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Overview of approaches to obtaining energy from heat including ground-based installation

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Climate changes resulting from the excessive use of fossil fuels and the consequences of their extraction from the earth's bowels motivate the scientific community to develop new concepts for efficient energy management, limiting damage to nature. The present mini-review is motivated by the fact that the last decade has seen significant progress related to the development of reviews, analyses, assumptions, comparisons, research, technological solutions, mathematical models and optimization of supply chains by researchers who consider the problem related to energy efficiency in its various aspects and from different perspectives. Good scientific practice is the use of Computational Fluid Dynamics (CFD) modeling techniques, which can easily and quickly simulate the paths and movements of the various flows, to achieve the above-described objectives. The mini-review aims to review approaches to obtaining electrical energy through heat, including ground-based installations. An original scheme for the production of biogas with geothermal storage with application for greenhouses is presented.

Keywords: Sustainable development, Exergy efficiency technologies, CFD, Supply chain

INTRODUCTION

Along with the rapid development of scientific and technical progress to improve their well-being, modern men are faced with serious challenges related to the future state of nature on earth.

Climate changes resulting from the excessive use of fossil fuels and the consequences of their extraction from the earth's bowels motivate the scientific community to develop new concepts for the efficient management of energy, limiting damage to nature. On the other hand, the use of fossil resources as energy sources is associated with a number of problems related to yield uncertainty, production uncertainties, supply uncertainties, demand uncertainties, geopolitical uncertainties, etc., which create conditions for impaired sustainability and various types dependencies affecting directly or indirectly the price of energy. In this line of thinking, green energy is sustainable energy, guaranteeing the independence of the source from which it is produced [2]. For this purpose, it is necessary to carry out a thorough analysis of the life energy cycle for each specific case and to determine the possibilities for optimal use of the energy input. This analysis will serve the decision-makers to apply it according to the economic, ecological and social aspect to achieve sustainable development of the potential initiatives (Figure 1).

In this context, in 2012 (changed 2018) The Parliament of the European Union has adopted the Directive 2012/27/EU on Energy Efficiency, which regulates definitions, conditions and rules with the aim of making Europe the first climate-neutral continent by 2050 [1].

The aim of the current mini-review is to study the approaches for obtaining mechanical and/or electrical energy, exergy and their applicability in land-based installations. In this regard, and due to purely economic considerations, research interest in the last ten years in this area has increased 3.63 times, according to the data, extracted from ref. [3], *cf.* Figure 2.

In their publications, the authors have carried out reviews, analyses, assumptions, comparisons, research, technological solutions, mathematical models and optimization of supply chains. The problem related to energy efficiency is considered in its various aspects and from different points of view. Regarding the ranking of the individual renewable energy sources, there are a number of disputes and contradictions depending on the viewpoints of the studies, but with regard to solar and geothermal energy, researchers are unanimous and define them as the first on the list. A further point in the implementation of energy efficiency is to pay attention to exergy or the energy-exergy system, aiming to achieve both energy and exergy efficiency [4].

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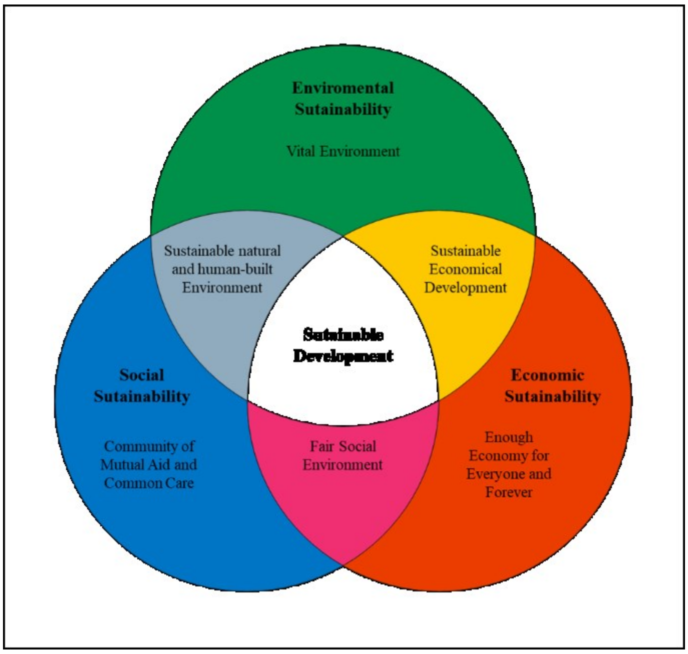

