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Energy sources for district heating systems. Transition from 1st to 5th Generation

Surse de energie pentru sistemele centralizate de termoficare. Tranziția de la Generația 1, la Generația 5

Daniel Muntean[1], Adriana Tokar[1], Danut Tokar[1], Alexandru Dorca[1]

[1]Universitatea Politehnica Timișoara,
Victoriei Square, Nr.2,Timisoara, Romania
E-mail: *daniel-beniamin.muntean@upt.ro, adriana.tokar@upt.ro, danut.tokar@upt.ro*

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Abstract: *Given the critical global context that has been reached in terms of air pollution caused by carbon emissions and other pollutants resulting from the combustion of conventional fuels, we urgently need to reduce the impact on the environment and find solutions that slow down global warming. Energy in various forms is a need that we cannot do without, but we must resort to primary sources that are as less polluting as possible and that at the same time ensure energy demand. Renewable energy sources must be exploited to the greatest extent possible and installations/equipment optimized for the highest possible efficiency. This paper presents the main conventional and unconventional energy sources, the evolution of their use over time and proposals for optimizing thermal and electrical energy production systems.*

Key words: fossil fuels, natural gas, district heating systems, renewable energy sources, heat pumps

1. Introduction

At the global level, the International Energy Agency's (IEA) provides an energy outlook through three main scenarios designed to help policymakers, industry leaders and researchers understand the future of the entire energy system by analyzing trends in demand, supply, technology and emissions. [1].

These scenarios address energy perspectives from current policies to measures to achieve net-zero strategic plans involving the transition to renewable energy, namely:

- Current Policies Scenario (CPS) – indicates policies and regulations that are already in place;

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- Stated Policies Scenario (STEPS) – indicates policies that have been officially proposed but have not yet been adopted, as well as other types of official strategic documents that indicate the direction of travel;

- Net Zero Emissions by 2050 (NZE) – indicates a path to reduce global CO_2 emissions by 2050. Romania's strategy for this scenario aims for massive decarbonization through the integration of renewable energy, increased energy efficiency, electrification and carbon capture [2].

A comparative picture of the evolution of the global average temperature for the three scenarios (CPS, STEPS and NZE) and the annual emission reductions in the NZE scenario, over a 5-year period, are presented in Fig. 1.

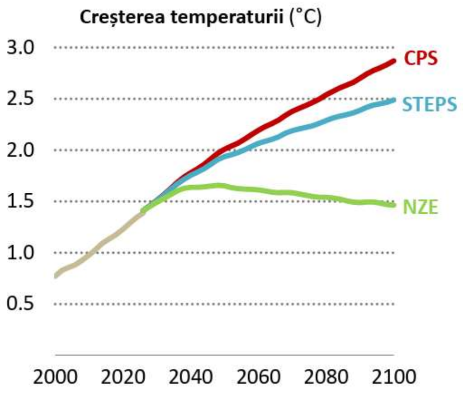

Fig. 1. Global average temperature increase and annual emission reductions from peak to 2035 in previous editions of the NZE scenario

An evolution of CO_2 emissions, by fuel type, is presented comparatively, in the world, in the EU and in Romania, in Fig. 2 [3].

