CAETS ENERGY REPORT 2022

TOWARDS LOW-GHG EMISSIONS FROM ENERGY USE IN SELECTED SECTORS

CAETS
International Council of Academies of Engineering & Technological Sciences

TABLE OF CONTENTS

Annexes

The Annexes to this report will be accessible in a separate publication. They contain information by country at the national level and/or, for some countries, on the sectors studied in the report, based on replies to a questionnaire. The information at the national level is in most cases based on the data of the International Energy Agency, completed by local data and comments prepared by the members of the Academy and/or by their members participating in the preparation of the report.

ACKNOWLEDGEMENTS

This report was written by the members of the Energy Committee 2021-2022 and prepared by Yves Bamberger (Academician) supported by Dr. Wolf Gehrisch and Dr. Gaël-Georges Moullec of the National Academy of Technologies of France. Contributing authors where of great help in providing, beyond their engineering expertise, country-specific input for comparative analysis and publication.

This report has been produced with the financial assistance of the National Academy of Technologies of France, the National Academy of Engineering of the United States and CAETS. The views expressed herein can in no way be taken to reflect the official opinion of France and do not necessarily reflect the views of any CAETS member Academies.

This paper was discussed by the International Council of Academies of Engineering and Technological Sciences (CAETS) which agreed to submit the report to international journals and policymakers worldwide. The authors are grateful to the delegates for their input, comments, and suggestions. Any errors or omissions are the sole responsibility of the authors.

Publisher: CAETS

District of Columbia, USA

E.I.N. 52-2251297

An IRS Section 501(c)(3) organization

Web : http://www.newcaets.org

This report was endorsed by the following CAETS Member Academies:

Academia National de Ingenieria of Argentina
Australian Academy of Technology and Engineering
Royal Belgian Academy Council of Applied Sciences
Canadian Academy of Engineering
Chinese Academy of Engineering
Croatian Academy of Engineering
Engineering Academy of the Czech Republic
Danish Academy of Technical Sciences
Council of Finnish Academies
National Academy of Technologies of France
National Academy of Science and Engineering of Germany
Hungarian Academy of Engineering
Indian National Academy of Engineering
Irish Academy of Engineering
Engineering Academy of Japan
National Academy of Engineering of Korea
Academy of Engineering of Mexico
Netherlands Academy of Technology and Innovation
Royal Society Te Aparangi of New Zealand
Nigerian Academy of Engineering
Norwegian Academy of Technological Sciences
Pakistan Academy of Engineering
Academy of Engineering Sciences of Serbia
Slovenian Academy of Engineering
South African Academy of Engineering
Real Academia de Ingenieria of Spain
Royal Swedish Academy of Engineering Sciences
Swiss Academy of Engineering Sciences
National Academy of Engineering of the United States
National Academy of Engineering of Uruguay

EXECUTIVE SUMMARY

Table of Contents

Introduction

The Energy Committee of the International Council of Academies of Engineering and Technological Sciences (CAETS) has been tasked with reviewing existing technologies which can be used immediately to reduce greenhouse gas (GHG) emissions in seven key sectors: Food and Agriculture, Buildings and Smart Cities, Oil and Gas, Chemicals, Cement, Iron and Steel, Information and Communication technologies. Some of our conclusions could apply as well to other sectors like aluminium.

The deployment of these technologies would lead to deep emission reduction before 2040 which explains why the primary time frame of the report is 2020-2040. However, these technologies are not sufficient to meet net zero targets by mid-century. Therefore, the report also highlights research and development needs for new or improved technologies and demonstrations for the near ready technologies (RD&D).

While many cost-effective GHG mitigating technologies exist, the GHG emissions are still growing in many countries and worldwide. Indeed, many obstacles remain. The purpose of this report is not to analyse all of them. Undeniably, social and economic issues are critical to the global implementation of the Paris COP21 Agreement and subsequent COP meetings. These issues include: the impacts of world population growth, improvements to the quality of life in developing countries and regions, choices made by political and industrial leaders, etc., and they are important aspects. However, they are not within the scope of this report which is technical and it is meant to highlight technologies suitable for lowering GHG emissions, their advantages and limitations, and describe the technical, economic and cultural barriers that may exist.

