]. Activities such as illegal wildlife trade, spread of invasive species and diseases, and the human impact on the Earth's climate is changing the nature of wild habitats. On account of this, various conservation strategies, initiatives, and technological solutions have been at the lead during the past couple of decades [2]. Two distinct approaches to the protection of wild species are considered, in situ and ex situ conservation. The Convention on Biological Diversity (CBD) defines *in situ conservation* as "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings," and *ex situ conservation* as "the conservation of components of biological diversity outside their natural habitats" [3]. Available technological solutions have eased, in practical terms, the demanding task of traditional means to study animals in their natural habitats.

Habitat preservation (*in situ* conservation), in an ideal world, should always be the highest priority and the most important single approach to protect entire ecosystems and many species simultaneously; however, the constant threat to habitat and wildlife populations and their potential annihilation makes their conservation especially challenging [4]. Although the *ex situ* conservation of wildlife species is never preferred over supporting natural places, the importance of zoos' conservation role has grown greatly over the past three decades [5]. Its role involves research that enhances the science and practice of conservation, field conservation projects, and supporting and engaging with conservation of animals in their natural habitats [5]. A modern zoo should strategically integrate both ex situ and in situ conservation [5]. Simultaneously, zoological parks and aquaria have radically increased efforts to improve animal welfare, through increasing understanding of animal cognition and behavior, where a variety of technological applications is currently being used with the same principles [6]. Technological innovations are also being used to promote conservation education. Zoos are in a special position to educate the public as they receive millions of visitors annually and can become a critical player in global conservation efforts.

This chapter reviews only some of the technology currently available for conservation. This review focuses primarily on tools that can be applied in both conservation approaches; the goal is to highlight how technology can offer insight into species conservation and how the evolution of technology can bring people of different research fields to work together and achieve lasting conservation solutions.

2. Technology-based wildlife in situ conservation

2.1 Bio-logging and bio-telemetry

Bio-logging and bio-telemetry have different forms of collecting information, but both comprise the monitoring of physiological, behavioral, or environmental information of organisms that are difficult to observe or often otherwise unattainable [7, 8]. Bio-logging technology records and stores the information in an animal-borne device (archival logger), and the information is downloaded once the logger is retrieved, unlike the bio-telemetry technology, which sends the information to a receiver that is emanated from the device carried by the animal [8]. For instance, Block states that the integration of environmental data with animal collected data has been simpler with the use of emerging electronic tagging and the remote sensing satellites, which provide a more precise and rapid environment sampling and higher resolutions of global views. New approaches using both technologies are changing the capacity to conduct ecosystem-scale science and to improve the capacity of scientists to explore unanswered ecological questions [9].

The technology of Global Positioning System (GPS) allows scientists to obtain precise movement patterns of an animal through GPS telemetry where the animal location and its distance to survey sites can be quantified [10]. Such technology has helped to identify, for example, the use of unpredicted habitats [11], to explore the social dynamics of reintroduced species [12], and to reveal unfamiliar life history characteristics of threatened species [13]. Animal-borne technology (referred to as animal-borne video and environmental data collection systems—AVEDs) gathers high-resolution datasets that can measure the animals' physiology, behavior, demographics, community interactions, and the environment animal inhabits [14]. A vast variety of these sensor types to collect data on wild animals' internal and external states have been packaged into lightweight units [14]. For example, in birds, lightweight geolocators or satellite transmitters have allowed practical reconstruction of the migratory routes and wintering areas for large and small birds, which can give opportunities to test predictions about migration strategies [15]. Animal-borne devices are also advantageous for testing hypothesis about drivers of habitat use. For example, a study on southern elephant seal (*Mirounga leonina*; [16]) in the Southern Ocean, which looked at the geographic distribution of core foraging areas and behavior and assessed the relative quality of the habitats regionally, demonstrates clear advantages of using satellite tracking systems and their assistance to understand more about the animal's response to varying environmental conditions and population viability. This information is vital for developing conservation-oriented management actions.

2.2 Camera traps

Camera traps are remote devices equipped with a motion or infrared sensor that automatically record images or videos [17]. They have become an important wildlife research tool; the decreasing cost gives researchers additional opportunities to monitor and reach a larger number of wildlife populations. Traditional approaches, such as visual, capture and trapping methods, can be labor-intensive and can require hundreds or thousands of person hours; whereas, camera traps can multiply the number of observers and make them more cost efficient [18]. The use of this technology has increased to address questions of species' distribution, activity patterns, population densities [19, 18], and among other questions.