Figure 1. Sustainable development and management concept [1]

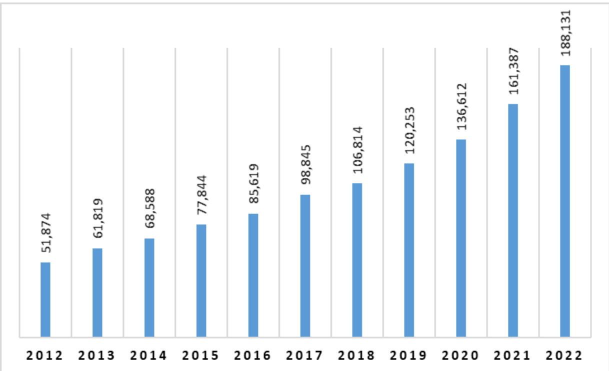

Figure 2. Activity according to the number of scientific publications related to energy efficiency for the period 2012 - 2022.

In developing a methodology for optimal operation of a geothermal power plant, Coskun *et al*. [5] found that when combined in the production of electricity with heating systems in greenhouse production, the exergy efficiency is satisfied at the highest level. The authors proposed seven variants of multi-generator installations for geothermal power plants, reaching 7-80% energy and 10-60% exergy efficiency. Ezzat & Dincer [4] are developing a geothermal energy system that includes solar energy. The authors present a thermodynamic analysis based on the energy and exergy in the system. Within their development, they achieved 69.6% energy and 42.8% exergy efficiency.

Dzhonova-Atanasova *et al.* [6] investigated compact latent heat storage systems for residential buildings to increase their efficiency. According to the authors, for the development of the optimization model for the design of these systems, certain requirements must be taken into account:

1. Achieving efficiency by combining time periods and cost of heat input.
2. The phase change substance used must meet the conditions to achieve the desired effect, be stable for a long time of operation, be available and have a low cost.
3. The most promising at the moment are heat accumulators with a compact size in a shell-and-tube configuration.
4. The heat accumulator must allow connection to different heat sources, as well as integration to existing heating systems.

EXERGY EFFICIENCY TECHNOLOGIES

Steam turbine

The steam turbine (Figure 3) consists of: Stator part - highly heated steam under high pressure enters the area of the stator blades, where it swirls and accelerates. Rotor part – the blades in the rotor part receive impulse and reaction forces from the accelerated and swirled steam, generating a torque in the rotor. There is a variety of steam turbines both in terms of number of stages (from 1 to 30 stages) and capacity range (up to 1900 MW).

One of the main applications of the steam turbine is the production of electricity by driving electric generators. As the temperature and pressure of the steam entering the turbine increases, the thermal efficiency also increases. Typically, inlet steam pressures in steam turbines of modern thermal power plants range from 24.1 to 33.0 MPa and temperatures range from 593°C to 630°C. The unit power of this type of power plants usually ranges from 600 to 1200 MW [7].