The Report offers insights; conclusions and recommendations that should be useful for leaders of industry, governments, professional organisations (especially engineering organisations), non-governmental organisations, and citizens. The report is intended to provide clarity on the complex issues of our subject: what is possible for the next 20 years, where are the difficulties in the different sectors and how to overcome them.

Who prepared this report and how?

The CAETS (International Council of Academies of Engineering and Technological Sciences) Member Academies have three main characteristics: (1) their members are drawn from most sectors of activity, mainly from industry and academia; (2) they are collectively independent and neutral, without *a priori* advocating for any technology or sector; (3) their reports are evidence-based and resulting from exchanges based on facts and on their diversity of experience. Indeed, CAETS, with its different Member Academies from various countries, reflects this diversity. They are allowing an international approach illustrated by the numerous case studies and examples reproduced in this report prepared by more than 60 fellows and some external experts of more than 20 countries.

Given the time (15 months) and the resources available for the preparation of this report, we have looked for sectors with substantial emission levels and where the diversity of our active members could make the greatest contribution. In 2019, the seven sectors selected accounted for 73% of industry's CO_2 emissions (see Chapter 0, *Fig. 0.2.*) and around 60% of worldwide methane emissions. We did not select electricity generation as this topic was already largely covered by previous reports, neither the transport sector which could be an entire future study by its own.

In this report, each of the above sectors is the subject of a dedicated chapter prepared by a subgroup of the Committee and discussed by the Committee. Each chapter was reviewed by external and internal reviewers. The chapters do not claim to be exhaustive but present the main elements, as seen by the participants, and are accompanied with examples taken from different countries. During our meetings, held remotely via teleconferencing, key messages and recommendations emerged from our often-lively discussions. They are not necessarily original or new but should, nevertheless, be most useful to implement!

Chapter 0: To set the scene

This chapter contains messages that are broadly applicable to all sectors. It presents the central role of low-carbon electricity in achieving emission reductions in the sectors considered. Electricity and heat are defined as low-carbon if they are produced with an average CO_2 content of less than 50 g per kWh over the life cycle of the installation. Low-carbon electricity is therefore mainly[1] produced by hydro, solar, wind and nuclear power.

As the different chapters of the report show, reducing GHG emissions, especially CO_2, is in many cases achieved through the electrification of all or part of the energy used, whether for home heating and cooking or for industrial processes. The level of such reduction depends on the electricity mix, which shows the importance of decarbonising the production of electricity. Such an approach should not overlook low-carbon heat, including the direct thermal use of solar radiation, nor heat networks using low-carbon sources (e.g. waste, biomass) or waste heat from industry. Finally, it is shown that some industrial processes cannot be fully electrified, like cement production. The use of hydrogen – if it is produced with low-carbon electricity - may be part of the solution, but has to be produced at an affordable cost.

Another approach is to capture the CO_2 which is produced on industrial sites and to use it or to store it underground (Carbon Capture Utilisation and Storage, CCUS). Some industrial pilot projects are already in operation. The system used for the capture has to be adapted to the industrial process in question such as burning coal to produce electricity or iron, heating the required materials to prepare cement. Many demonstration and pilot projects are currently operating and planned worldwide. The solutions for the use of CO_2 seem to be very limited, whereas for storage they are already technically significant. The added costs and the societal aspects are real concerns, but the use of Carbon capture and storage (CCS) will certainly be needed to reach “net-zero” by the middle of the century.

Improvements in energy efficiency are about using less energy to heat, to move, to deform, to break, to transform, etc… This is almost always beneficial, although global rebound effects may reduce or annihilate the achieved GHG reduction. However, improving the efficiency of a system using fossil fuels can be more expensive and lead to higher emissions than replacing the system by another using low-carbon electricity. In other words, putting energy efficiency first is not synonymous with putting low emissions first: this is one of the key messages of this initial chapter. It illustrates the importance of using the right indicators when defining energy policies.

