The impacts of different heating systems on the environment: A review

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Abstract

This paper presents a review of the environmental impacts of most heating systems drawing together published literature on the subject, not previously available. Here, a comparison between the different systems such as coal, wood, oil, natural gas, heat pump, geothermal and solar energy is provided in terms of their environmental impact. The most important parameters considered are the emission rate and toxicity. This places the coal-fired system as the worst among all heating systems regarding the impacts on the environment. On the other hand, renewable energy sources are the most preferred sources decreasing total emissions and air pollution. In order to make a comparison between the different systems, the emissions that must be taken into consideration are CO, CO_2, NO_x, SO_2, PMs, N_2O, CH_4, volatile organic compounds, polycyclic aromatic hydrocarbons and aldehydes.

Nomenclature	
ASHP	air source heat pump
ATES	aquifer thermal energy storage
BTES	borehole thermal energy storage
CCHP	combined cooling, heating and power

CHP	combined heat and power
DH	district heating
DHC	district heating and cooling
DS	district system
EF	emission factor
GE	geothermal energy
GHG	greenhouse gas
GSHP	ground source heat pump
HEPA	high efficiency particulate air
HP	heat pump
IWH	industrial waste heat
LPG	liquefied petroleum gas
NG	natural gas
PAH	polycyclic aromatic hydrocarbons
PM	particulate matter
SNG	synthetic natural gas
SPF	seasonal performance factor
VOC	volatile organic compounds
WHR	waste heat recovery
Subscripts	
2.5	particles with diameter less than 2.5 micrometres
10	particles with diameter less than 10 micrometres

1. Introduction

In air conditioning systems, the priority is ensuring convenient and comfortable indoor conditions due to their direct effect on human health and well-being. The issue stands behind the techniques that are responsible for providing the indoor environment with the needed thermal quality while being economically feasible [1]. Unfortunately, in winter, heating systems depend almost on fossil fuel energy [2] such as coal [3], oil [4], and natural gas [5]. This is accompanied by severe environmental risks such as gas emissions [6], global warming [7] and noise pollution [8]. Due to these serious negative impacts, it is utmost necessary first to focus on the large heating systems which is the case of district heating [9, 10]. This is also very crucial because of its rapid growth and spreading. Thus,

endeavors have been recently encouraging to use alternative heating systems based on renewable energy sources such as solar [11] and geothermal [12]. Heating systems have huge impacts on the environment especially because of some common usages, for instance; central heating is most frequently used depending on coal-fired boilers followed by thermal power plants then by gas-fired boilers [13]. There are some other factors that are involved in air pollution in big cities and these are mainly the topography and meteorology [14].

In north China, 40 - 60 % of the total deaths are caused by emissions of heating systems regardless of other health injuries [15]. This is due to the high dependency in rural China on solid-fuel heating systems [16] that have high pollutant emissions and mainly $PM_{2.5}$ [17, 18] and polycyclic aromatic hydrocarbons (PAH) [19] that lead to an increase in cancer risk [20]. Recent research studies tend to focus on investigation of heating system emissions using modern accurate techniques and the corresponding impacts on the environment [21]. These effects cannot be estimated easily based on the energy sources used because it is just one of various factors influenced [22] such as emissions' losses and efficiency [23] that are directly related to the thermal environmental comfort [24-26]. In [27], a new method was proposed and compared to a base case for estimating residential heating impact. The results showed that the percentage error of the estimated environmental impact with respect to the real observations could be reduced from 35.1% to 4.16% as an average percentage. Usually, the considered pollutant emissions are CO, CO_2, NO_x, SO_2, PMs, N_2O, CH_4, volatile organic compounds (VOC), PAH and aldehydes. Moreover, the authors in [28] have used "immissions" as a new term to represent the impact of emissions on health depending not just on the rate of pollutants but stack height such that, at constant emission rate, as the stack height increases, the immissions will decrease.

The concentrations of the toxic substances could vary in the same region according to the specific local elevation [29]. Hosseini *et al*. [30] investigated the effect of thermal buoyancy force on the air pollution in canyons. The authors deduced that the type of canyon affects the airflow which is responsible for controlling the pollutants' flow. Therefore, canyons are categorized into three types depending on the height to width ratio: broad, regular, and deep.

Besides that, it is necessary to make sure at first that the indoor environment is healthy for living. The indoor air quality is almost monitored by measuring the temperature, relative humidity, CO, CO_2, $PM_{2.5}$ and PM_{10}. Several studies were performed to show that during winter, people are almost living in unhealthy mediums because of the disruption and high pollutants that are able to cause asthma [31]. This is usually due to the insufficient amount of ventilation which must be treated in a way to cope with the indoor thermal and pollution aspects. The ventilation process and its duration relies on the indoor thermal distribution such that in the case of floor heating, it is inversely proportional to the floor temperature [32]. The supply conditions of heating need to be selected taking into consideration the thermal comfort [33, 34] and its effect on physical health and especially on elderly people [35]. In other words, human health concerning physiological and psychological (sensation) responses directly depends on the thermal indoor conditions [36].

The emissions vary from one system to the other according to the start, stop and operational duties [37]. Many previous studies have been performed to investigate this issue such as decreasing the supply temperature which is a very good technique to achieve a low temperature heating system for reducing the total emissions [38]. Monitoring emissions in heating and non-heating seasons is almost required in order to draw out the effect of heating

on emissions [39, 40]. The Nudging method was used to study SO_2 and NO_2 emissions based on an Ozone Monitoring Instrument [41]. This method presents a detailed map showing the sources of SO_2 and NO_2 emissions, allowing comparison of the difference between heating and non-heating seasons with respect to the meteorological conditions.

CO is almost always produced due to the improper duty of burner cycling or if the load is less than the lowest rated combustion power. It could be decreased by optimizing the control and design parameters such as air exchange rate and ambient air quality. Electrochemical sensors are usually used to measure the indoor CO concentrations [42]. This measurement is necessary to make sure that pollution levels do not exceed World Health Organization guidelines. Polychlorinated dibenzo-p-dioxins and furans (PCDD/F) are toxic substances usually formed due to the addition of wastes to the combustion to perform a rapid start-up for instance. PCDD/F emissions do not have too many variations while using single stove or central heating in the case of wood and coal systems [43]. It is necessary to keep in mind that the environmental damage and climate change also could affect the heating demand in the coming years and especially due to global warming [44]. This is more significant at high elevations, while taking into consideration that the future heating demand is also influenced by the development of population [45].

The current paper presents a review of all heating systems including their impacts on the environment. This will be based mainly on the energy sources used. These energy sources are solid fuels (coal and wood), oil, natural gas, and renewable energy (solar and geothermal). In addition, the effects of the different heating systems' technologies will be also investigated such as heat pumps, district heating, waste heat recovery and poly-generation plants.