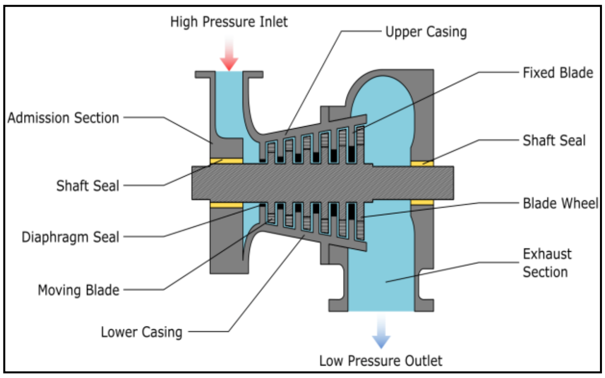

Figure 3. Schematic diagram of the operation of the steam turbine [8]

Thermoelectric method

Thermoelectric generators are devices that directly convert thermal energy into electrical energy. These devices are promising for a number of reasons: they are environmentally friendly, i.e. they do not generate harmful emissions, they are silent during their operation, in terms of construction, they do not have moving parts, i.e. their maintenance costs are low. The principle of operation of these devices is based on the properties of the included P-type and N-type semiconductor elements connected to each other by a wire as shown in Figure 4. Current flows through the n element, passes through the wire to the p element. Under the action of heat, electrons from n elements will move to the coldest place, this will create a current in the wire. The holes in the p cell will move in the same direction as the current. In the presence of a heat source, the device works as an electrical generator. Despite their undeniable qualities, thermoelectric generators cannot provide the necessary efficiency for mass application, which in turn encourages scientific activity in this area [9].

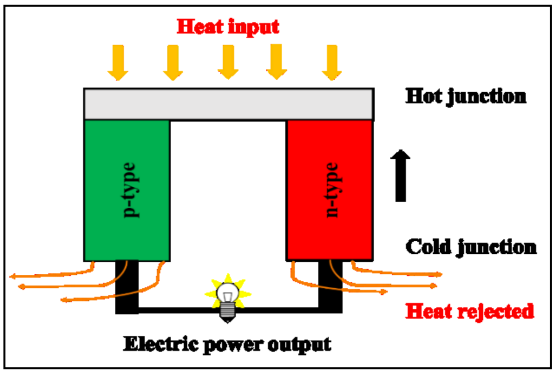

Figure 4. Schematic diagram of a thermoelectric generator [9]

Stirling engine

The Stirling engine itself is an external combustion piston engine. The driving force in it is the change in the pressure of the fluid in the cylinder chamber, as a result of its passage through "warm" and "cold" zones, as well as the alternation of compression and throttling processes. Theoretically, the efficiency of the Stirling machine is equal to that of the Carnot cycle. In terms of construction, there are three types of these machines α, β and γ (Figure 5). In the α-type, the engine is two-cylinder, with cylinders connected in a common volume of working fluid , while β- or γ-type engines are single-cylinder, and the difference between them is in the location of the hot and cold zones [10].

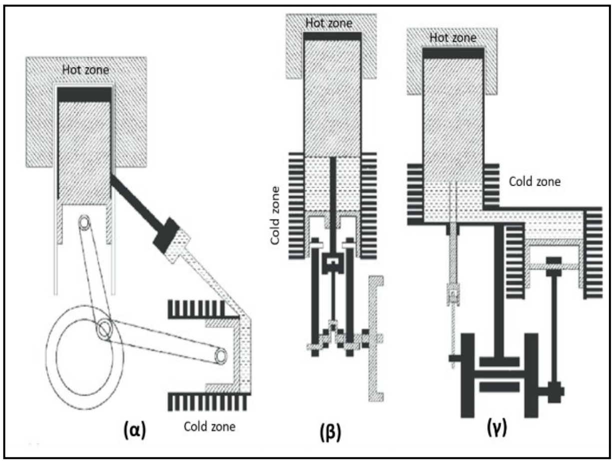

Figure 5. Schematic diagram of Stirling engine types [11].

Heat pumps

The principle of operation of the heat pump is related to the reversal of the direction of the heat flow and is based usually /most often/ mainly on the vapor compression cycle. Characteristic of the vapor compression cycle is the presence of a liquid refrigerant that circulates in the system. Liquid refrigerant absorbs heat from the space where cooling is needed and can also deliver heat to the space where heating is needed. A compression heat pump, as shown in Figure 6, is used for space heating by raising low-temperature energy (from water, ambient air, etc.) to the temperature of the heating system by doing work on the fluid using a compressor.