Another key message of this introductory chapter is the need for comprehensive and consistent policies to be enacted faster and implemented at lower cost. Examples include promoting the replacement of gas boilers with electric heat pumps in homes. Heat pumps should be available where needed, in sufficient quantities and at acceptable costs, installers should be qualified and widely available, and an economic model (which would include acquisition costs, operating costs, possible investment aids, etc.) linked to electricity tariffication should be proposed. Building regulations should be adapted, and appropriate public information campaigns should be developed. For a policy concerning new housing, it is also necessary to foresee training for architects, engineers, design officers and real-estate promoters. Such global programmes, involving millions of actors and stakeholders, require clear, understandable and stable policies for widespread implementation.

This highlights the problem of rapidly reducing emissions while time frames differ, as the lifespans of different technology systems vary significantly. For example, the typical time frame for changing a mobile phone is about 2 to 3 years, while it could be 15 years for a boiler, 30 to 100 years or more for a building, and 20 to 50 years for many factories. Comprehensive Life Cycle Assessment (LCA) helps to evaluate such questions as whether extending the lifespan of an existing appliance vs. replacing the appliance as soon as possible with another that emits less can reduce total emissions.

[1] Biomass is the subject of divergent opinions within the Committee, because of the emissions it produces when burned. Another issue, controversial and outside the scope of this report, is its other possible uses for food, biofuel and consequent competition for land use

This introductory chapter also addresses the rebound effect, recycling, the role of information and communications technologies, and education and training, which play a key part in the development of all areas of human activity. Lastly, this chapter is complemented by an Appendix on three strong levers for reducing emissions: heat pumps, which are not yet widely known; life cycle analyses, which are not used adequately; and hydrogen, whose potential is often either underestimated or overestimated.

Chapter 1: Food and agriculture systems (FAS)

This chapter describes how the FAS has gone through deep transformations to feed the world, which has generated sustainability concerns that call again for a profound transformation acknowledging climate change, conflicts, disruptions, and wars that globally impact the FAS. Since the FAS is responsible for 25 to 33% of the GHG emissions (depending on the definition), reduction of its GHG emissions is an essential element of the FAS transformation but is not the only one; it implies trade-offs among diverging sustainability objectives and across the various scales of time and space and calls for strengthening the capacity to address such trade-offs through evidence and arbitration mechanisms.

Science and technology have been key in generating the past transformation of food systems and will remain so. Yet innovation does not always contribute to sustainable development! At the same time, in many countries, there is currently a call for significantly reducing the consumption of animal-based foods, especially from the younger generation, for a healthier diet with less meat. There remains much controversy, for example regarding the mobilisation of disruptive technologies (such as alternative protein foods, 3D-printed foods, aquaculture / aquaponic systems, and advanced greenhouses including vertical farms) because of entrenched long-standing traditional local practices, on the one hand, and concerns about increasing concentration in an industrialised agri-food sector, on the other hand.

The chapter describes avenues for reducing the emissions of two important GHGs produced by the FAS: methane from ruminant livestock and from rice cultivation, and CO_2 along the supply chain from farm to fork especially through energy efficiency and electrification. The chapter insists on the importance of assessing the potential contribution of each specific technology taking into account the local, ecological, economic, and social contexts and the way technology may be applied in practice. Some examples are developed to illustrate this need: ‘digital agriculture’, which involves advanced sensors, artificial intelligence, data integration, big data, drones, robots, and tracking technologies.

The potential role of biotechnology and nanotechnology to reduce GHG emissions in the FAS, the co-location of solar photovoltaic (‘agrivoltaic’) and wind turbines with agricultural activities, and the use of biomass for energy production, are also described. A strong recommendation is made to only use bioenergy in situations where it does not compete with food production.

