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INVENTORY OF REFRIGERANTS IN USE FOR COMMERCIAL PURPOSES IN BOSNIA AND HERZEGOVINA

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Abstract

The paper presents the results of the inventory of refrigerants in use in Bosnia and Herzegovina and a discussion of their harmfulness to the environment. Data on the types, amount of cooling media, type of user and purpose of use were collected through a survey. The research sample included 297 facilities with 745 samples of refrigeration equipment covering facilities from different sectors such as: banks, industry, shopping centres and stores, hotels and hospitals. The findings of this research are important for the analysis of the level of application of environmentally friendly coolants. The research showed that in Bosnia and Herzegovina HFC coolants are mostly used with a share of 96% and HCFC with a share of 3%, while the use of other types of cooling fluids is negligible. Refrigerants that have an ODP equal to zero are mainly used. Natural refrigerant R-717 has the largest share of 36.3%, followed by HFC R-134A with a share of 24.9%. Refrigerant R-404A has the highest GWP of 4210 and a share in the total mass of 16.8%. Refrigerant R-410A, has a share of 16.5% in the total mass and a GWP of 2080. The work identifies promising alternative refrigerants with lower global warming potential (GWP) as a potential environmental substitute for refrigerants under control R -404A, R-410A and R-134.

Keywords: refrigerants, environmentally friendly gasses, global warming potential, ozone depletion potential

1. Introduction

Refrigerants are used in cooling and air conditioning processes, and they might have a negative impact on the environment in terms of ozone damage and global warming caused by the emission of refrigerants. Scientific findings about their harmfulness provoked the signing of international agreements to limit or phase out the use of refrigerants with high ozone depletion potential (ODP) and high global warming potential (GWP). The first agreement was the Vienna Convention for the Protection of the Ozone Layer (1985), followed by the Montreal Protocol on Substances that Deplete the Ozone Layer (1987) and a series of subsequent amendments agreed to control the consumption and production of ozone-depleting substances (ODS). Since 2010, the use of chlorofluorocarbons (CFCs), halons and carbon tetrachloride - gases that are mostly used in refrigeration and air conditioning devices, fire protection systems and laboratories - has

been completely prohibited. The ban on CFCs, that are second generation of refrigerants, stimulated the development of substitutes, first with hydrochlorofluorocarbons (HCFC) and then hydrofluorocarbons (HFC). The HFCs have minor effect on stratospheric ozone, but some of them have a significant GWP. Those were third generation of refrigerants. The first generation of refrigerants (1830 and 1930) had high flammability, toxicity and reactivity. Second generation refrigerants were based on low toxicity and flammability, while the focus of third generation refrigerants was protection of the ozone layer. (Fig1) [1]

However, a concentration of the HFCs in the atmosphere of most currently measured HFCs are increasing in the global atmosphere. HFC emissions increased by 23% from 2012 to 2016 and currently amount to about 1.5% of total emissions from all long-lived greenhouse gases as carbon dioxide-equivalent emissions (GtCO2-eq) [2]. This required the introduction of additional control measures, so the Montreal Protocol has been amended with the ratification and entry into force of the Kigali Amendment (2019), which includes control measures to reduce hydrofluorocarbons (HFCs). Since 2010, the fourth generation of refrigerants with low global warming potential, such as hydrofluoroolefins (HFO) and hydrochlorofluoroolefin (HCFO), has been developed. The fourth generation of refrigerants possess characteristics such as low-global warming potential (GWP), non-toxic, non-flammable, and zero-ozone depletion potential (ODP). (Fig1) [1],[3]. The refrigerants are also expected to have excellent thermodynamic and thermophysical properties. [3]