2. Heating Systems

The main factor affecting the environment in a heating system is the type of heating source used which can be found in the form of coal, natural gas (NG), solar, bioenergy, geothermal and diesel oil.

2.1 Solid-Fuels

Amongst all heating systems, wood and coal burning has the highest amount of CO emissions. According to [46], the $PM_{2.5}$ emissions is the highest when using coal (1.56 kg/tce) followed by oil (0.4044 kg/tce) then by NG (0.08 kg/tce) if considering a constant heating load.

2.1.1 Coal-Fired Boiler

Burning coal as a source for residential heating has a very low efficiency as well as high impacts on the indoor and outdoor air quality. Globally, use of coal-fired heating systems is decreasing, however, it is still very hard to find attractive alternatives due to coal abundancy and low price [47]. CO emissions depend on the amount of carbon in the fuel. CO emissions and burning rates are linearly related when the carbon content is stable [48]. VOC [49, 50] significantly increase in the flue gas when the temperature in the drop-tube furnace is high. In addition to the effect of temperature, the condensation rate and VOC rates are inversely proportional [51]. The incomplete combustion of coal and low efficiency in residential heating stoves cause huge haze pollution. In order to decrease this pollution, it is better to use semi-coke coal rather than the raw coal, but the remaining problem is that stoves using these low emissions fuels will lead to extra fuel consumption [52] (see Table 1).

Table 1: Difference between semi-coke and raw coal according to proximate and ultimate analyses [52]

Coal	HV (MJ/kg)	Proximate Analysis (%)				Ultimate Analysis (%)			
		Moisture	Ash	Volatile Matter	Fixed Carbon	Carbon	Hydrogen	Nitrogen	Sulphur
Raw Coal	20.413	8.95	17.02	58.80	24.18	56.95	3.34	0.59	0.20
Semi-Coke	28.936	5.66	6.52	11.98	81.50	77.68	1.18	0.71	0.30

2.1.2 Biomass and Wood

Gebremedhin [53] reported that in Norway, the potential of biomass is much higher than that currently used while knowing that burning stoves are causing 60 % of the total PM emissions. Wood is better than oil regarding the PM emissions' DNA damaging and short-term cytotoxicity [54]. Wood burning [55, 56] methods are widely used for residential heating while they still have significant emissions of PM, organic aerosol, black carbon [57] and other pollutant compounds [58]. This is mainly due to the cleaning processes of ash that result in releasing fine and coarse particles. Even though ash removal duration is not too long, but there is a need for using filters such as HEPA (High Efficiency Particulate Air) [59]. Introducing biofuel to the existing district systems (DSs) contributes in decreasing the greenhouse gas (GHG) emissions. Therefore, it could be an effective solution just if biomass is an unlimited source in the heating region [60]. There are different types of wood used in these stoves such as old logwood, modern logwood, automated pellet, and others. The Pellet (natural wood) stove has the lowest pollutant emissions as compared with other old wood stoves [61]. While, among all biomass fuels, charcoal is the best choice to be used for space heating that produces very few amount of smoke and has a thermal efficiency of 46 % [62] (see Table 2).

Table 2: Emissions of some biomass fuels [62]

Fuels	**Carbon monoxide (mg/MJ)**	**Nitrogen oxides (mg/MJ)**	**Sulfur dioxide (mg/MJ)**
Firewood	1489	12.54	19.00
W. shavings	1403	9.72	17.89
H. shell	1667	5.65	20.52
W. shell	2445	8.78	31.65
P. shell	2422	18.32	37.72
S. shell (sweet)	1405	4.52	23.26
S. shell (hot)	1449	4.77	21.49
Corncob	3276	0.75	3.75
Charcoal	2095	2.62	0

Old heating stoves can cause hazardous respiratory diseases, for this reason, improvements are needed. According to [63], some modern technologies are having more negative effects on lungs' inflammations compared to the old technologies. This shows that the degree of toxicity needs to be taken into consideration and not only the amount of emissions. The culture has a great influence on these improvements in order to encourage and give motivations for the users. It is also necessary to note that, the environmental solution is economically feasible because one of the main goals is to decrease fuel consumption [64]. The wood burning process is divided into two phases: initial and stable. The highest amount of emissions are usually produced during the initial phase except the fine particles in which

they are more in the stable one [65]. Figure 1 shows the difference between the emissions of different biomass fuels burning with respect to the time after ignition.

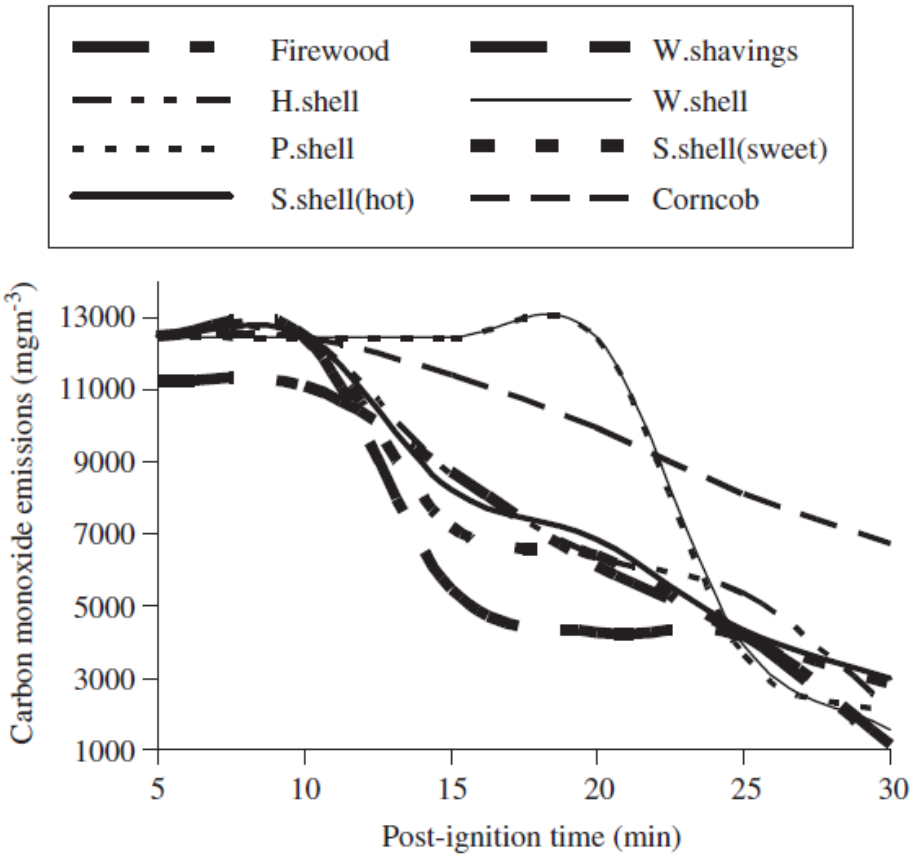

Figure 1: Carbon monoxide emissions of selected biomass fuels with respect to the time after ignition [62]

Biomass and bio-char preheating is a good technique to improve the system's performance, while it obviously causes extra PM emissions. The temperature is a significant factor that affects the size and amount of PM produced. This relation cannot be considered proportional because in fact these emissions have specific peak temperatures. In [66], it was noticed that $PM_{1.0}$ emissions could reach its peak at 500˚C while it starts to decrease again after exceeding this temperature. Some sources and systems cannot be easily compared because one may have less CO emissions while higher NO_x than the other for

instance. In Italy, open field burning of vine residues is very frequently used for heating due to the high abundance of vine. High environmental impacts are recognized because of this usage which imposes to find alternative techniques. Figure 2 presents a comparison between burning vine residues and pellet wood boilers [67].