The chapter suggests developing an enlarged database on and analysis of the different technologies and their local uses. It insists on the necessity to develop strong investment in research and expertise, not only for the development of technologies but, also, as is the case in other sectors, but especially for FAS, for their adaptation to local contexts in order to achieve real improvements and for the assessment of their footprint. Finally, the FAS as a system of systems requires the design and acceptance of an array of different approaches, valuing scientific evidence as much as possible.

Chapter 2: Buildings and smart cities

Like the previous chapter on the FAS, this chapter deals with a high emitting sector (some 37% of the world CO_2 emissions in 2019), where the local conditions are very important. Decarbonisation addresses residential and non-residential buildings, including the construction and operation of new buildings and the operation of existing buildings. Because of their lifespan, the retrofitting of existing buildings plays a major role. Besides the energetic quality of the building envelope and the equipment used, occupant behaviour has a major influence on energy consumption.

To design low-carbon, low-energy buildings, the Committee recommends an energy hierarchy principle: first, choose low-carbon materials and energy sources and second, apply the most efficient equipment (taking into account their affordability). Applying this principle to retrofitting in order to reduce the emissions in the most affordable way requires evaluating the right level of insulation and the implementation of a low-carbon heating system.

Photovoltaic (PV) or solar thermal panels are more and more often installed. For buildings where the auto-generation of energy is not an option or insufficient, as it is generally the case in cities, electrification using low-carbon electricity from the grid remains the most efficient decarbonisation solution. This applies in particular to the 4 basic energy-consuming needs: heating, cooling, heating water and cooking. For each, the chapter recommends solutions.

Two important points should be mentioned here: (a) the increasing importance of cooling since more than half of the global population lives in countries that require space cooling and because climate change is increasing the need for cooling; (b) today, in many emerging countries, biomass burning in low efficient and dangerous cooking stoves is still in use and needs to be replaced by more efficient appliances.

Increasing electrification prompts the question of flexibility in electricity consumption, which refers to its ability to be interruptible and adjustable, e.g. shifting the use of a water heater or a washing machine to times when there is much (or cheap) electricity, for example in the middle of a sunny day when photovoltaic is generating lots of electricity. The flexibility in the consumption will have an increasing role in regard to the insertion of intermittent renewables.

Another aspect is the decarbonisation of urban energy supply systems, including not only the district heating systems but also, and increasingly so, the district cooling systems. The permanent difficulty to equate the need for heat and its production suggests developing inter-seasonal heat storage, an option not much used today. This leads to a brief presentation on smart cities – principally on the energy needs of buildings. We do not discuss other aspects of smart cities, like overall energy management, transport, water supply, and health care.

The path to a sustainable stock of buildings must be facilitated by an integrated policy package adapted to local conditions. Furthermore, additional efforts in education and training are needed. Case studies are presented, one on the decarbonisation of a slum in Buenos Aires and two on district heating networks in China.

Chapter 3: Oil and gas

This chapter reminds us first that the world still heavily relies on fossil fuels. In 2019, fossil energy sources provided more than 84% of global primary energy demand, and oil and natural gas account for more than 57% of the world's total. The use of crude oil and natural gas has been increasing worldwide, especially in less developed countries, and will likely continue doing so in the near- to medium-term future which is the focus of this report. Regardless of future needs for oil and gas for energy purposes, non-energy uses, especially for the chemical industry, will probably increase.

For this reason, it is important to examine whether the oil and gas industry can reduce its GHG emissions in all phases of oil and gas production, transport, refining, and distribution. In 2019, while 76% of the emissions from oil and gas was produced by their consumption by end users, 24% resulted from oil and gas industry processes. This 24% represented around 8% of the worldwide GHG emissions, i.e. about 2.65 $GtCO_2$ and around 2.5 $GtCO_{2e}$ from methane (CH_4).

The current cumulative investments in the oil and gas industry amount to trillions of dollars and facilities have life spans of decades. Most of these facilities tend to be highly optimised for the types of oil and gas they receive and the products their markets require. This makes it challenging to apply major changes on a global scale and at a rapid pace. Nevertheless, the future oil and gas industry will be significantly different from the present one.