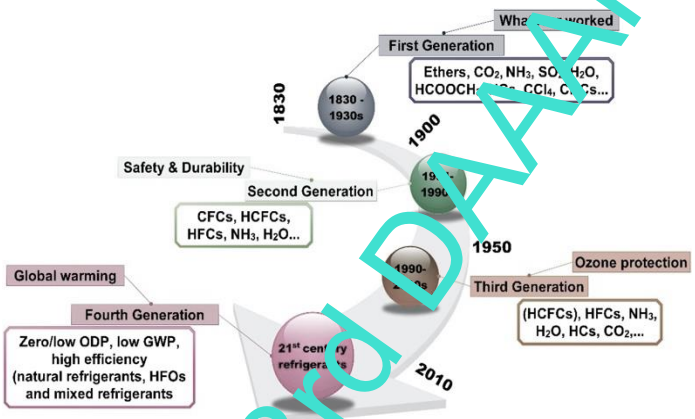


Fig. 1. Progression in the refrigerants over time [3]

Bosnia and Herzegovina ratified the Vienna Convention and the Montreal Protocol, which created prerequisites for the implementation of activities on the phase down of the consumption of substances that damage the ozone layer. Bosnia and Herzegovina as a developing country and a country of Article 5 of the Montreal Protocol (consumption of the controlled substances does not exceed an annual calculated level of consumption of 0.3 kilograms per capita) is obliged to introduce HFC control measures as follows:

- Determination of base consumption for the period from 2020 to 2022;
- Freezing consumption at the level of basic consumption in 2024;
- Reduction of consumption by 10% until 2029;
- Reduction of consumption by 80% by 2045.

Under this background the objective of this research is to diagnose the use of refrigerants in Bosnia and Herzegovina and determine the baseline as an input for policymakers in the design of effective policies to comply with the Vienna Convention, Montreal Protocol and its amendments.

The main contribution of this study is to understand which refrigerants are in use, in which type of refrigeration system, what is the purpose of the refrigeration equipment and the sector in which the equipment is used.

2. Metho

The research sample for the analysis of refrigerants and their impact on the environment included 297 facilities located in 10 major cities and 64 municipalities in Bosnia and Herzegovina. (Fig. 2) .

Fig. 2. Overview of places where refrigeration equipment was registered in BiH

Authors established a database that contains information on the type of refrigeration system, the type of refrigerant used, the purpose of the refrigeration equipment and the sector in which the equipment is used. Refrigeration devices and refrigerants are recorded in facilities of various uses such as: banks, shopping canters and markets, hotels, hospitals, bakeries, processing and canning of fruits and vegetables. meat and dairy industry, etc. Data are grouped into 4 sectors: i) Trade sector, ii) Industry and manufacturing, iii) Tourism, iv) Health care/administrative buildings. The analysis of the harmfulness of cooling fluids was done on the basis of global warming potential and ozone depletion potential.

3. Results and discussion

Shopping canters and stores (commercial sector) have the largest number of registered facilities, the share of which is 68%, while the tourism and hospitality sector has the smallest share, around 3%. (

Fig. 3). The most used are hydrofluorocarbon (HFC) refrigerants with a share of 96%. Hydrochlorofluorocarbons (HCFC) are represented with a share of 3%, while the use of other types of refrigerants is minor.(

Fig. 4).

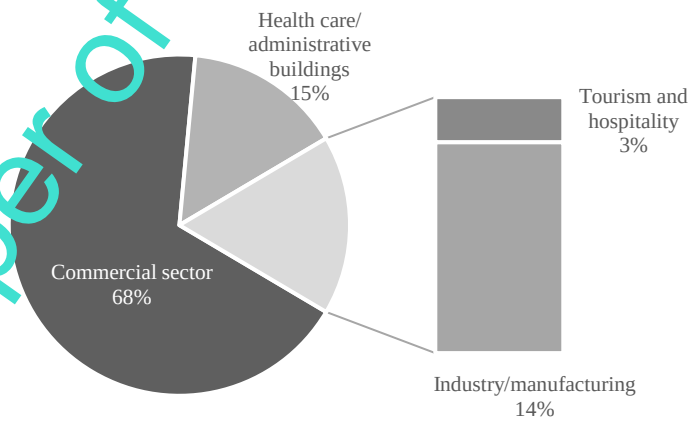


Fig. 3. Sector representation in the researched sample (%)