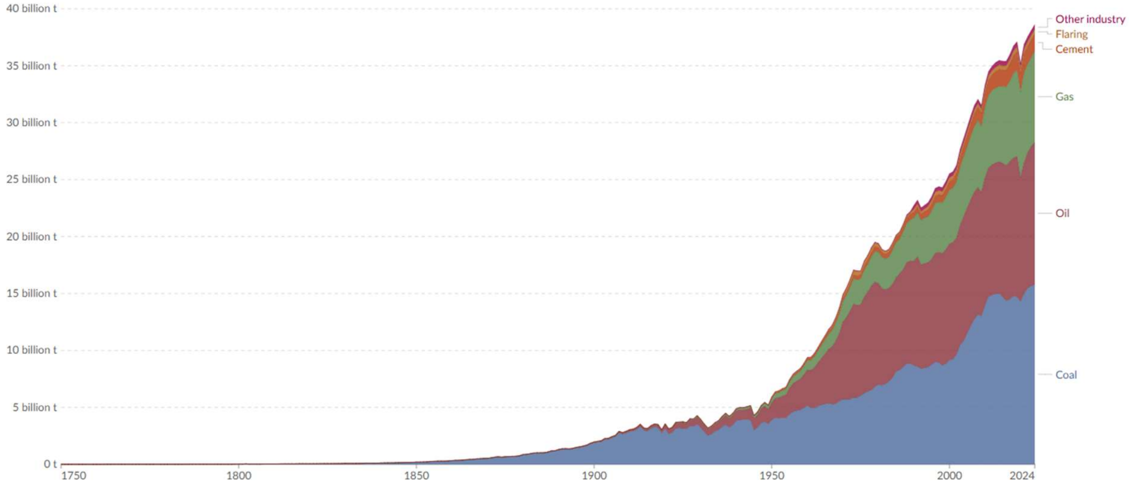

Fig. 2. CO_2 emissions by fuel or industry type, World

Generation I transported steam at temperatures above 200°C using concrete pipes. As a result, it was not particularly efficient and was replaced due to the risk of pipe bursting. Generation II used concrete pipes to transport pressurized water at temperatures above 100°C and is known as high-temperature district heating. Generation III uses pre-insulated pipes buried directly in the ground and operates with water at supply temperatures between 65 and 95°C. Generation IV district heating systems are now being developed and referred to as low-temperature district heating systems (50–60°C). When end-user temperatures are increased with heat pumps, ultra-low supply temperatures (35–45°C) are also used [4]. Generation V district heating is an extension of generation IV, a new concept based on a decentralized network that allows direct energy flows between and within buildings. Its key features are: low exergy network using low-temperature heat sources; closed thermal energy loops that ensure the exchange of heat and cold between groups of buildings; integration and synergy between thermal and electrical networks; 100% renewable energy target [5]. The evolution of district heating generations over time is presented in Fig. 3 [6].

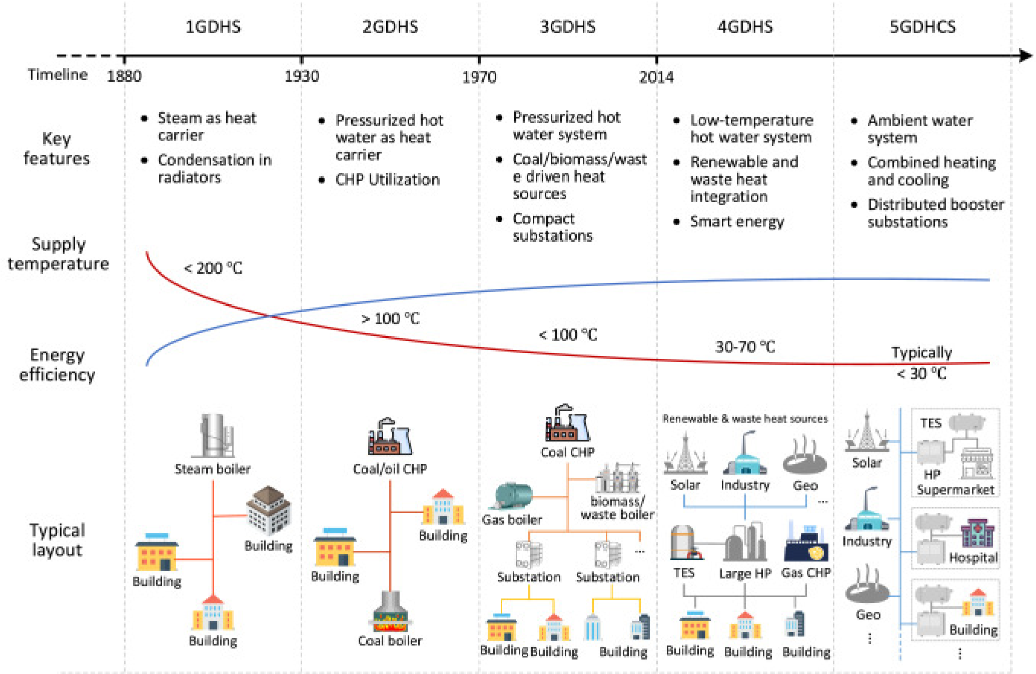

Fig. 3. The Evolution of District Heating Systems

2. Current status. Technologies and systems used

2.1. Fossil fuels

Until recently, coal was the main source of thermal energy, being responsible for high emissions of CO_2, but also other pollutants (SO_2, NOX, PM2.5 and PM10 particles, heavy metals, CO, etc.). Even though efforts are being made to optimize the efficient use of coal, the trend is towards total replacement.

For the period 2020-2030, Fig. 4 [7] shows coal consumption in the world. It can be seen that at the EU level there is a slight decrease starting from 2025, which is expected to continue until 2030. In the USA and Asian countries, a slight increase is recorded until 2030. However, the stabilization of energy consumption produced with coal stabilizes, by 2030, in a narrow band, except for China, Asia and India.