The Committee recommends a strong emphasis on reducing the flaring of methane and fugitive methane emissions in all phases of oil and gas production, transport, and refining/processing. Technologies to abate methane emissions/leaks are available and many are already cost-effective. The IEA estimates that 45% of emissions can be abated at no cost under 2021 gas prices.

The oil and gas industry uses oil and gas as energy sources for its own needs, in particular, to produce heat. The Committee recommends exploring the increased electrification of the oil and gas industry to substitute for the direct heating and cooling of process streams. To achieve this, operators of oil and gas facilities should consider switching to electric options where feasible and where they are likely to have a positive impact on lowering GHG emissions. Furthermore, it is suggested to explore additional steps to lower CO_2 emissions from the exploration and production sectors through the reduction of flaring and the implementation of efficiency improvement and new technologies.

The chapter also highlights two other important points: 1) the need for greater emphasis on using and improving LCAs (Life Cycle Assessment models) in the oil and gas industries, and 2) the continuous evaluation and development of the potential of CCUS opportunities for oil and gas operations.

Chapter 4: Chemicals

The chapter first emphasises that most of the existing thousands of chemical products are manufactured with 'primary' chemicals obtained by using (and not by combusting) feedstock produced by the oil and gas industry. The chapter is focused on the analysis of GHG emissions resulting from the production of the four highest-tonnage primary products (ethylene, propylene, ammonia and methanol), acknowledging that additional emissions result from their derived products.

As the production of these chemicals entails specifically high energy requirements, the chemical sector was responsible in 2019 for 15% of the total GHG emissions (8.4 $GtCO_2$) of the overall industrial sector. With 5% of this total, ammonia is the largest contributor of all chemicals. Over the next 20 to 30 years, economic and population growth will continue pulling demand, as for the last 20 years. As a result, it is imperative to reduce the GHG emissions in the sector. It is important to keep in mind that such emissions may result not only from the energy source used for the production processes but also from the chemical reactions themselves.

As a particularly complex, integrated, capital- and skills-intensive industry, with many long-lasting assets, the chemical sector faces enormous challenges in the transition to net zero carbon. There is no single or simple solution available today to decarbonise the chemical industry, but there are nevertheless important avenues that can guide the industry immediately towards its decarbonisation goals. Among those avenues, the Committee recommends the reuse of products (mainly plastics), the recycling of other carbon-based materials, and the reduction in the specific consumption of nitrogenous fertilisers by increasing application efficiency.

Further recommended actions include the electrification of process heating with low-carbon electricity, in particular in steam cracking, to replace coal and natural gas, which are currently used. Moreover, it is recommended to modify the chemical processes in order to substantially reduce the emissions, if not completely – by increasing, for example, the use of ethane in the production of ethylene, or replacing coal with natural gas in the production of methanol. Concerning ammonia synthesis, which is using hydrogen, the recommendation is to develop large-scale low-carbon hydrogen production via electrolysis using low-carbon electricity; alternatively, if hydrogen is produced from fossil fuels, it has to be with CCUS. CCUS will be required not only for the production of hydrogen but also for other chemicals-producing facilities to meet the 2050 decarbonisation objectives.

Due to the chemical industry's many connections with the entire economy, from its raw materials to its products, it is recommended to systematically use Life Cycle Analysis for the chemical products at global levels.

Chapter 5: Cement

Cement is widely used in the construction sector (buildings, bridges, dams, etc.). In itself, its production is a highly energy-intensive process and by far the most CO_2 emitting phase of the cement industry, from raw materials to ready-to-use construction materials, such as for example concrete. For this reason, the chapter on cement is focused on its production.

As a first step, the chapter presents the general correlation between GDP growth and cement demand in different countries and concludes that demand growth will be mostly driven by developing countries. This will apply in particular in areas such as infrastructure and real estate. In 2019, the worldwide cement industry was responsible for around 7% of global carbon emissions (some 2.5 $GtCO_2$). It is thus one of the largest CO_2-emitting sectors. Its decarbonisation is therefore crucial.