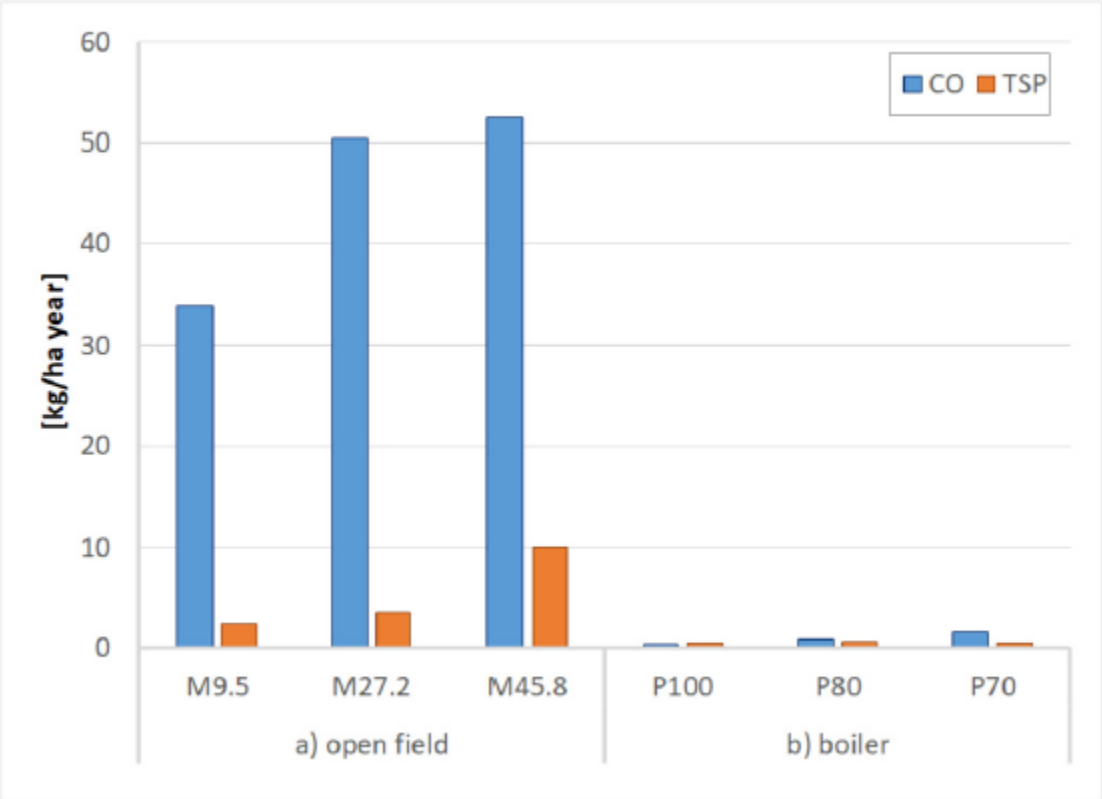

Figure 2: Yearly emissions due to burning pruning vine residues in open field and pellet boilers [67]

2.2 Oil

In some countries and regions, oil is the main heating source such as diesel due to the low price of this heating system, burner, and fuel. PAH and formaldehyde are substances that present the toxicity of PMs. The PAH toxicity resulting from biodiesel is 13 times less while formaldehyde is twice more than that of oil. For this reason, biodiesel is preferred

[68]. Austria is one of the countries that depends on oil-fired boilers for heating. Recently, pellet boilers and oil condensing boilers are found to be good alternatives to the old oil-fired boilers. The demand of pellet boilers has been increasing significantly due to its low GHG emissions compared to oil and to decrease the demand of fossil fuels. However, pellet boilers have other negative effects on the environment such as the Tropospheric Ozone Precursor Potential and Human Toxicity [69]. Eric [70] compared between oil heating systems with that of liquefied petroleum gas (LPG). The author deduced that using LPG instead of oil in Europe could serve in reducing the carbon footprint by 50%.

2.3 Natural Gas

From the environmental point of view, it is better to replace solid-fuel heating systems with natural gas (NG) boilers in order to decrease the amount of CO_2 emissions [71]. Replacing wood burning stoves with compressed NG has also effects on $PM_{2.5}$ emissions such that in Santiago (Chile) [72], 2.07 microg/m^3 has been reduced as an annual average value. However, it is necessary to be aware of potential NG leakage which is considered worse than CO_2 in terms of global warming. Aste *et al*. [73] performed a study on national gas boilers and their effects on NO_x emissions in Italy from 1999 to 2000. It was shown that there is a need for boilers' replacement in order to reduce these emissions by using condensing boilers (see Figure 3). Flue gas quenching has a major impact in decreasing CO and NO concentrations because of the formation of oxidation reactions [74]. Synthetic natural gas (SNG) causes less haze pollution (52 %) such as $PM_{2.5}$ but higher GHGs (65 %) compared to coal. On the contrary, the SNG has low efficiency which imposes to consume extra amount of energy. Thus, it should be adapted in a way to balance between

pollution in urban and SNG-producing areas because otherwise the pollutants will be indirectly transferred from urban to producing regions [75].