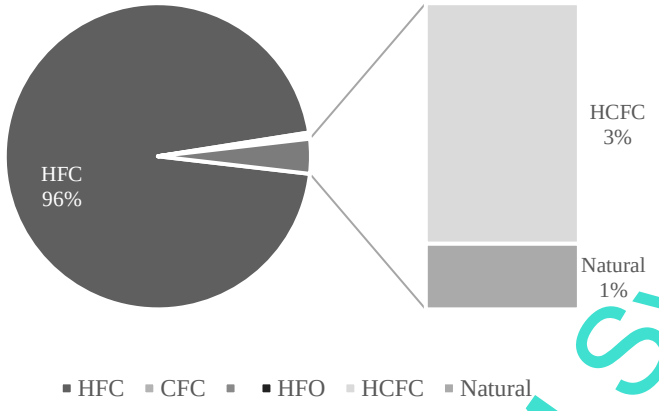


Fig. 4. Shares of use of refrigerants (%)

The total mass of refrigerants registered amounted to 6.7 t. The total of 17 types of refrigerants has been registered having a mass between 8,7 kg to 2,4 tones. Ten of them are HFC, while there is also banned CFC still in use.

No	Refrigerants	Type	Mass (kg)	GWP at 100-yr time horizon [2]	ODP
1	R-407C	Blend HFC	2328,90	1730	0
2	R-404A	Blended HFC	1095,83	4210	0
3	R-410A	Blend HFC	11111,01	2080	0
4	R-134A	HFC	16470,00	1360	0
5	R-22	HCFC	360,90	1780	0,05
6	R-717	Natural (Carbon Dioxide CO_2)	24072,00	0	0
7	R-407A	Blend HFC	70,00	2070	0
8	R-744	Natural (Ammonia NH_3)	380,00	1	0
9	R-32	HFC	36,00	705	0
10	1233zd (E)	HCFO	25,00	3,7	0
11	1234yf	HFO	25,00	<1	0
12	1234ze (E)	HFO	25,00	<1	0
13	R-12	CFC	50,00	10300	1
14	R-143A	HFC	303,00	5080	0
15	R-407F	Blend HFC	47,60	1790	0
16	R-417A	Blend HFC	10,00	2346	0
17	R-449A	Blend HFO/HFC	8,70	1370	0

Table 1. List of registered refrigerants in BiH

The CFC refrigerant R-12 has share of only 0, 02%, but it is ODPs. According to the Montreal Protocol, Bosnia and Herzegovina was required, as developing country, to phase out the CFCs by January 1, 2010. Beside its ozone depletion potential, it is refrigerant with the highest GWP of 10300, among those registered in Bosnia and Herzegovina.

Refrigerant R-717 (ammonia) has the largest share in relation to the total mass and is 36.3%. The GWP of this refrigerant is 0, with atmospheric lifetime of 0,019 years. This is a natural refrigerant, with widespread use in medium and large food, beverage and preservation industry and has growing potential in HVAC chillers, thermal storage systems, process cooling and air-conditioning, district cooling systems, supermarkets, and convenience stores. R-717 at concentrations above 300 ppm have toxic effects and is “moderately flammable” in air when its concentration ranges between 16% and 28% weight. [4]

R-22 is HCFC that is, like R-12, regulated by the Montreal Protocol. The protocol identified CFC refrigerants and HCFC as substances possessing exceedingly high ODP. For developing countries, the complete phase out of HCFC is scheduled for January 1st, 2030.

As for other cooling agents, the following have a significant share in relation to the total mass (fig. 5):

- R-404A with a share of 16.5% in the total mass, whose GWP is 4210, and ODP is zero;
- R-410A with a share of 16.8% in the total mass, whose GWP is 2080 and ODP is zero;
- R-134A with a share of 24.9% in the total mass, whose GWP is 1360 and ODP is zero.