In terms of waste heat, the heat pump can improve the efficiency to a value that can be more than twice the energy consumed by the device [12].

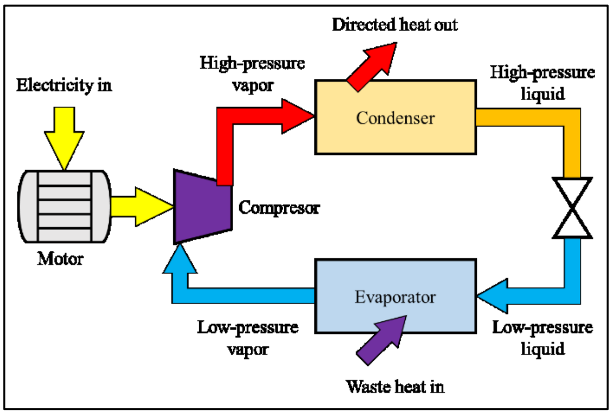

Figure 6. Schematic diagram of a compression heat pump.

RESEARCH ACTVITY RELATED TO TECHNOLOGIES IN EXERGY EFFICIENCY

The last decade has seen significant progress related to the development of reviews, analyses, assumptions, comparisons, research, technological solutions, mathematical models, and optimization of supply chains by researchers. Table 1 considers the problem related to energy efficiency in its different aspects and from different points of view. The authors present the development of new technologies and the improvement of existing ones to improve their efficiency in order to minimize energy costs and to achieve a nature-friendly economy.

CFD MODELING FOR ENERGY EFFICIENCY

To achieve the above objectives, it is a good scientific practice to use CFD modeling techniques, which can easily and quickly simulate the paths and movements of the various flows. This is of particular importance in the design of steam turbines, where the driving force is derived from the rate of change of momentum of a high-velocity steam jet impinging on a freely rotating curved blade [41].

Through the use of CFD techniques, different ways to increase the performance of thermoelectric generators can be analyzed, such as efficient direction of heat flows, as well as the construction material, shape and spatial arrangement of heat exchangers [42]. When implementing projects related to the application of the Stirling engine, it is of particular importance to assess which of the types (α, β, and γ) is the most effective for the specific situation and, accordingly, in which it is permissible to be modified. Comparisons can be made in terms of power output, heat transfer and thermal efficiency. For this purpose, a CFD simulation is applied for the three types of Stirling engines in which the respective efficiency is evaluated [43].

Table 1. Research contribution in areas related to improvement of classical technologies and development of new ones to improve energy efficiency.

Energy converting machines	References	Scientific direction
Steam turbine	[13], [14], [15]	Using solar energy to generate electricity through a steam turbine and salt tower.
Thermoelectric method	[16], [17], [18], [19], [20], [21], [22], [23], [24], [25]	Using a thermoelectric method to produce electricity from geothermal sources.
Stirling engine	[26], [27], [28], [29], [30], [31], [32], [33], [34], [35]	Using a Stirling engine engine to convert geothermal energy into mechanical energy and its application.
Heat pumps	[36], [37], [38], [39], [40], [6]	Heat pump application using geothermal energy.

The design of ground-based heat pumps requires consideration of peak heating and cooling loads. It is important for the system to take into account both the input and output energy, as well as the frequency of operation of the heat pump. The intensity, speed and perimeter of heat propagation in the soil where the heat pump is based are investigated. CFD simulation enables the construction of a 3-D model to achieve an objective view of the change in the above-described parameters and the possibilities for the overall optimization of the system [44].

Based on the research done in this way, it can be concluded that in every field of energy-related technologies there is potential for development and improvement. We present a concept (Figure 7) for the improvement of the biogas production and realization technology described by Ganev & Beschkov [1], where the addition of land-based installations is envisaged to improve the exergy efficiency of the project. The excess heat from the cooling of the cogenerator is taken to a horizontally located, ground-based heat exchanger. The goal is to achieve the effect of a heat accumulator. In addition, it is planned to build a greenhouse above the soil where the heat accumulator is located, which will, on the one hand, produce agricultural produce and, on the other hand, play the role of an insulator from atmospheric conditions.