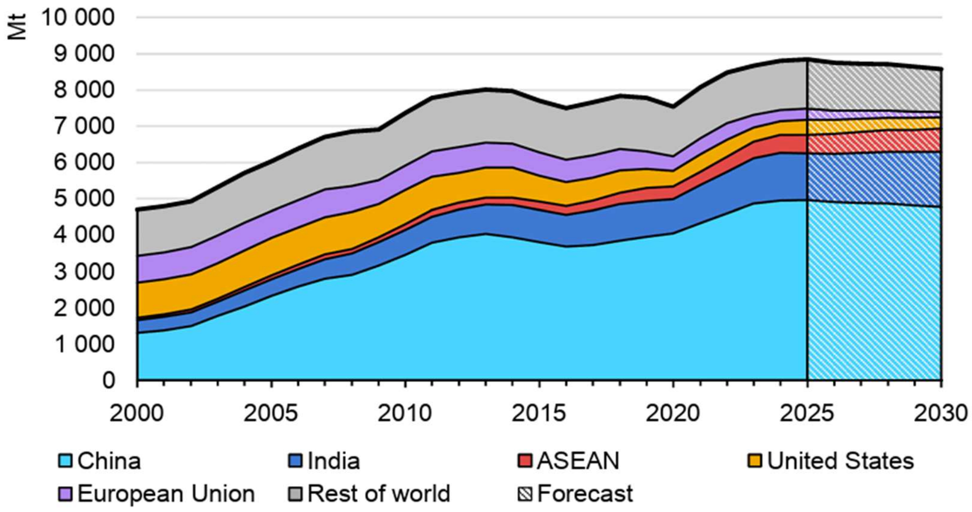

Fig. 4. Global coal consumption

At the Romanian level, although the country is engaged in a rather slow energy transition, coal has remained a safe source for high energy consumption. Romania's coal reserve is sufficient for the next decades, compared to current consumption [8].

With all the advantages that coal offers, its major disadvantage is that it is the least environmentally friendly conventional energy source. Through the emissions of CO_2, SO_2 and NO_2 as a result of coal combustion, it is estimated that this fuel has contributed massively to climate change and implicitly to global warming. In Romania, currently, considerable greenhouse gas emissions, in a percentage of about 70%, are recorded in the production of thermal and electrical energy, which can be seen in Fig. 5 [9].

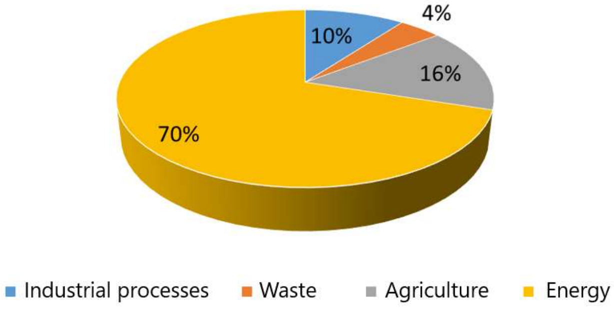

Fig. 5. Greenhouse gas emissions in different sectors

2.2. Natural gas

The use of natural gas mixed with coal (co-firing or alternative use) in district heating systems has emerged as an energy transition strategy imposed by the need to reduce polluting emissions, but also to maintain the security of thermal energy supply. Some district heating systems have resorted to partially replacing coal with natural gas in order to reduce pollution, and others use gas, either to support coal ignition or to take over peak load during winter. In either variant, coal is the basis, but the addition of gas offers greater flexibility in operation and a decrease in polluting emissions.

An evolution of CO2 emissions responsible for natural gas consumption, in the world, is presented in Fig. 6 [3].

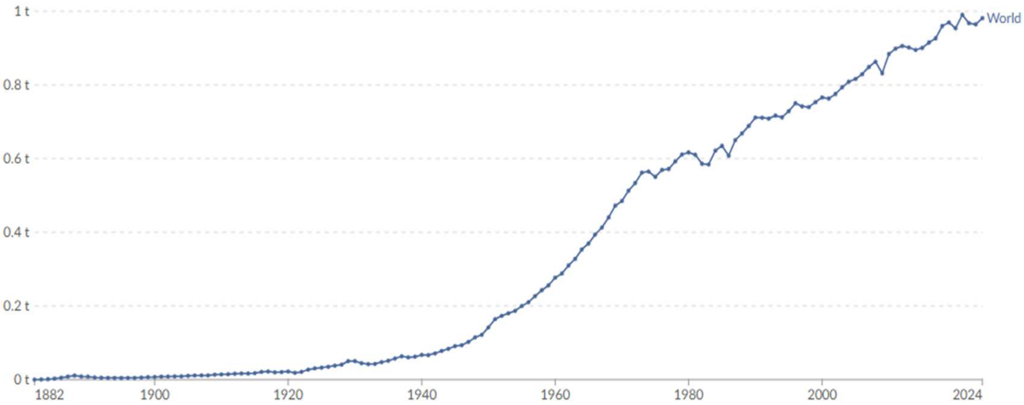

Fig. 6. Evolution of CO_2 emissions

În acest context al tranziției energetice prin startegia energetică pe termen lung, României a stabilit trei scenarii prin care a fixat ipoteze privind utilizarea cărbunelui și GN în ceea ce privește producerea de energie electrică și căldură [10].

Comparativ cu 1990, în 2030 se preconizează o reducere d 85% a emisiilor de gaze cu efect de seră pentru toate cele trei scenario Fig.7 [10].