Cement is a versatile and durable material mostly produced with readily-available local resources such as limestone, clay and marl. Around 50% of the CO_2 emissions from cement production are due to calcination, the chemical reaction liberating CO_2 from limestone and producing the 'clinker', the base of cement. Around 40% of the emissions are due to the burning of fossil fuels used to reach the 1 450°C required by the calcination to take place.

Worldwide, coal represents 70% of the emissions of the fossil fuels used for calcination, which is the central and most energy-demanding process. Alternative fuels such as carbon-containing industrial wastes or biofuels can be used and are described. The use of low-carbon hydrogen, if available, is also advocated. Furthermore, it is recommended to increase energy efficiency and proceed with electrification where possible, as well as to increase heat recovery, which is not yet widespread.

Modifying the composition of the basic raw materials, replacing for example some limestone with fly ash etc., can reduce CO_2 emissions. This may modify the properties of the resulting cement, positively or negatively, allowing the development of new types of cement for different purposes. Notwithstanding, this will not entirely solve the CO_2 emission problem. Therefore, CCUS will be needed, although this is still not a completely proven technology for cement and will increase the cost of cement.

Existing solutions and policies for cement production in different countries are described and completed by five case studies from India, Norway, Belgium, Canada and China. Clear, stable, and holistic public policies, as well as incentives promoting a reduction in CO_2 emissions, are recommended. The large-scale deployment of already mature solutions is encouraged. The Committee urges close cooperation between the cement and other industries to benefit from the use of different wastes, non-recycled elements, granulated slag from steel blast furnaces, etc. either as fuel substitutes or alternative raw materials.

The Committee stresses the importance of R&D efforts to further reduce the GHG footprint of cement making and encourages the development and industrial demonstration of related technologies. Exploration in the area of CCUS and CO_2 mineralisation in some rock formations, in order to obtain affordable ways to reach deep decarbonisation, is also encouraged.

Chapter 6: Iron and steel

Like for cement, the demand for steel is expected to increase as the global population grows and nations around the world seek to improve their standards of living: steel is a necessary and difficult to replace material in a wide range of applications.

The chemical reduction of iron ore requires much energy. Thus, the production of steel, which is iron with no more than 2% carbon and some additives to adjust its properties, is by nature energy intensive. The first step of the process, which needs the most energy, is to obtain iron from iron oxide, the second is to transform iron into steel. When using scrap as the feedstock, the first step is not needed: this shows the merit of recycling!

Coal is the dominant energy source in the most frequent production processes, the 'BF-BOF' (Blast Furnace / Basic Oxygen Furnace) route, which, in 2020 provided 73% of worldwide steel production. A second used route is the 'EAF' (Electric Arc Furnace) route, employing both scrap and/or Direct Reduced Iron (DRI) using gas. The EAF route, using electricity, represents 26% of the worldwide steel production. As a consequence, in 2020, the emissions from the steel industry were of the order of 2.6 Gt of CO_2, representing around 8% of global anthropogenic CO_2 emissions.

Considering the urgency of the reduction of CO_2 emissions and the lifetime of many existing facilities, the Committee recommends implementing every possible and economically affordable, even marginal, reduction of CO_2 emissions for existing steel plants by increasing energy efficiency, utilisation of residual energies, partial electrification for heating, use of biomass, better control, etc.

To eliminate CO_2 from the process, although there is no single final scenario, direct reduction of iron ore (DRI) using low-carbon hydrogen, followed by Electric Arc Furnace (EAF), seems to be one of the most viable options and a long-term solution to achieving carbon-neutral steel production. Various processes are under development and at pilot scale: their economic viability will certainly be proven before 2030. The availability and cost of such low-carbon hydrogen and low-carbon electricity will be key for the massive implementation of these processes.

The chapter contains case studies describing pilot projects from different countries (and steelmakers) including China, Korea, Japan, Sweden, Finland, the United States of America, France, and Germany.

It is worth mentioning that CCS in combination with steel production has not yet been proven on an industrial scale. This could change during this decade with several projects at different stages of implementation in different countries.