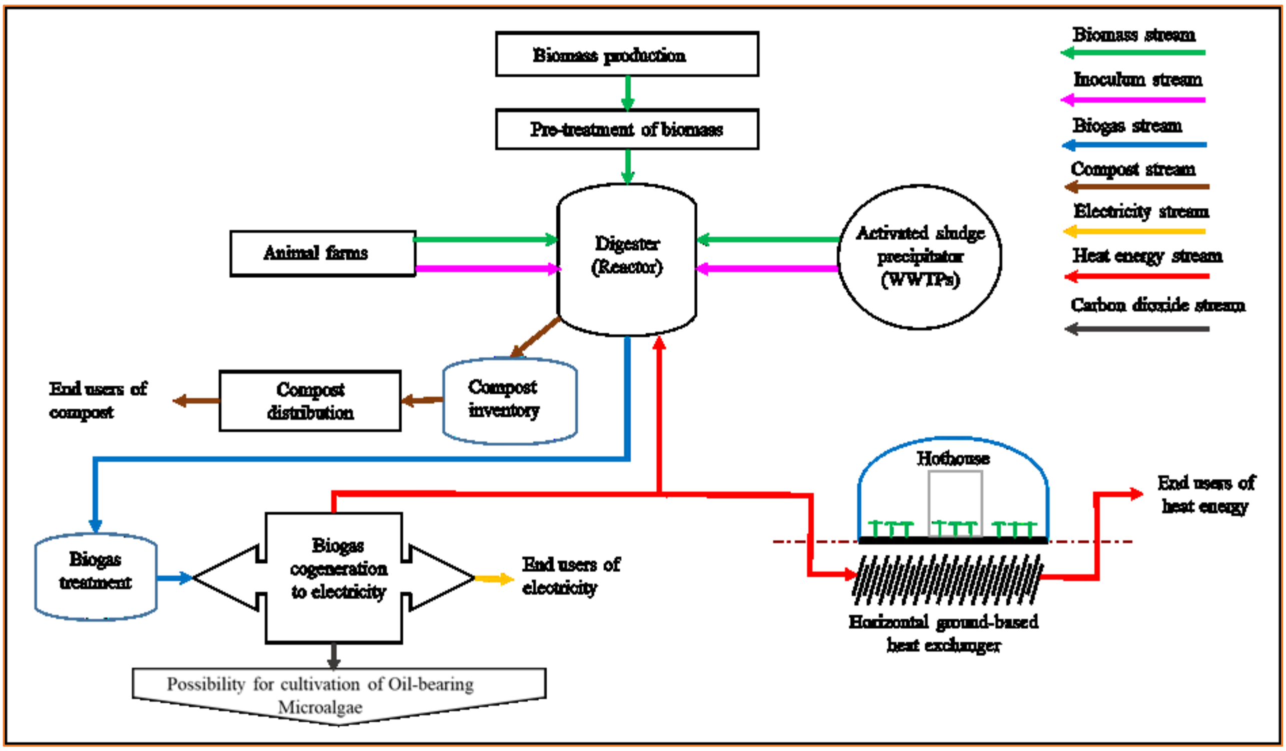

Figure 7. General framework of the biogas supply chain

CONCLUSIONS

1. Green energy is sustainable energy, guaranteeing the independence of the source from which it is produced.

2. The energy life cycle analysis for each specific case allows optimal use of the energy input. To achieve the goal, it is appropriate to optimize the resource-insurance chain by building a mathematical model, guaranteeing the sustainability of the system from the point of view of ecological, economic and social sustainability.

3. An essential moment in the realization of energy efficiency is to pay attention to exergy or the energy-exergy system to achieve energy and exergy efficiencies.

4. Compiling a CFD simulation model for each specific case can give a clear idea of the distribution of heat flows in the installations and can serve as a tool for improving energy and exergy efficiency.

5. At present, every area of energy-related technologies has potential for development and improvement.

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