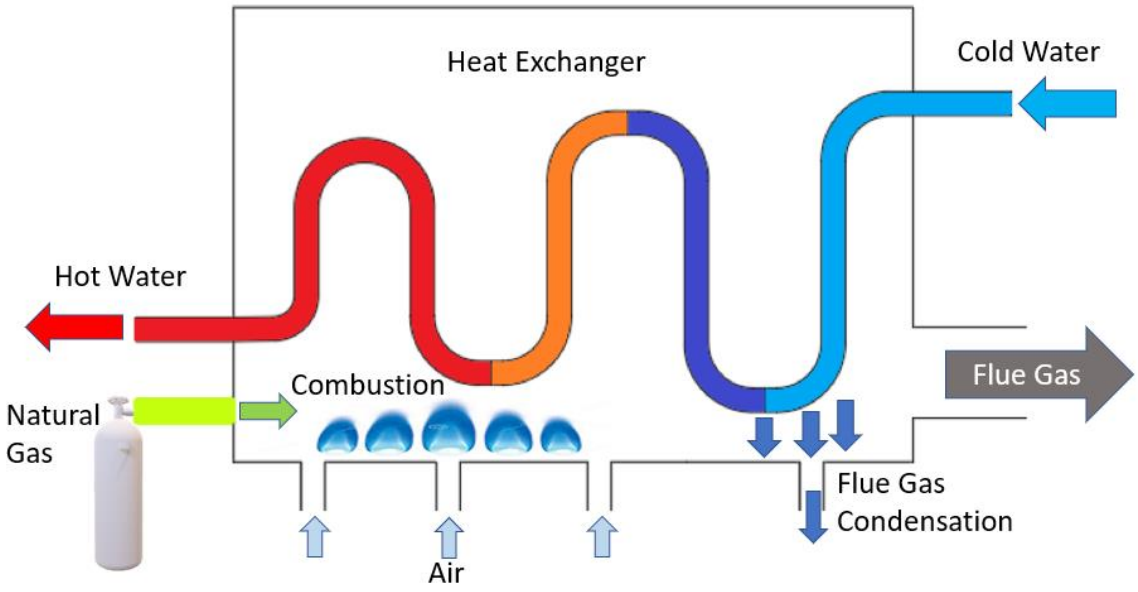

Figure 3: Natural gas condensing boiler

2.4 Air Source Heat Pump

Air source heat pumps (ASHPs) are driven by electric motors in order to supply the compressor with the required work. Indeed, the emissions of such systems are indirectly dependent on the energy sources and technologies supplying the grid with electricity. The performance of a heat pump (HP) relies mainly on the type of working fluid. In several recent studies, CO_2 has been chosen as the working fluid because it is highly abundant. The COP of the CO_2 heat pump depends on the outdoor temperature such that if the ambient temperature increases, the amount of emissions will decrease. It also relies on the seasonal performance factor (SPF), in which significant decrease in the emissions could be attained at SPF higher than 2.44 [76]. Usually, the CO_2 HP is based on supercritical [77] and trans-

critical [78, 79] cycles with R134a sub-cooling device which can help in achieving the optimal performance. The total cost reduction when using a CO_2 HP is 120 % and 26 % compared to the coal and natural gas boilers respectively [80]. Even though, the CO_2 HP emits slightly more amount of CO_2 compared to gas boilers, but it is still very attractive as a replacement for coal and especially in those countries that are not rich with NG (see Figure 4).

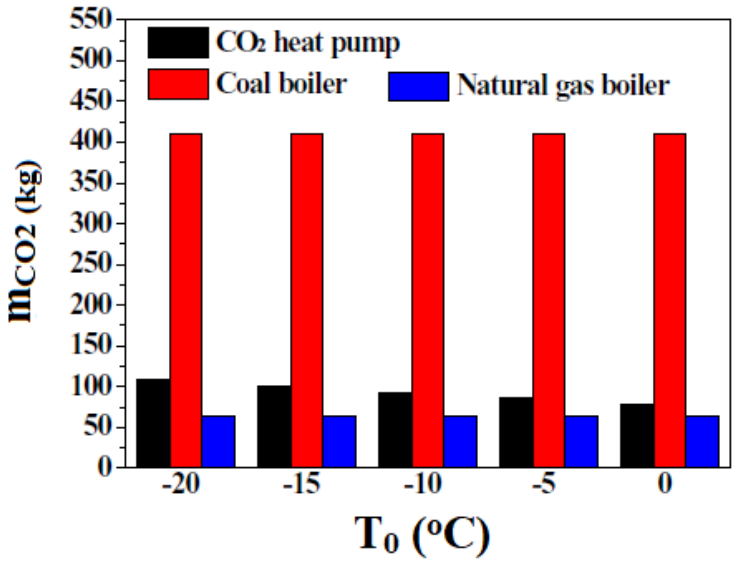

Figure 4: Comparison between coal, natural gas, and CO_2 heat pump [73]

2.5 Renewable Energy

In [81], it was deduced that renewable energy could reduce CO_2 emissions by 40 times compared to that of coal and lignite. Hybrid systems may also contribute in decreasing these emissions and especially if based on RESs [82]. This will furthermore help in overcoming the stochastic nature of most RESs. From this point of view, it is highly preferred to use energy storage systems (ESSs) to stabilize the whole energy system. The main disadvantage that must be taken into consideration is the long payback period in many

cases [83]. However, the priority is to focus on green ESSs from the environmental point of view such as fuel cell [84, 85].

2.5.1 Solar

Solar energy could be used for direct utilization such as heating water or stored [86] by the help of an ESS (see Figure 5). It is necessary to store the heat supplied by the solar energy to be used at night otherwise an auxiliary system must be activated. Solar heating [87] systems are able to reduce 250.4 kg of CO_2/year as an average value for specific units studied in Brazil [88]. This value depends on the climatic zone and the traditional systems used in the region. There may exist many systems that could help in decreasing CO_2 emissions such as the solar water heating but it is not preferred due to economic and cultural perspectives in some cases [89]. Therefore, prioritization is very important in order to focus at first on the environmental aspect. Usually, solar energy systems do not have direct impact on the environment, however, the pollution may occur during the manufacturing and maintenance processes [90].