Needing less energy to produce 'new' steel, the utilisation of ferrous scrap is expected to gradually increase. The Committee recommends continuing to expand the use of steel scrap, even if there will not be enough scrap available to replace iron ore. It could be facilitated through the adoption of common rules and specifications but also the development and implementation of new scrap processing technologies to improve impurity removal.

Steel production has the potential of becoming low-carbon in the future. Nevertheless, as the chapter concludes, many challenges remain: the scale and efficiency, availability of low-carbon hydrogen and electricity, investment needs, stranded assets and return of capital, approvals from regulators and policymakers, skill shortages, etc. The Committee recommends incentivising pilot projects, simplifying and accelerating permitting procedures, and ensuring competition while sharing experiences.

Chapter 7: Information and Communications Technology (ICT)

The chapter first describes the current situation in this industry sector. On the one hand, ICT is increasingly ubiquitous, consumes more and more energy and induces more and more emissions. On the other hand, ICT contributes to human development and many other activities while, in some cases, reducing energy consumption and GHG emission in other domains. One striking example, witnessed during the COVID-19 period, is the development of videoconferencing to substitute for travelling and human mobility. Indeed, it is a public policy dilemma to simultaneously promote expansion in ICT facilities and reduction in GHG emissions. Another important message of the chapter is that data on the impact of ICT in terms of energy consumption and emission is largely imprecise and lacking.

ICT systems (laptops, servers, network routers, wireless transmission systems, etc.) consume electricity, most of them around the clock. Manufacturing the devices requires electricity and/or energy not only in the manufacturing process but also in the extraction/production of the required minerals and products, and this is generally not accounted for in consumption estimates. The 2019 worldwide electricity consumption from the ICT sector was estimated at 2 000 TWh (8.5% of total electricity consumption), corresponding to some 3% of CO_2 emissions, half of it accounting for equipment manufacturing. This consumption has been steadily increasing, even though the energy efficiency of ICT equipment, measured in bit per Wh, has been increasing: we can now store, process and transmit much more data for the same unit of energy. However, new developments such as artificial intelligence (AI), 5G and cryptocurrencies will clearly lead to further increases in electricity use and CO_2 emission.

The chapter does not cover manufacturing/decommissioning but is focused on ICT's operational points. One of them is Data Centre consumption and, in that respect, the case study of Ireland describing the consequences of having simultaneously attracted numerous data centres and developed intermittent electricity is presented.

Data Centers being at the core of the issues related to ICT electricity consumption, the first recommendation is to continue improving their efficiency through relevant measures and effective management practices. The second recommendation relates to the significant increase in energy consumption associated with the expansion of 5G and suggests initiatives to reduce such consumption. The third recommendation touches on forthcoming ICT system developments, as an increasing number of small data centres will constitute the so-called 'edge' system: evaluating the impacts of architectural choices on electricity consumption and CO_2 emissions for these new deployments still needs more research.

The final recommendation of the chapter tackles the lack of reliable data by proposing the development of metrics and systematic studies on energy consumption and emissions in the ICT sector. Once gathered, these data should also be made widely available.

Chapter 8: Conclusions

The Conclusions reminds us all of how urgent it is to act without further hesitation, and thus advocates the massive and rapid deployment of the available technologies described in the different chapters. It is not only about investing money for transforming the different sectors, but also about investing in people and expertise, by developing holistic views. Many difficulties and conflicting interests as well as conflicting priorities between sustainable objectives stand in the way of a rapid implementation of these recommendations.

We, the members of the CAETS Energy Committee are deeply convinced that these difficulties are surmountable and possibilities exist to act far more rapidly, inclusively and efficiently through comprehensive global approaches to reduce GHG emissions, and this is what the report calls for. We hope that the key messages from the Chapter 0 and the messages and recommendations from the seven chapters will effectively contribute to reduce GHG emission. We are also convinced that our respective Academies, as well as the CAETS as a whole, could be better involved and more actively mobilised to advise policymakers and industry leaders in order to reach the 2030-2050 goals on GHG emissions.