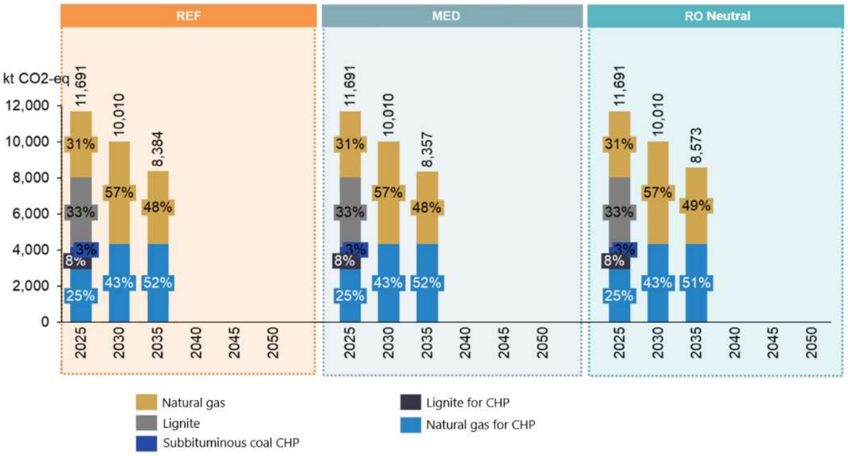

Fig. 7. Emissions evolution in the 3 scenarios: REF, Medium and RO Neutral

2.3. Renewable energy sources

The use of solar energy in district heating systems represents a sustainable investment and a necessity for the transition to RES, both at the EU level and at the Romanian level, considering the aspects presented above regarding the abandonment of coal and NG. Solar energy is the key factor in the transition of district heating systems from the 3rd generation to the 4th generation, a source that also plays a significant role in the transition to the 5th generation.

Figure 2 shows that direct solar energy is approximately 2850 times greater than the total energy we currently need on a global scale, therefore we only need 0.035% of solar energy to meet all the world's energy demand [11].

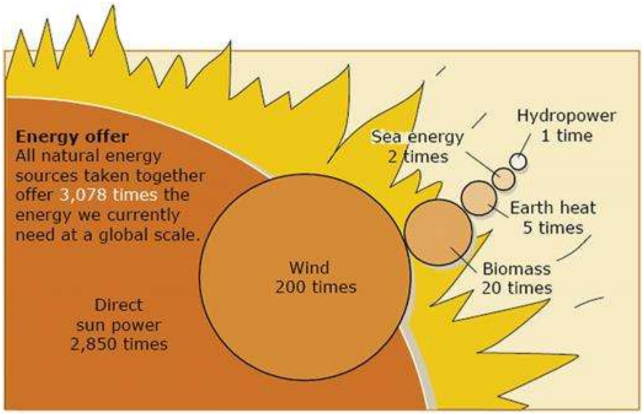

Fig. 8. Intensitatea diferitelor tehnologii de energie alternativă [12]

Fig. 9 shows the evolution of the installed capacity for producing energy from solar sources, in the world and more specifically in different regions.

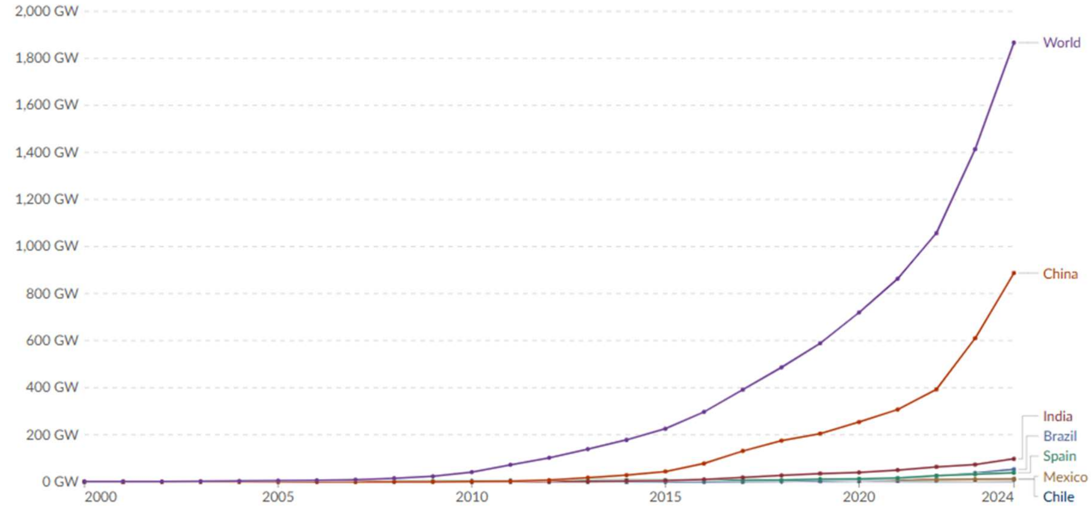

Fig. 9. Installed solar energy capacity [3]

Fig. 10. presents share of cumulative power capacity by technology, between 2010 – 2017 [12].