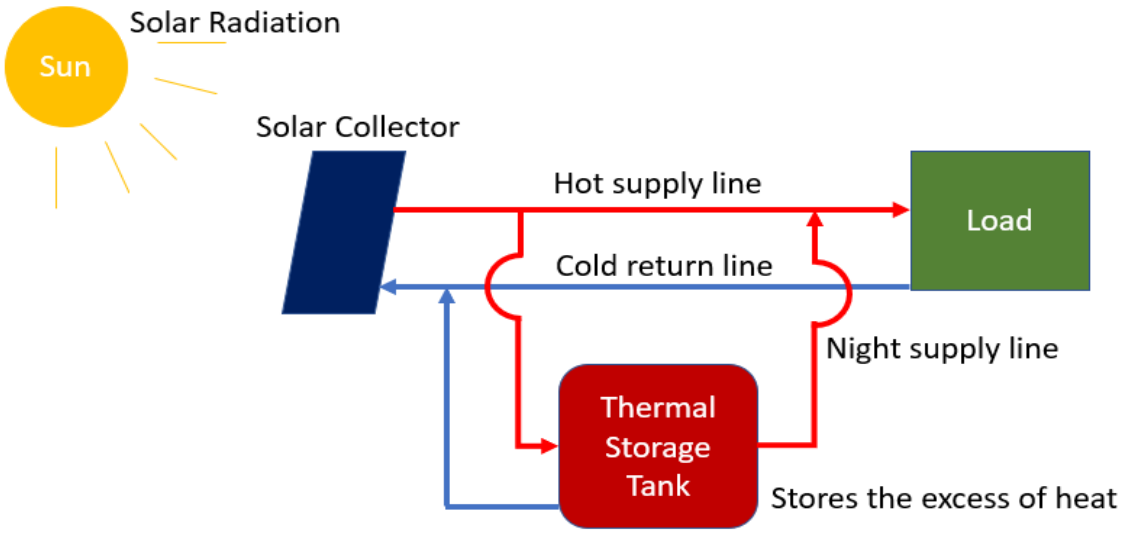

Figure 5: Solar heating system coupled with a thermal storage tank

2.5.2 Geothermal

Geothermal energy (GE) is a very attractive renewable energy source recently due to its independent and non-stochastic nature. It could be used to provide both heating and cooling by the help of the ground source heat pump (GSHP) (see Figure 6). This system takes advantage of high underground temperature in winter with respect to the ambient temperature. In comparison with the conventional ASHP, the GSHP requires less electricity to operate since the ground source compensates this energy difference. This occurs due to the ability of the ground to evaporate the working fluid at a higher temperature. In order to increase the potential of GE; seasonal storage need to be adopted leading to less carbon emissions such as borehole thermal energy storage (BTES) and aquifer thermal energy storage (ATES) [91]. The GSHP is one of the most preferred replacements to NG but still not developed totally to cover all aspects [92]. In [93], it was shown that replacing NG space heating boilers and fossil fuels for heating with efficient HPs such as GSHP and ASHP will decrease the primary energy required by 60 % and CO_2 emissions by 90 % in Europe. Chen *et al*. [94] found that using HPs for heating instead of coal DH systems could reduce the CO_2 emissions by 43 %. On the other hand, condensing gas boilers could be also a better solution than ASHPs in places where solid fuel is the primary source of energy.

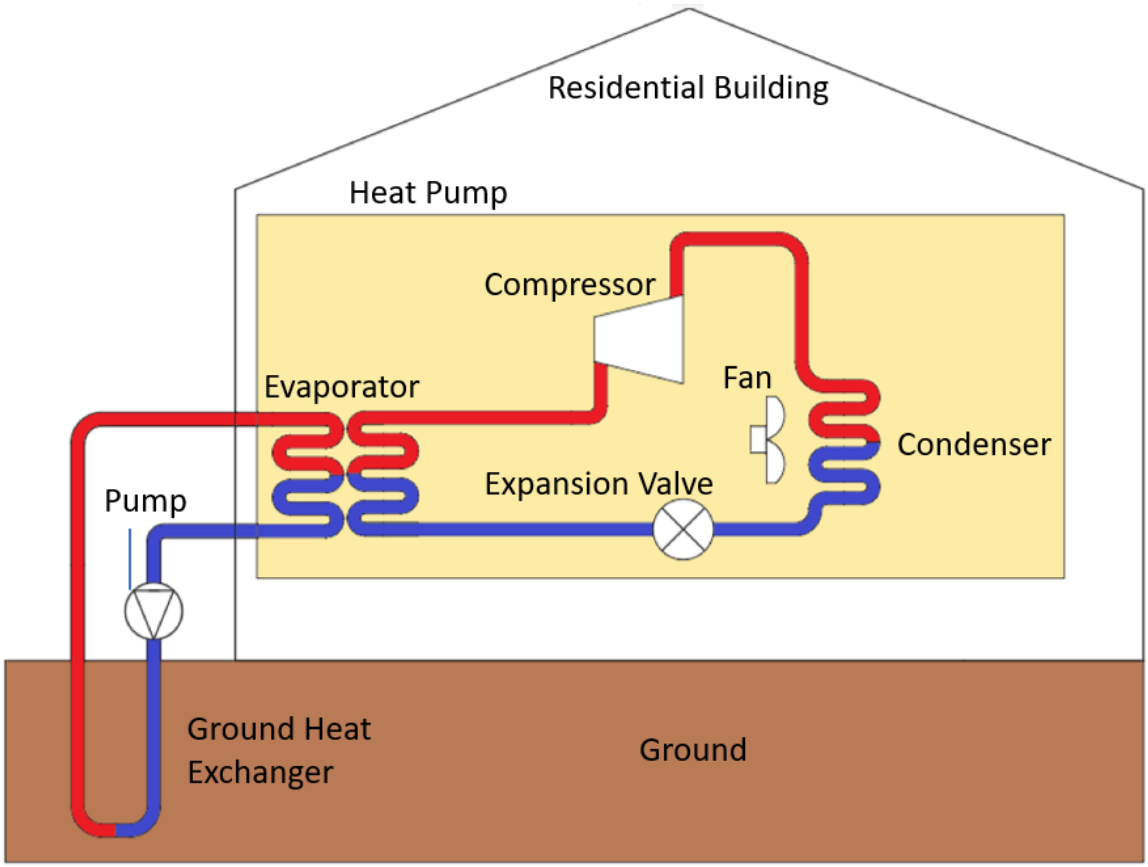

Figure 6: Ground source heat pump in heating mode

3. District Systems

The Emission Factor (EF) of district heating (DH) depends on fuel combustion, handling, and transportation of fuels per delivered unit. If the system is working at constant power, more CO_2 emissions will be released because of the extra amount of energy consumption. Figure 7 represents the concept of DH and its specifications. Recently, district systems (DSs) had jumped to the fifth generation which is based on supplying low temperatures and usually relying on renewable energy sources, and both aim to increase the systems' efficiency, decrease losses and emissions [95, 96]. This generation is also known as bidirectional district heating and cooling system (DHC). In a study performed in Moscow [97], which is the largest city in the world using DH, where it was noticed that the CO_2

emissions were directly proportional to the mean thermal emissions. Since these systems are very large, the network infrastructure construction will indeed have a major impact on the environment in addition to the operational phase. Poland is the country with greatest dependency on DH in Europe, but the problem is that it uses coal as a primary source. Thus, it was recommended to use municipal waste incineration in which it is considered as a better choice than individual systems because of the modern techniques and cleaning methods involved [98]. The expansion of DSs is accompanied by severe problems such as the increase in mass flow rate which may cause large vibrations in addition to the increase in CO_2 emissions. Therefore, performing an optimal expansion is of major importance to solve the mentioned problems while being aware from exceeding technical limitations regarding velocities and pressures [99]. DSs' pipes are usually formed from steel that can be subjected to corrosion over long periods. Chemicals could be a solution to decrease this effect. It was found that oxygen injection is an eco-friendly way in which it activates an oxidation reaction allowing an increase in the corrosions resistance of these pipes [100]. DH has a high environmental performance, but it is still not always preferred depending on the type of source supplying the main system. It is highly recommended to use solar energy and especially the 4-pipe network configuration, while on the other hand, NG is better to be used in individual boilers in each dwelling alone [101].