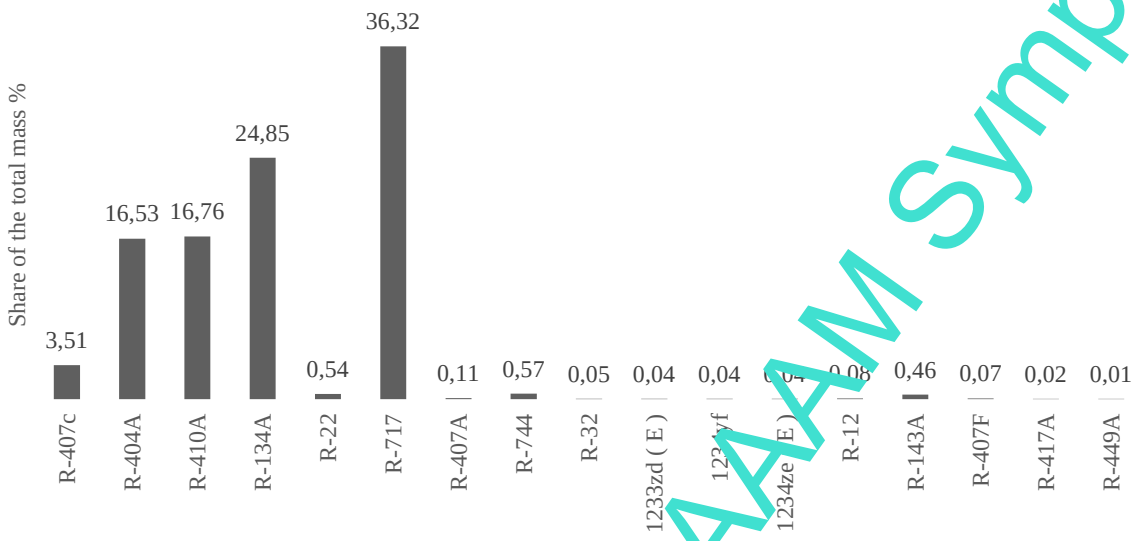


Fig. 5. Share of refrigerants in the total mass (%)

Taking into account the GWP and the total mass, the most harmful refrigerant from the list, which is widely used in Bosnia and Herzegovina, is blend HFC R-404A with the GWP of 4210. R-404A is composed of R-125/R-143a/R-134a with share of 44/52/4 % respectively. It has low toxicity, and it is not flammable; its boiling point allows it to work in low temperature refrigeration applications. R-404 A was used as a successful replacement for R-22 in refrigerated transport, which was possible even while maintaining the existing equipment. Keeping existing equipment in refrigerated transport has proven to be a cheap solution and a wise option in times of crisis. R-22 and R-404A have similar thermodynamic characteristics. [5]

The EU F-gas regulations of 2015 set restrictions on the use of HFC refrigerants with the GWP >2500. The regulation aims to reduce the supply of HFCs from 100% in 2015 to just 21% of that total in 2030, and prohibits the use of refrigerants with the GWP > 2500 in new stationary refrigeration equipment, except for those intended cooling the product to temperatures below – 50 °C. This restriction applies to R-404 A as well as R-12 and R-143A, both having the GWP above 2500. [6] Scientists have analysed the gases R-448A, R-449A, R-454C, R-455A, R-442A, R-407H and R-452A as substitutes for R-404A and they have noticed a lot of differences between them. R-455A and R-465A represent the maximum reduction of the coefficient of performance (COP), while R-442A, R-449A and R-407H can represent an energy benefit. [7] The R-404 A is also widely used for the plug-in type refrigerating or freezing equipment in restaurants, health institutions, markets, etc. Due to the provisions of the EU F Gas regulation [6], which allows the use of only refrigerants with GWP < 150 for hermetic refrigerators/freezers of small capacity from January 1, 2022 refrigerants to replace R404-A with refrigerants with GWP < 150 have been investigated. The researchers suggested that the refrigerants R-454C, R-455A, R-457A and R-465A can be used as alternatives to R404A in all types of plug-in equipment such as both freezers and chillers and it is possible to achieve reduction in GWP about by 95% as a result of using those alternatives. [8]