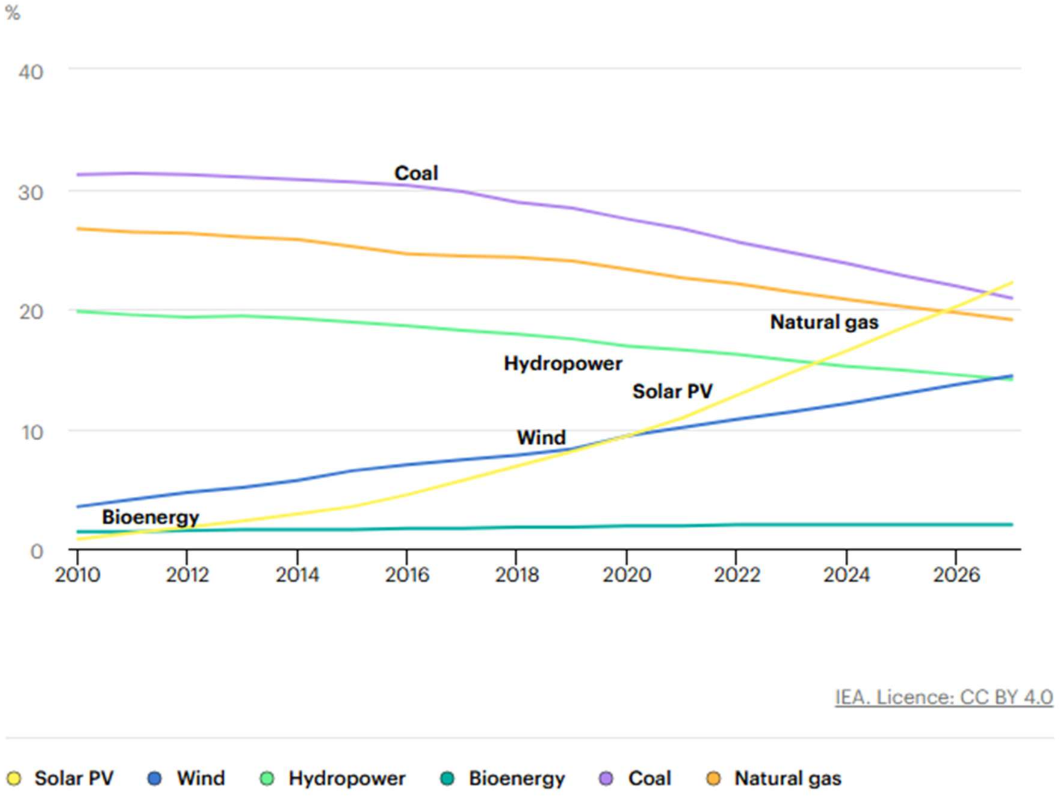

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Fig. 10. Share of cumulative power capacity by technology, 2010-2027

Fig. 11 presents annual solar PV installed capacity 2000-2004 [13].

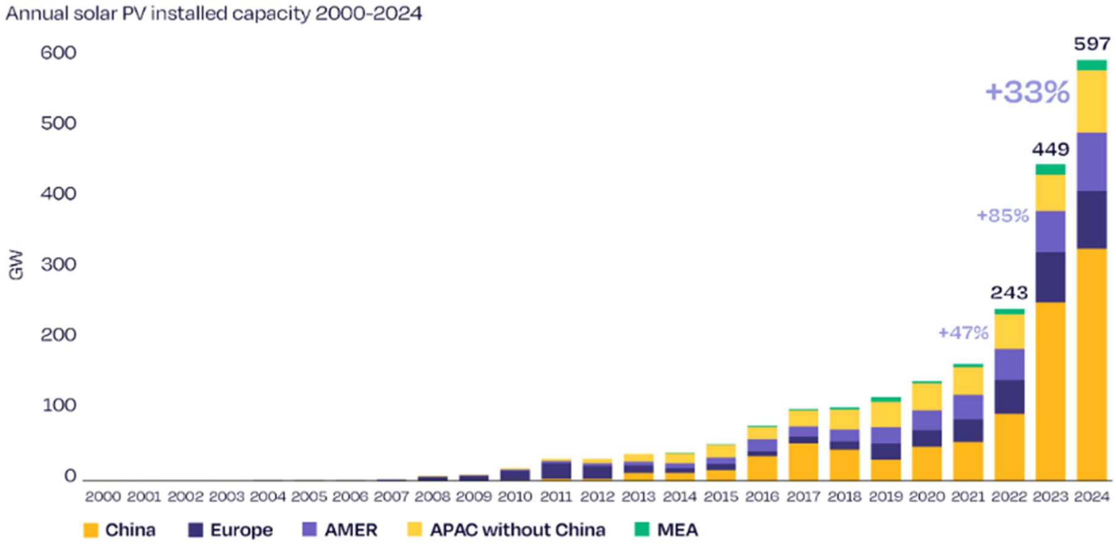


Fig. 11. Annual solar PV installed capacity 2000-2004

Although photovoltaic panels are usually used for direct electricity generation, they can be integrated into district heating systems through heat pumps.