Camera traps offer a practical approach to answer many questions about wildlife besides the density or estimation of animal populations. Behavioral studies using camera traps, such as the first ever done by Gysel and Davis (1956) where they essentially described a simple system to photograph wildlife, help us understand how different species use their habitat [20]. For instance, Bauer et al. [21] examined scavenging behavior of puma in California through camera traps and telemetry. While puma are known to be opportunistic predators, their results indicated that pumas are also opportunistic scavengers. A more recent study in chimpanzees (*Pan troglodytes*; [22]) examined community demographic changes (births, deaths, emigrations, immigrations) and community composition (age/sex structure). The authors found that camera traps allowed for a practically accurate approximation of demographic composition and variation within and among social groups. They also highlight that such technology may provide more accurate and precise measures of fine-scale group abundance.

2.3 Additional technologies

The emerging technology of synthetic biology is rapidly expanding and currently applied to conservation. This field is capable of editing natural genomes in an extremely precise manner, through deleting a target gene and/or inserting a synthetic one (CRISPR/Cas9 technology), which can bring the efficacy of genetic modification to a new level [23]. Some examples of the main conservation problems with possible solutions through the application of synthetic biology are as follows: (a) habitat conversion by creating or modifying microorganisms that consume hydrocarbons in order to clean up oil spoils [24] or by using systems to produce man-made palm oil and so reducing tropical forest alteration [25]; (b) overexploitation, where production of materials that can substitute rhino horn ivory or deep sea shark squalene [26]; and (c) invasive species, where the use of chromosome alterations and gene drives to stop reproduction in these species. The latter is yet associated with esthetic, moral, and ethical issues in which Piaggio and colleagues [23] call for a robust decision-making and a risk-assessment framework in the application of synthetic biology to conservation concerns.

Track plates offer a further efficient method to detect wildlife, and they have been used in an array of ways to monitor several animal species. Originally, track plates were developed to monitor rodents' abundance, and were subsequently adapted for use with carnivores [27]. Back in the 1980s, such tools commonly comprised an aluminum plate in a plywood box, and usually, a bait was placed near the back of the box. The negative track impressions were created after the underlying plate surface was revealed, when the animal's foot removed soot [27]. Other tracks of mammals were and are created by using, for instance, smoked kymograph paper [28] sand, ink-coated tiles [29], mineral oil mixture and carbon black [30], or contact paper and dispersed printer toner [31]. Track plates are considered economical and reliable devices that can provide robust measurements of animals' abundance. For example, Connors et al. [32] used track plates to measure abundance and local predation risk created by white-footed mouse (*Peromyscus leucopus*) foraging activity, and they conclude that such devices were a trustworthy means of quantifying local risk of attack by terrestrial mammals without significantly modifying the spatial distribution of risk. A more recent study by Smith et al. [33] confirms that a well-designed trap to enclose the track plate can be fairly inexpensive, nonintrusive, and an easy monitoring tool. They specifically looked at whether breeding phenology of a generalist predator was associated with human responses to climate change. For this, they assessed seasonal abundance of small mammals using presence/abundance data collected from track plates, along with motion-activated trail cameras to obtain visual corroboration of the identity of small mammals visiting traps.

Environmental conditions can be diverse as a result of new extremes temperature and precipitation patterns and novel assemblages and interaction species due to the human-assisted spread of exotic species [34]. In light of this, Wood et al. [34] state that such environmental changes call for conservation to become more predictive. The development of technology which helps to predict key conservation outcomes including animals' distribution, their demographic and physiological states, and their interactions between individuals and species is urgently needed. A study on Canada lynx (*Lynx canadensis*; [35]) assessed behavioral differences with changing environmental conditions by developing a multiscale prediction model of lynx distribution and found within their results that individuals tend to use more mature, spruce-fir forests than any other structure stage or species. The authors, through the insights gleaned from their approach, state that understanding and predicting habitat use is essential in conservation management, particularly for species that are threatened or endangered.

3. Technology-based wildlife ex situ conservation

The International Union for the Conservation of Nature states that ex situ collections include "whole plant or animal collections, zoological parks and botanic gardens, wildlife research facilities, and germplasm collections of wild and domesticated taxa" [36].