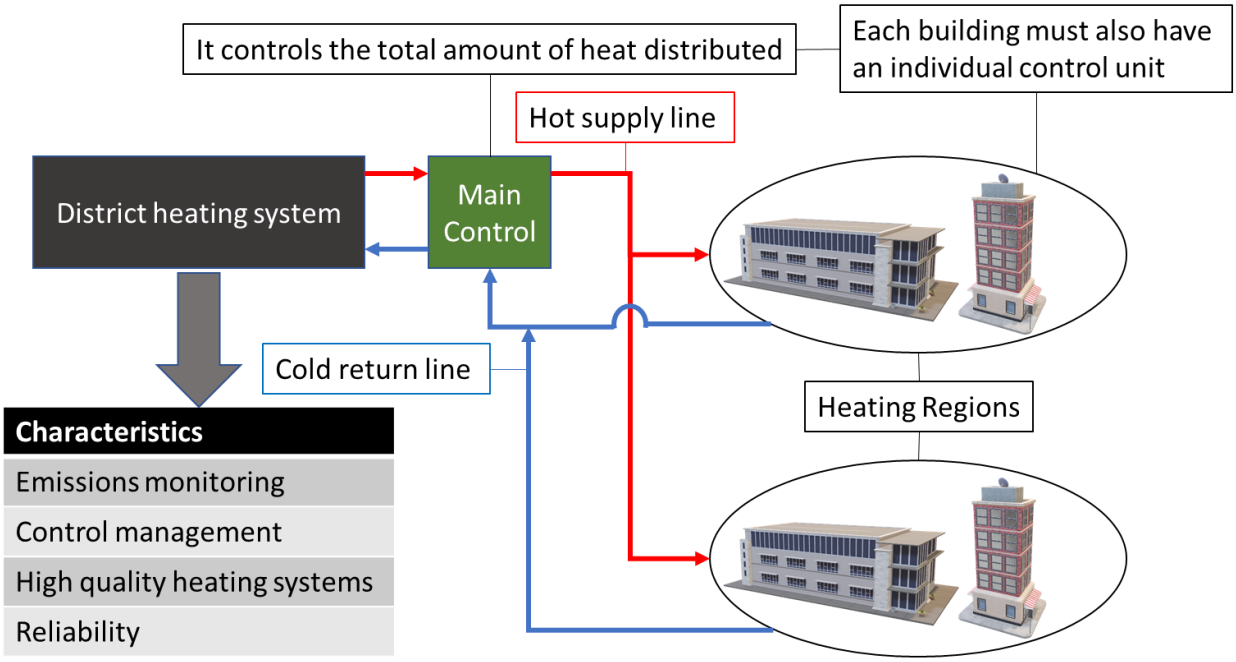

Figure 7: District heating system concept and characteristics

4. Waste Heat Recovery

In most fossil fuel-based energy systems, there are huge amounts of heat wasted to the environment. This energy could be recovered otherwise in order to activate heating systems. This will indeed mitigate the emissions and their environmental effects because the temperature of flue gases is one of the major factors that control the impact of emissions on the environment. Waste incinerators can be used for DH in populated regions but also have significant effects on human health. Waste heat recovery (WHR) systems mainly contribute in decreasing fine PMs [102]. The highest amount of wasted heat could be found in the industrial sector known as industrial waste heat (IWH). Therefore, it is very crucial to study the feasibility of IWH in order to be recovered and utilized again in the form of combined heat and power [103] (see Figure 8). Several recent research studies have investigated techniques to improve the industrial sector via WHR systems. One of the most

important technologies is the heat pipe [104, 105]. This technology was not only valuable in the industrial sector; however, it was very beneficial in the different waste treatment systems such as municipal waste treatment [106]. Furthermore, this technology could also be used for thermal energy storage [107]. All these utilizations make the heat pipe one of the most promising technologies in WHR applications.

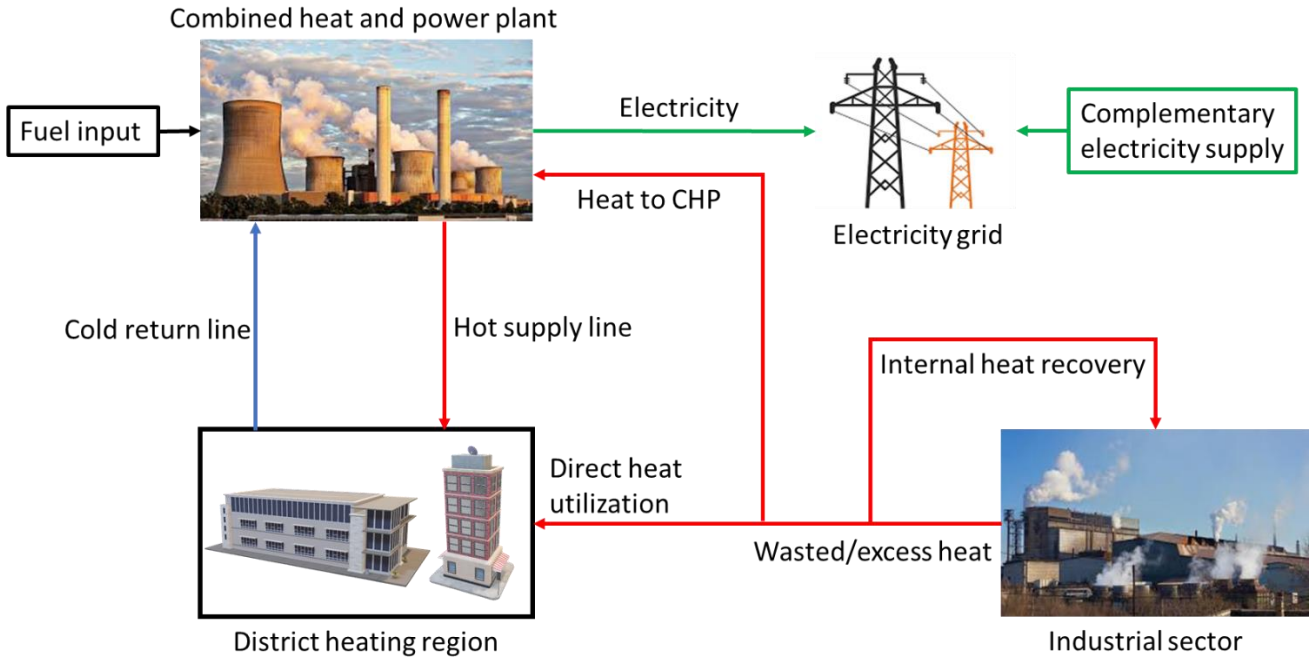

Figure 8: District heating system supported with excess industrial heat

5. Poly-generation and Hybrid Systems

Poly-generation plants aim to supply different types of demands. They are found in two different forms: co-generation and tri-generation. The former is also known as combined heat and power (CHP) [108] while the latter as combined cooling, heating and power (CCHP) [109]. These systems have the ability to decrease the CO_2 and NO_x emissions [110]. In order to supply different forms of energy, it is necessary to use multi-energy sources as shown in Figure 9. In other words, the adoption of hybrid energy systems is

required. These hybrid systems are able to reduce the environmental impact compared to the traditional heating systems. This is due to the decrease in energy losses because they will be transferred to the required form rather than been lost. Hybridization has a great potential in increasing the penetration of renewable energy especially when the renewable source is incapable of standing alone. This is the case of solar energy because it is always absent at night. Hybrid geothermal systems [111] are also highly favorable knowing that GE is usually considered as a low-grade source.