Photovoltaic panel technology has evolved greatly in terms of materials used (from silicon – classic panels to perovskite – bifacial panels).

The main advantages and disadvantages of the main types of photovoltaic cells are presented in Table 1 [14].

Table 1

Advantages and disadvantages of the main types of photovoltaic cells [14]

Panel Type	Efficiency	Advantages	Disadvantages	Research Results
Polycrystalline	12–15%	Low price	Sensitive to high temperatures; short lifespan; low efficiency	Solar cell efficiency decreases significantly as temperature increases.
Monocrystalline	15–25%	High efficiency; suitable for commercial use; long lifespan	Expensive	Monocrystalline solar cells offer a very high output efficiency, while being among the most expensive solar cells compared to others.
Amorphous Silicon (Thin Film)	12–15%	Reduced costs; flexible; easy to manufacture	Short lifespan	Thin-film photovoltaic panels offer a short lifespan, but provide good constructability, being very flexible and lightweight.

The heat pump consists of four main components: a compressor, a condenser, an evaporator and an expansion device.

The refrigerant enters the compressor as a saturated vapor and is compressed to the condenser pressure, causing its temperature to rise above ambient. Then, the superheated refrigerant vapor enters the condenser and releases heat to the environment at constant pressure.

The liquid refrigerant is throttled by the expansion device, resulting in a temperature drop below the indoor air temperature.

The refrigerant enters the evaporator, absorbs heat from the conditioned space and evaporates completely. It then returns to the compressor as a saturated vapor, completing the cycle [15].

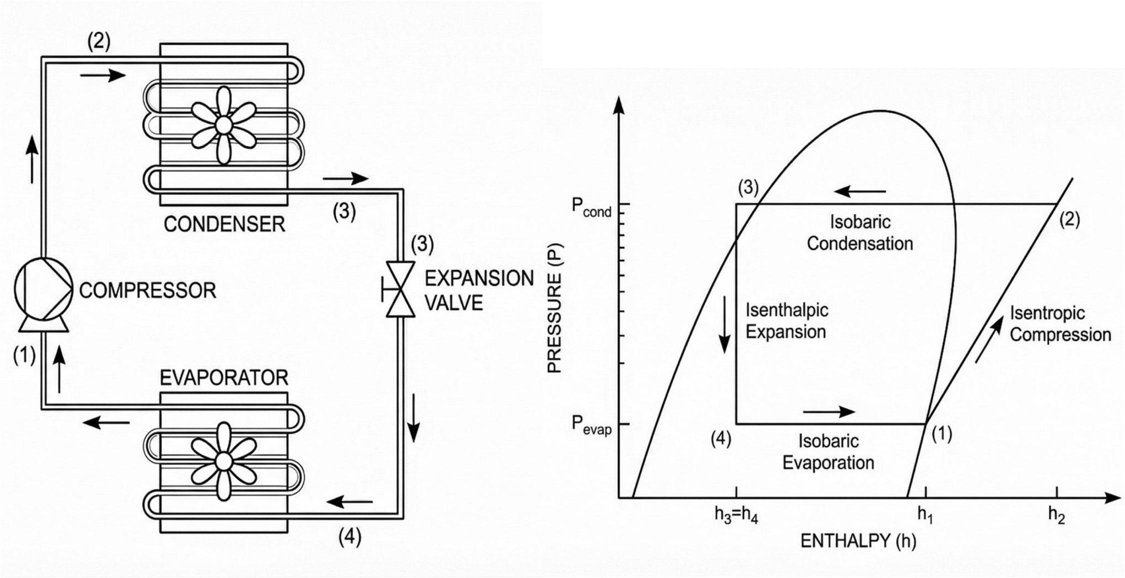
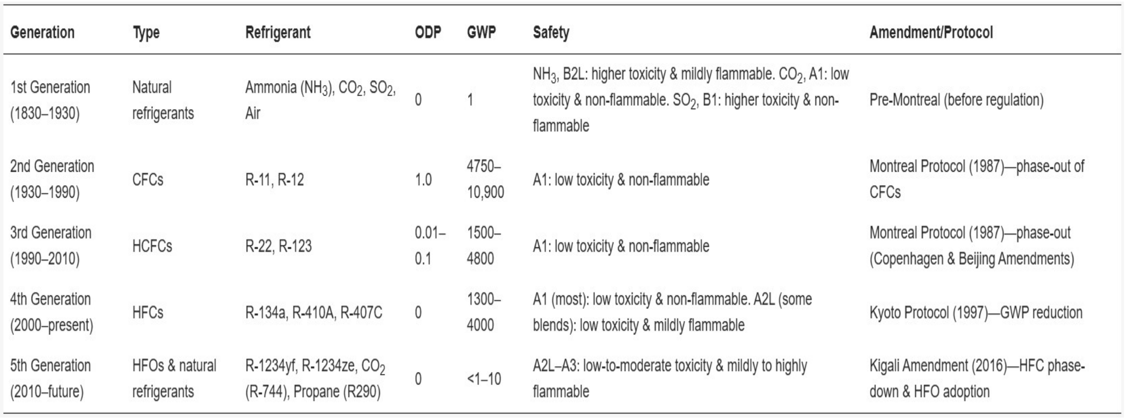