The world is facing an alarming loss of biodiversity, where inflation of extinction rates is mainly driven by human actions [37]. Zoos and aquariums have taken different conservation actions to mitigate threats to species and their extinction in the wild. They have contributed to the genuine improvement in IUCN Red List status of species through captive breeding and reintroduction conservation measures [38]; however, their contribution to conservation of species goes further than that.

3.1 Digital technology

The use of technology in educational settings, such as guidebooks and handled computer tour guides in museums or tourist destinations, is becoming more common nowadays. Zoological parks and aquaria institutions have long used technology to promote conservation education. The increase of digital technologies use offers the public a more meaningful animal encounter, while building a higher interest in educational activities, conservation campaigns and in conservation itself [39]. Interactive computers at exhibits show short movies and information about a particular specie, influencing visitors' awareness of conservation issues and conservation-related behavior [6]. Some institutions allow and invite visitors to take immediate conservation action on an issue of their choice by directly contributing money [6].

Live web cameras operated by zoos display videos of the animals at the zoo on websites, which are available to the general public. For example, the Dublin Zoo has live webcams to see live footage of the animals from wolves, penguins, elephants, and from the African Savanna area. This technology explicitly seeks to motivate conservation awareness through appealing experiences, which bring animals and humans together.

Further applications of technology in captive environments, such as animal behavior and animal conservation, have the objective to increase animal welfare and to benefit scientific research on many areas. For instance, animal cognition research, which benefits significantly from the use of technology, can be an effective way to evaluate the mood, behavior, and welfare of zoo-housed animals [40]. In a recent study [41], researchers measured anxiety responses to noisy, unpredictable, and repeated events on simple cognitive tasks in three different primate species: chimpanzees, *Pan troglodytes*, Japanese macaques, *Macaca fuscata*, and western lowland gorillas, *Gorilla gorilla gorilla*. This kind of investigation of the animals' subjective or affective experience is important to understand about the animal's state of wellbeing, which can be important to their survival and reproduction [41]. Another application in welfare research is to provide the captive animals with more control over their environmental enrichment and surroundings. Control of environmental elements, such as access to outdoor areas or to privacy, temperature, sounds, and with nontechnological objects can be one of the keys to improving their welfare [42, 43].

3.2 Technology devices

The use of animal-attached technology by researchers in zoos has increased remarkably over the last 10 years. Welfare and behavioral scientists can monitor movement patterns, locomotor activity, track use of space, health issues, postural behaviors, and a range of behaviors indicative of positive welfare and so understand a bit more the animal's view of its social and physical environment [44].

Devices such as GPS are applied in zoos to examine questions about patterns of movement, activity levels, or habitat use. This technology has also been used in assessing relationships among animals. A study on African elephants [45] collected GPS coordinates to calculate the average distances between individuals with the aim of determining the social structure of individuals to potentially improve management in determining appropriate group setting to ensure the individual and group well-being.

Accelerometers are also used in zoo animals to regularly monitor baseline patterns of behavior and to detect signs of discomfort or disease.

Knowledge of an animal's behavior through these kinds of devices on captive animals can inform and contribute to the species management and conservation. Researchers illustrate [46, 47] the value of collecting data from captive individuals. For instance, technological devices are commonly calibrated in captive animals before using them in wild counterparts, this involves time-synchronizing behavioral observations with the associated device readings [47].

4. Conclusion

The use of technology in conservation should be seen as force that can transform the work of researchers from across all fields interested in the protection of species. There is a serious need to understand the efficacy of both in situ and ex situ approaches to maximize their value for studying remaining populations. Furthermore, collaborations between ex situ and in situ communities can equally provide useful information, and for that reason, both approaches should be complementary rather than discordant.

Author details

Xareni P. Pacheco
Centre for Research in Applied Biological Sciences (CICBA), Autonomous University of the State of Mexico, Mexico

*Address all correspondence to: mxpachecop@uaemex.mx

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The aim of this book is to compile some of the green technologies applied to improve the environment on Earth. The success of these technologies is built from humility; from this ethical principle, the concept of honest broker is defined in this work. Some of the biggest environmental problems, such as soil pollution by heavy metals and pollution from the mining industry and massive coal plants, are also addressed. Additional subjects depicted here include geothermal energy, plasma technology, and the correct use of electric vehicles, and demonstrate a promising scenario to diminish greenhouse gases.Likewise, caring for wildlife is essential; the correct use of certain technologies depicted here can contribute to their conservation.

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