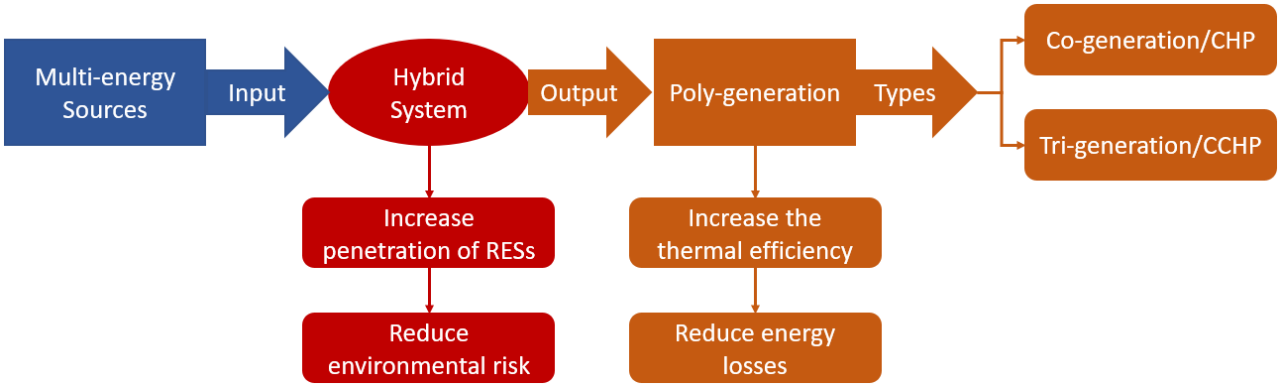

Figure 9: Poly-generation plant characteristics and hybrid energy systems

6. Heating Systems' Pollutant Emissions

As presented in the literature, there are several types of pollutant substances produced by heating systems. There is a similarity between most heating systems in terms of emissions, however, they are different in their quantity and toxicity. For instance, CO_2 is a greenhouse gas that is usually emitted from all heating sources. The result shown in Figure 10 can be deduced from the numerous reviewed studies to compare the effect of all heating systems. This pyramid presents a scale for the environmental impact of the different heating systems. Coal is placed at the top since it has the highest influence, while at the bottom the green color reflects the effect of RESs which is very nil. This does not mean that coal has

the highest amount of all emissions. As an example, wood produces more PM than coal, and natural gas boilers produce more CO_2 in some cases. However, if the whole amount of emissions is taken into consideration at once in addition to their toxicity, coal will be the greatest pollutant heating source as mentioned.

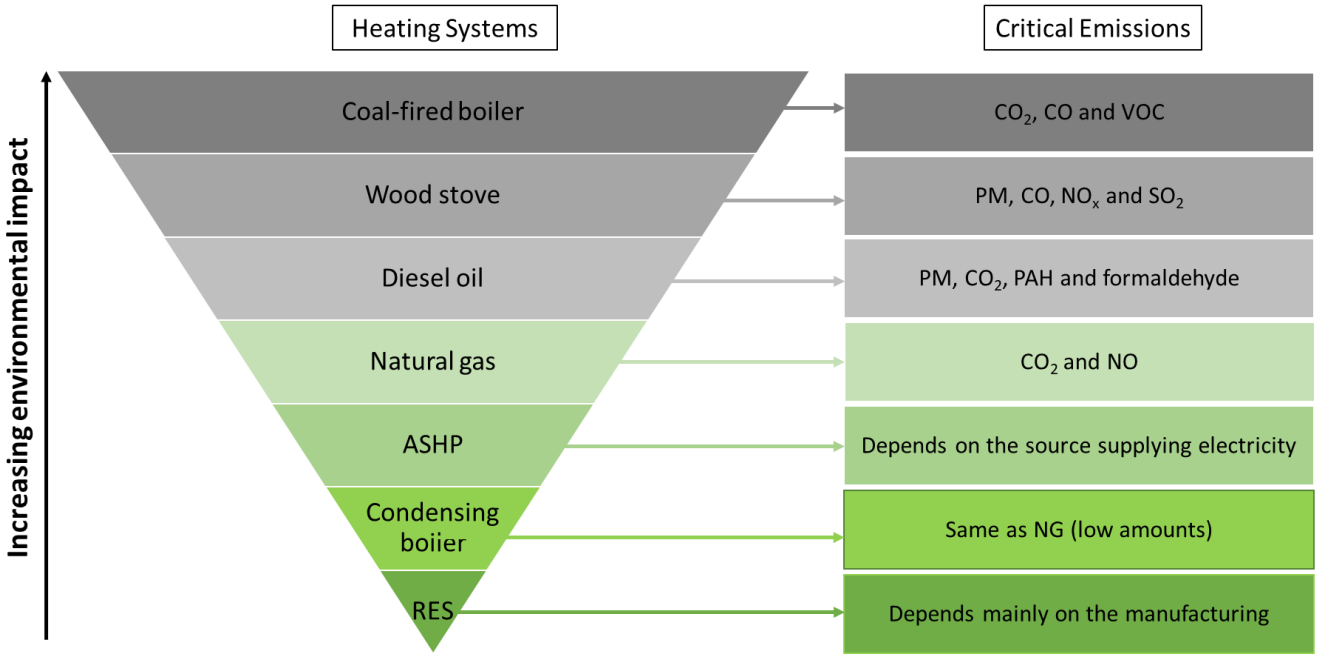

Figure 10: Comparison between the different heating systems according to their environmental impacts

7. Discussion

The environmental impact of heating systems is increasing as a matter of fact due to the increase in population. The importance of this effect is also rising which can be noticed from the studies reviewed in this paper such that most research studies are performed in the last three years and expected to develop more and more in the future.