Fig. 12. The operating principle of the heat pump [15]

Table 2 summarises the progression of refrigerant generations. Refrigerant-based strategies are no longer viewed as isolated efficiency enhancements but as enabling constraints that define the feasible design space for optimized heat pump systems.

Table 2

Evolution of refrigerant generations



Generation	Type	Refrigerant	ODP	GWP	Safety	Amendment/Protocol
1st Generation (1830–1930)	Natural refrigerants	Ammonia (NH_3), CO_2, SO_2, Air	0	1	NH_3, B2L: higher toxicity & mildly flammable. CO_2, A1: low toxicity & non-flammable. SO_2, B1: higher toxicity & non-flammable	Pre-Montreal (before regulation)
2nd Generation (1930–1990)	CFCs	R-11, R-12	1.0	4750–10,900	A1: low toxicity & non-flammable	Montreal Protocol (1987)—phase-out of CFCs
3rd Generation (1990–2010)	HCFCs	R-22, R-123	0.01–0.1	1500–4800	A1: low toxicity & non-flammable	Montreal Protocol (1987)—phase-out (Copenhagen & Beijing Amendments)
4th Generation (2000–present)	HFCs	R-134a, R-410A, R-407C	0	1300–4000	A1 (most): low toxicity & non-flammable. A2L (some blends): low toxicity & mildly flammable	Kyoto Protocol (1997)—GWP reduction
5th Generation (2010–future)	HFOs & natural refrigerants	R-1234yf, R-1234ze, CO_2 (R-744), Propane (R290)	0	<1–10	A2L–A3: low-to-moderate toxicity & mildly to highly flammable	Kigali Amendment (2016)—HFC phase-down & HFO adoption

2.3.1 Optimizing the heat pump refrigeration cycle

Ejector-Assisted Vapour Compression Cycle – Fig. 13 [15].

