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GREEN ENGINEERING AS AN ANSWER TO CLIMATE CHALLENGES

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Abstract:
Energy supply issue is no longer just about making more comfortable life of the mankind. Technologies that have been developed in the last two centuries slowly but surely led the life on the planet Earth to its limits. Global warming indicated even more than a century ago caused significant climate change that we are witnesses around the globe. Causes and consequences of these changes are well known today and new technologies desperately need to be developed in order to save our civilization on the planet Earth.

Technologies based on burning fossil fuels as energy source with no doubt should be replaced with other ones which are not harmful to the environment. These energy sources are most commonly named as "green" ones. Some of technologies that use green energy have been developed a century ago but only in new millenium their wider implementation, modernization and development of new ones become our new reality

***Keywords**: Climate change, green engineering, global warming, greenhouse gases (GHG), industrial revolution.*

Introduction

Throughout its history mankind has been developing different technologies in order to make his life easier. Sometimes that was accompanied by suffering of other individuals, groups of people and even vast part of other nations. Since almost two centuries ago some of newly developed technologies have become harmful to the planet either.

As a starting point could be set the First industrial revolution period (approx. from 2nd half of 18th till first 3rd of 19th century) when human and animal labour based technologies are transformed into various machineries and their related processes. These transformations accelerated economic growth, increase in production and consequently in consumption of common people. Out of these positive effects,

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Industrial revolution has had social side effects as increasing of women and children labour in dangerous and unhygienic conditions as well as creation of wide gap between the rich and the poor [1].

But, for this research another fact related to the First industrial revolution is more important. Majority of newly created technologies relied on fossil fuels burning; mostly coal, as a main energy source in running various machineries, mostly steam driven. However, with the Second industrial revolution (approx. 2nd half of 19th till First World War) where internal combustion engine has been invented mankind finally paved the path to change the climate globally. Namely, this kind of engine use fossil fluids (gas or liquid) as a fuel in combustion process. As a results of combustion are mainly carbon based gases released into the atmosphere causing undesirable greenhouse effect along with other human activities products and processes that take place in nature as well.

Main purpose of this paper is to provide a comprehensive overview on how anthropogenic factors influencing climate change and what has to be done by it to mitigate the risks of reach the point of no return in global warming. The research is focused on the green engineering - based technologies and challenges they are facing.

Human Activity Role in Climate Change

Greenhouse effect was natural phenomenon throughout history of our planet which allowed biological development and survival on Earth protecting it from cooling and even from freezing. But with various human activities particularly from two centuries ago, mankind is a witness of upset in the balance of naturally present GHGs and anthropogenic ones, what led to global warming and finally to changes in climate on global level. There are many of anthropogenic influences as dominant forces that causing the enhanced greenhouse effect. They are mostly related to fossil-fuel combustion resulting in CO_2 emissions but also related to agriculture and land-use changes including deforestation, certain industrial processes, landfilling of wastes, refrigeration etc. when other GHGs are released into the atmosphere as well.

There are various GHGs such as water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Ozone (O_3) as well as a suite of halogen-bearing gases (like fluorocarbons) that are derived from industrial activities and other gases with ability to absorb energy and slowing the rate at which the heat escapes from Earth to space. Among them, in order of atmospheric concentration with the biggest impact on greenhouse effect are: water vapor, carbon dioxide and methane [2]. There are two key ways how GHGs differ from each other relating to global warming. Firstly, it is their ability to absorb energy - radiative efficiency and secondly, how long they stay in the atmosphere - lifetime. Mostly because of its ability to remain in the atmosphere even for thousands of years CO_2 will be in focus furthermore.

Generally speaking, consequences of anthropogenic influence on climate change are the most visible as [3,4]:

- Sea-level rise and possible flooding of low-lying areas;
- Melting of glaciers and sea ice;
- Changes in rainfall patterns with implications for floods and droughts;
- Changes in the incidence of climatic extremes, especially high-temperature extremes;
- Ocean acidification.

Consequently, these climate change effects have impacts on various ecosystems and environment in wider sense, as well as on key economic sectors such as agriculture and water resources and finally on health [3].

Green Engineering Basics

By development of human society various engineering disciplines and their sub-disciplines emerged. One of the latest one is **green engineering** as a consequence of urgent need to solve global problems that occurred by implementation of some engineering solutions in order to solve various problems. So, green engineering could be defined as "the design, commercialization, and use of processes and products in a way that reduces pollution, promotes sustainability, and minimizes risk to human health and the environment without sacrificing economic viability and efficiency" [5]. What is directly come out from the definition is that green engineering, like many of newly developed engineering disciplines must take into the consideration many various factors in order to find the best solution. Quite often these factors could be opposed among themselves and green engineers should prioritise criteria for selection of the best solution taking into account the order in the definition of green engineering: 1. reduce pollution, 2. promote sustainability, 3. minimize risk to human health and the environment 4. without sacrificing economic viability and efficiency.

In order to better define the field of green engineering as highly multidisciplinary engineering approach, there were set its **12 principles** which are [6]:

1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible.
2. It is better to prevent waste than to treat or clean up waste after it is formed.
3. Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Targeted durability, not immortality, should be a design goal.
8. Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
9. Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. Products, processes, and systems should be designed for performance in a commercial "afterlife".
12. Material and energy inputs should be renewable rather than depleting.