Environmental effects of heating systems

The impacts of each heating system can be detected by measuring and comparing the emissions of each source and their toxicity. From this point of view, solid fuels involving coal and wood can be considered as the most dangerous systems [42] while renewable energy such as solar and geothermal have the least environmental risks. As it was presented in this paper, it is not easy to compare and choose among all systems due to the interference of several factors. The comparison between the different heating systems is very important in order to choose the most suitable one for each specific case. Even though these differences can vary from one application to the other according to the operating conditions, there are some specifications that can characterize each system with respect to their common usage and frequent previous utilizations. Figure 11 shows the relation between heating systems and the environment. The total amount of emissions and their toxicity are the most important factors that need to be monitored as well as the size of emitted particles, stack height, highest temperature, and operational duties. It is necessary to avoid high flue gas temperatures, that's why quenching is a good choice which is a method used to cool down the flue gases. In addition, the continuous operation is usually preferred to get rid of start and stop losses. DH can shave the negative effects of these operational strategies due to its continuous supply.

Recommendations

It is most essential to increase the penetration of renewable energy and waste heat recovery systems in order to minimize both toxic and global warming gas emissions. This can be performed by constructing new plants or by retrofitting existing ones. In addition, enhancements can be done by supplying different types of loads from the same plant such

as co-generation and tri-generation plants. Furthermore, using different heating sources will ensure stability, especially in the case of renewable energy-based systems. Thus, it is highly recommended to use hybrid systems and poly-generation plants that can shave high peak loads [112]. Providing filters such as HEPA [59], modern ash removal techniques and electrostatic precipitators [113] is a must in all types of heating systems to reduce their emissions and toxicity. This will contribute in decreasing both indoor and outdoor air pollution. The governments should increase pollutants' taxes according to their toxicity in order to decrease the total emissions and their effects [114]. This will indeed enforce all consumers to use new eco-friendly heating systems and encourage the people to replace the old boilers with modern types [115].

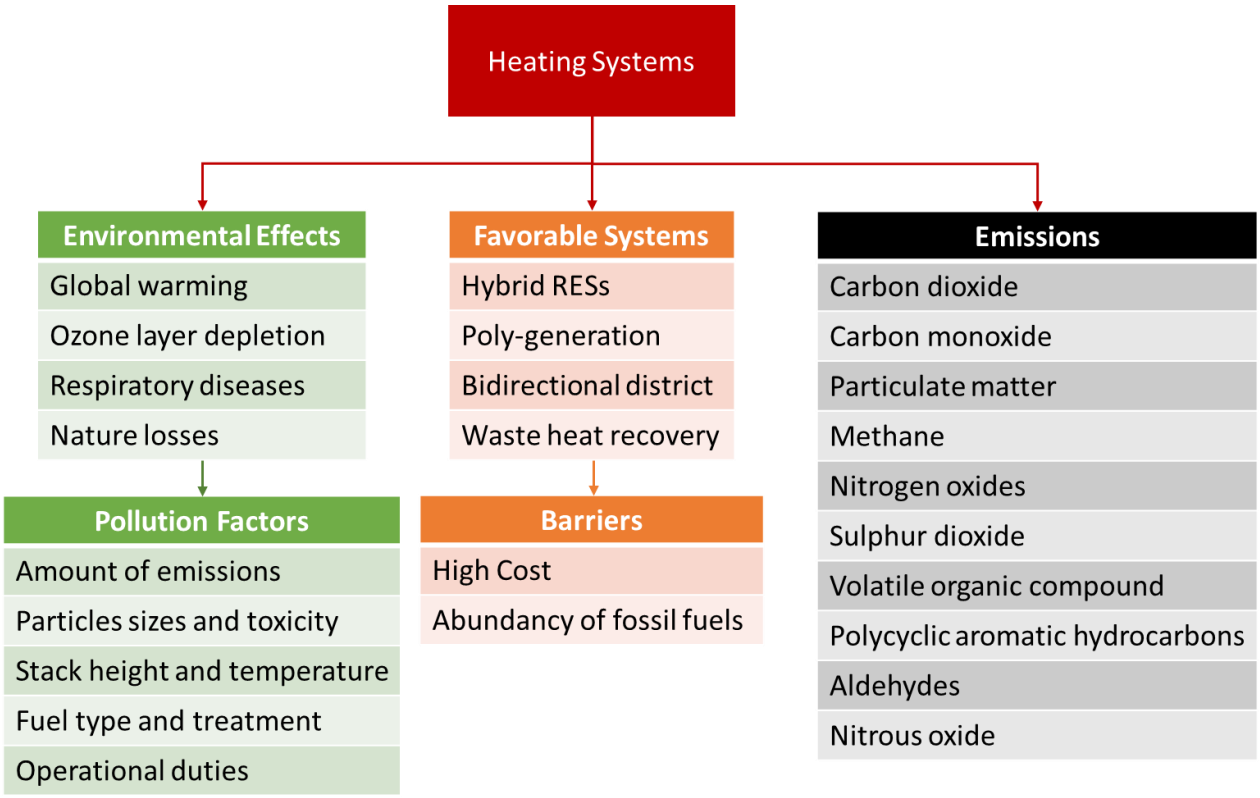

Figure 11: The impacts of heating systems on the environment; factors and barriers

Key elements for future work

- Investigating the environmental impacts for the other types of loads (cooling and electricity).
- Parametric study to choose the best source for specific supply conditions such as the temperature and humidity.
- Designing new hybrid systems with the lowest possible environmental risks taking into consideration the economic feasibility.

8. Conclusion

Environmental pollution has been shown to be significantly different between seasons such that it is very high during winter due to the critical impact of heating systems. The pollutants that are usually monitored to study the heating effects are CO, CO_2, NO_x, SO_2, PMs, N_2O, CH_4, volatile organic compounds, polycyclic aromatic hydrocarbons, and aldehydes. There are several types of heating systems commonly used such as coal, wood, oil, NG, DH, HPs (air source and ground source), solar and WHR. Among all mentioned types, the coal-fired boiler has the highest amount of pollutant emissions followed by wood and then by oil, while the RESs such as solar and geothermal have the least environmental impact. This result was not deduced from measuring only the concentration of emitted substances, it is also based on their toxicity as well. There are several factors that affect the impact of emissions such as the size of particles, temperature, stack height and operational duties. Thus, in many cases flue gas quenching must be applied to decrease the temperature of these emissions. This will indeed help in capturing toxic substances easily such as in condensing natural gas boilers. According to the studies reviewed, it is highly recommended to use renewable sources in order to provide heating and to benefit from

wasted energy by recovering heat from existing plants. WHR has showed a significant influence on the enhancement of conventional heating systems due to the huge amount of wasted heat. This technology could be applied to the industrial sector, waste treatment and individual energy systems. Furthermore, it is necessary to retrofit old heating systems by introducing modern types of filters and ash removal techniques. There is still a major problem which is the abundance and economic attractiveness of some heating fuel sources that are environmentally damaging such as coal which is the most commonly used type. For this reason, it will be a very attractive solution if the government would increase the pollutant taxes which will impose on the users to replace these systems by new eco-friendly systems.

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