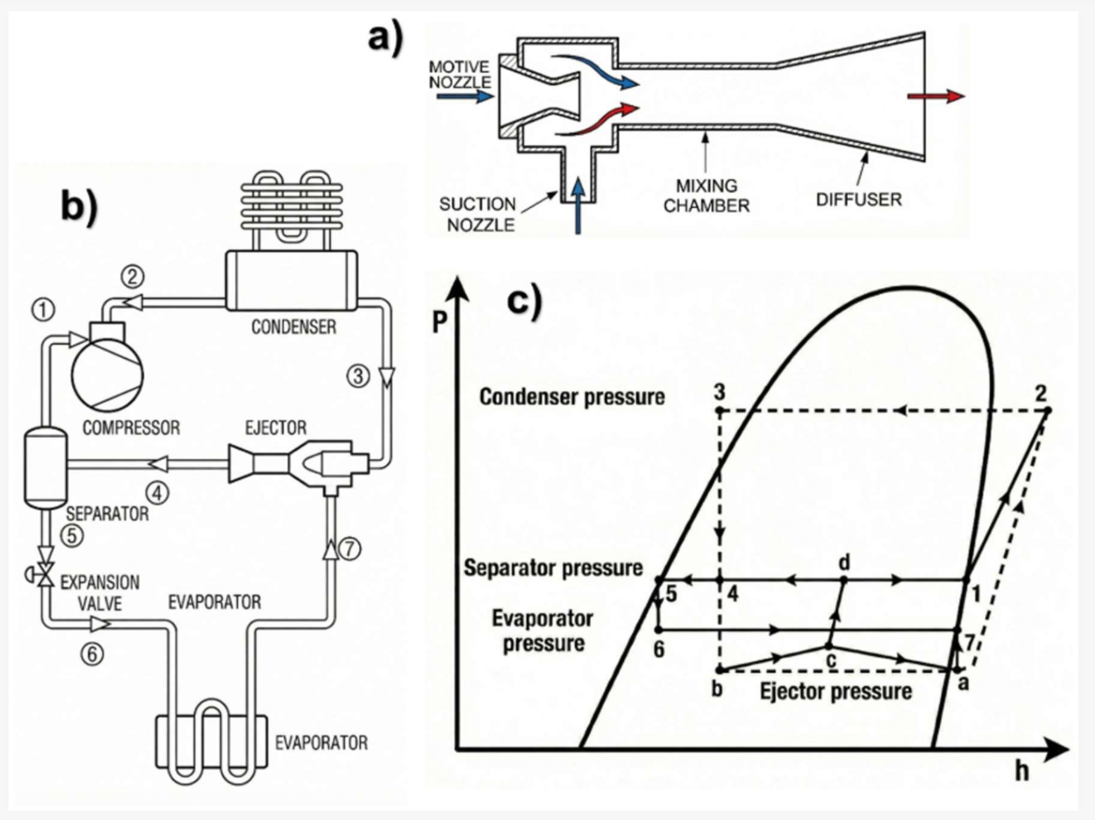


Fig. 13. Ejector-Assisted Vapour Compression Cycle [15]
(a) Schematic diagram of the basic ejector design, (b) VCC with ejector cycle, and (c) P-H diagram, where (3-b-a-2) is the basic VCC cycle

Internal Heat Exchanger Subcooling – Fig. 14 [15].

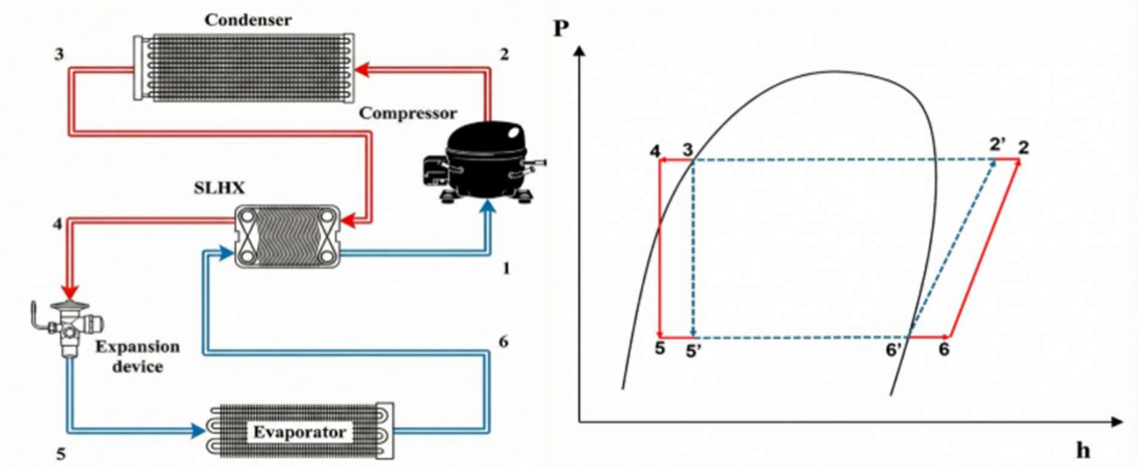


Fig. 14. Scheme of the modelled IHX & P-H diagram [15]

Thermoelectric Cooler (TEC) Integration – Fig. 15 [15].

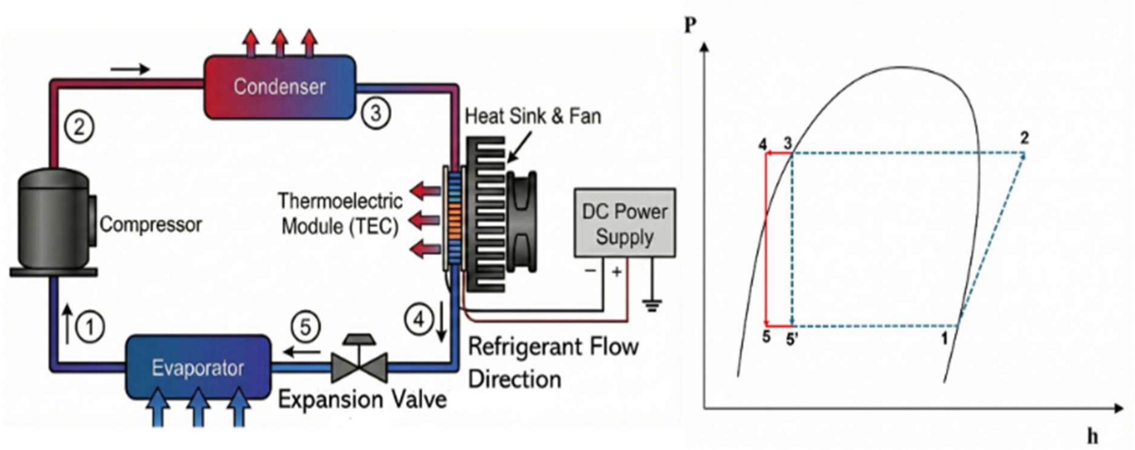


Fig. 15. Thermoelectric Cooler (TEC) Integration [15]

3. Conclusions

Considering the global energy needs, the solution is not necessarily to completely exclude certain fuels considered more polluting, but to use them together with renewable energy sources depending on need/weather conditions/efficiency. Renewable energy sources still have many limitations for which solutions must be found to optimize the installation systems so that energy can be provided constantly and at optimal parameters.

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