R-410A is blend refrigerator made up of 50% R-32 and 50% R-125 and was developed as an R-22 replacement for air conditioning systems. The EU F Gas regulation [6], also effects R-410A, as the split air conditioning systems, are limited to operating with refrigerants whose GWP is below 150. Various researchers tested potential R-410 low GWP alternatives against main parameters such are: increases or decreases in cooling/heating capacity, COP, and compressor discharge temperature. Some studies addressed also the Total Equivalent Warming Impact (TEWI) and Life Cycle Climate Performance (LCCP) analyses provide a measure of total CO_2 emissions over the equipment lifespan. A comprehensive analysis of different studies related to comparison between R-410A and alternative refrigerants is presented in [9]. Based on the analyses performed the author recommends R-452B and R-454B, both available on the market as suitable alternatives. Both refrigerants presented for most of the reviewed studies that the COPs and the cooling (or heating) capacities are similar to systems operating with R-410A, as well as that they have lower TEWI and LCCP

values. The R-452 provides an overall performance closer to match R-410A, resulting in minimal equipment redesign and costs. while R-454b is the most environmentally friendly refrigerant. [9].

Although with the GWP lower than 2500, HFC-134a remains the most abundant HFC in the global atmosphere and has the largest annual growth rate and emission. The global annual mean mole fraction reached 89.5 ppt in 2016, up from 67.7 ppt in 2012. Global emissions have increased by an average of 10 Gg yr−1 since 2008, faster than emissions of any other HFC. [2]. Like other HFCs, it is regulated by the F-Gas Regulation, which determines deadlines, in relation to the type of equipment in which it is used, after which the gas can no longer be in use (

Table 2).

Products and equipment		**Date of prohibition**
Refrigerators and freezers for commercial use (hermetically sealed equipment)	that contain HFCs with GWP of 2500 or more	1 January 2020
	that contain HFCs with GWP of 150 or more	1 January 2022
Stationary refrigeration equipment, that contains, or whose functioning relies upon, HFCs with GWP of 2500 or more except equipment intended for application designed to cool products to temperatures below –50 °C		1 January 2020
Multipack centralized refrigeration systems for commercial use with rated capacity of 40 kW or more that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more, except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP of less than 1500 may be used		1 January 2022
Movable room air-conditioning equipment (hermetically sealed equipment which is movable between rooms by the end user) that contain HFCs with GWP of 150 or more		1 January 2020
Single split air-conditioning systems containing less than 3 kg of fluorinated greenhouse gases, that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 750 or more		1 January 2025

Table 2. F-Gas regulation restrictions against HFCs [6]

The fourth generation of refrigerants, with the zero ODP and the GWP below ten, namely 1233zd (E), 1234yf, 1234ze (E), have minor share of 0,12% in total mass. Those HFOs are commercially important short-lived replacement compounds that have been developed as the replacement for the controlled HFC refrigerants [2]. In recent years, scientists are putting lot of attention to study various aspects of HFO refrigerants such as the thermodynamic and transport properties, flammability and oil compatibility, boiling and condensation heat transfer performance and their performance in actual vapour compression refrigeration systems. There are still some open areas to be further investigated: flammability of HFO refrigerants while considering the effects of temperature and relative humidity on lower flammability limit (LFL) and upper flammability limit (UFL), oil compatibility of high boiling HFO refrigerants at various temperature and pressure, identification of suitable compressor oil for each and every HFO refrigerant, the boiling and condensation heat transfer performance investigations of HFO/oil mixtures at various oil concentrations, etc. [10]

The registered refrigeration equipment has several areas of use:

- Refrigeration of storage;
- Refrigeration of premises;
- Deep freezing of goods;
- Heating of premises;
- Heat pumps;
- Ice production;
- Industrial processes cooling.

Refrigeration equipment has the largest application in the area of refrigeration of storage, which accounts for 44.4%, and refrigeration of premises, which accounts for 42.7%. Freezing of goods has share of 10%, industrial process cooling 1,7%, while share of other areas of use amounted to less than 1%. (Fig. 6)