However, we are still witnesses that logic of capital at least on short term, more or less neglects these principles in favour of profit gain. Right here is the most challenging situation what green engineers should face. They are forced to find the engineering solution for the problems that could be overcome by implementing one from the variety of methods and techniques where productivity, efficiency and quality can be increased with profit gain but without harmfull impact to the environment as well as to the society.

Research & Results

As it stated previously, anthropogenic influence caused climate change. But, vise versa it should play the most significant role in finding way out of it. Consequently, **green engineering** has one of the crucial roles in mitigating climate risks. Technological inventions aimed for reducing

GHGs emissions to the atmosphere must include: *a*) Increasing the use of renewable energy sources and switching to less carbon intensive fuels; *b*) Reducing energy consumption; *c*) Sequestering CO_2 by enhancing biological absorption capacity in forests and soils; *d*) Capturing and storing CO_2 chemically or physically [7].

Table 1: *Engineering solutions and challenges for climate change mitigation*

Area	***Aim/Challenges***	***Solutions***
Renewable energy technologies	• Become increasingly efficient and cost-effective alternatives to fossil fuel-based energy production • Continued R&D needed	• Solar panels, • Wind turbines, • Hydropower systems • Geothermal solutions
Energy Efficiency in Infrastructure and Industrial processes	• Need to prioritize energy efficiency in the design and construction of buildings and infrastructure • Implementing more energy-efficient technologies → long-term energy savings	• Sustainable architecture • Green building materials/practices • Smart energy management systems • Enhancing less energy-intensive economic activities
Circular Economy and Sustainable Practices	• Reducing the environmental impact of infrastructure development and industrial processes, • Imperative to minimize waste and make the most of resources	• Recycling and repurposing materials • Self-sustainable farms and households • Reforestation • Agric. soil management improving • Peat land restoration • Resilient water and wastewater management
Smart Transportation Systems	• Reducing the carbon footprint of transportation	• Electric vehicles • Efficient public transportation • Innovative urban planning
Carbon Capture and Storage	• Capturing CO_2 emissions	• Developing technologies that capture CO_2 from industrial processes and power plants
Challenges and Ethical Considerations		
• **Technological Lock-In**	• Existing technologies and infrastructure make it difficult to transition to more sustainable alternatives	• Investing in and adopting newer, environmentally friendly technologies
• **Environmental Justice**	• The impacts of climate change disproportionately affect vulnerable communities	• Social equity and inclusivity • Fair distribution of burdens and benefits of environmental interventions
• **Global Collaboration**	• Climate change is a global issue that requires international collaboration	• Establishing global partnerships
• **Individual Actions**	• Reducing energy consumption • Sustainable consumption	• Conserving energy at home, using public transportation, and reducing air travel • Choosing sustainable products, reducing waste, and adopting a plant-based diet.

Sources: Compiled by author & adapted to [8]

European Union puts significant efforts forward to achieve the aim proclaimed in European Green Deal namely to become climate-neutral by 2050 [9]. According to this EU forces its companies to find out new business paradigm considering non-financial aspects of their operations, such as environment, society and governance out of their financial reports. **Corporate Sustainability Reporting Directive** (CSRD) that entered into force in 2023 is new European regulatory framework for sustainability. Unlike financial reporting, climate related disclosures and other non-financial reporting includes three additional dimensions: *a*) the impact of the activity on the climate; *b*) climate risks weighing on the company and *c*) how the organisation manages these issues. CSRD seeks to increase the economic flow towards more sustainable business models throughout the European Union [10].

Table 2: *CSRD topics*

Reporting topic	***Description***
Environmental protection measures	• Businesses must disclose specific initiatives to reduce their environmental footprint, including resource conservation and pollution prevention strategies.
Social responsibility and treatment of employees	• This includes everything from employee health and safety protocols to employee benefits and company culture.
Respect for human rights	• Companies must discuss their policies on human rights and how they ensure these rights are not violated within their operations.
Anti-corruption and bribery measures	• Businesses must explain their strategies to prevent corruption and bribery, including corporate governance measures and ethics training programs.
Diversity on company boards	• The CSRD requires companies to provide a detailed breakdown of the diversity of their board members, focusing on aspects such as gender, age, and nationality.

Source: [11]

CSRD as an administrative instrument is oriented to investors who can re-orient their investments towards more sustainable technologies and industries, based on comparable sustainability information. On the other side, CSRD forces companies to find out sustainable technologies i.e. **green ones** which will improve their attractivenesss for investors.

Conclusions

In last two centuries, mankind received huge benefits by using coal, gas, oil and nuclear energy in meeting its energy needs. On the other side, various agricultural, industrial and economy processes in general also leaving their footprints on climate and the planet in whole.

Different engineering disciplines provided technologies that enabled companies to profit more or less neglecting other business outputs. Warning signals that our planet sends to us have arisen the necessity for changing recent business paradigms predominantly led by profit gain. New engineering inventions are desperately needed in order to mitigate future climate risks. **Green engineering** should provide new technologies which could significantly decrease anthropogenic influence on climate. But, it must be supported by new policies on global level which will be in favour for companies that take into account non-financial aspects of their businesses such as environment, society and governance in order to ensure their sustainability on long run.

The fact that mankind is the main driver of today's climate change implies that the future evolution of the Earth's climate system will largely depend on its future decisions mostly in implementation of green technologies and its' supportive policies [12].

Finally, by widespread implementation of green technologies, we could slow down global warming while the process of "healing" the planet will last for centuries.

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