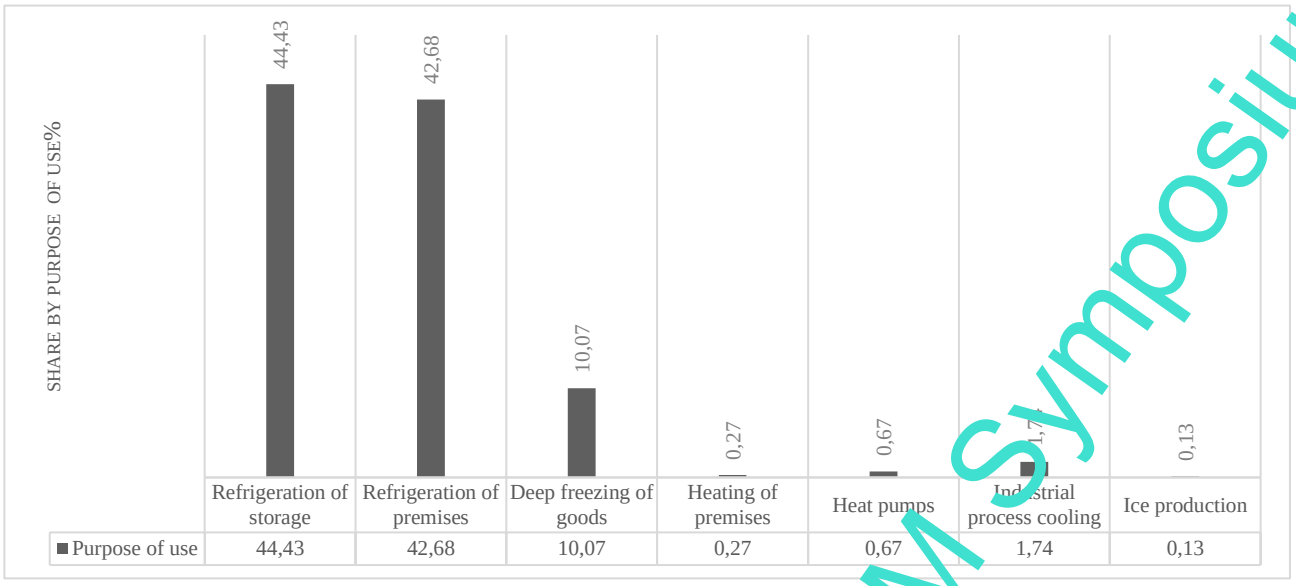


Fig. 6. Share by purpose of refrigeration equipment (%)

R-717 is represented in Bosnia and Herzegovina in the industry and production sector. (Fig. 7) The largest application of R-134A is in the administration and healthcare sector, whose share is 40.6%, and a similar level of application is in the commercial sector, whose share is 37.5% (Fig. 8). Refrigerant 404 A has the largest application in the commercial sector, that share is 78.5%. Refrigerant R-410A is most widely used in the commercial sector, with a share of 60.6%, and this refrigerant is also widely used in the administration and healthcare sector, with a share of 25.7%. (Fig. 9) R-407C is most widely used in the commercial sector, with a share of 44.4%. Also, this refrigerant is widely used in the administration and health sector, whose share is 42.8%. (Fig. 10)

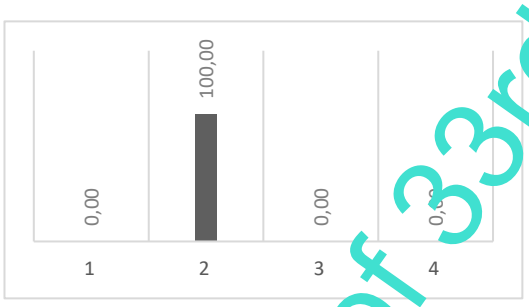


Fig. 7. Share of R-717 per sector (%)

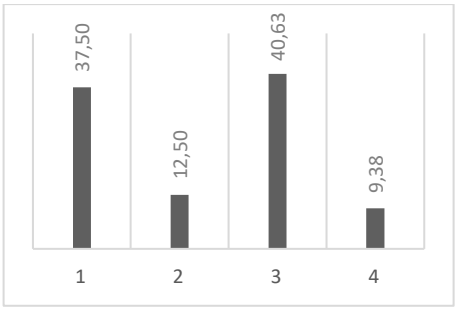


Fig. 8. Share of R-134A per sector (%)

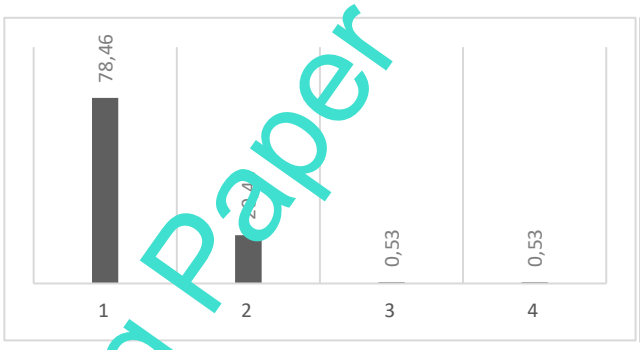


Fig. 9. Share of R-404A per sector (%)

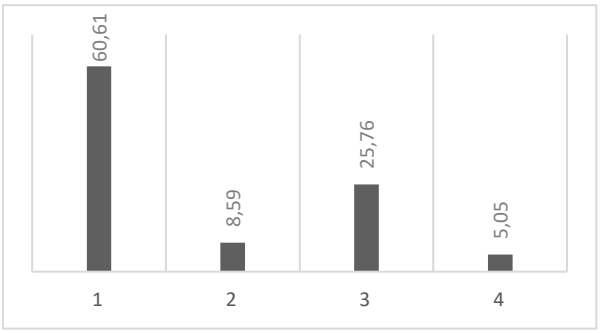
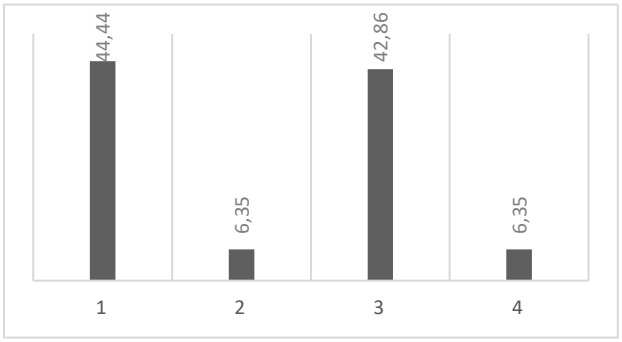


Fig. 10. Share of R-410A per sector (%)



Legend:
1-Commercial sector
2-Industry and manufacturing
3-Administrative and health care buildings
4-Tourism and hospitality

Fig. 11. Share of R-407C per sector (%)

4. Conclusion

The results of this study provide an approximation of the way in which refrigerants are used in different sectors in Bosnia and Herzegovina and enable an assessment of the current situation in the context of the level of use of environmentally acceptable refrigerants. The results should be taken with a small reason because not all facilities and equipment are registered, but they give a clear picture of the types, dominant representation of refrigerants and the sectors in which they are used. The main obstacles to the registration of refrigeration equipment are the lack of data on the number of hotels, motels, restaurants, supermarkets, etc., as well as the lack of a legal obligation for equipment owners to submit data to competent authorities.

Out of the total registered mass of 6,7 t , the most commonly used refrigerant gases are HFC with share of 96%, while environmentally friendly gases such as natural gas R-717 or fourth generation gases HFO/HFCO are not frequently used. Refrigerants having ODP equal to zero are mostly in use, except for banned CFC R-12 and HCFC R-22 which has to be phased out until January 1st, 2030. Although both of the controlled refrigerants are present in the research sample with a very small percentage of 0,62 % it indicates that better control of import, use and service and maintenance of equipment is needed.

Refrigerants R-143a, R-404A have a share of approx. 17% their GWP is greater than 2500 and should be phased out until January 1st, 2030. HFC gases with the high GWP: R-407C, R-407F,R-417A and HFC/HFO R-449A are represented with only 0,21%.

Although the EU F-regulation does not refer to non-EU countries, Bosnia and Herzegovina as EU accession country should speed up phasing down of R-134 A and R-410-A, with gases having the GWP below 150. 78% of the total R-134A is used in administration & healthcare and in a commercial sector. With a share of 78.5%, R-404 A has the largest application in the commercial sector. R-410A is widely used by administration & healthcare and a commercial sector. Industry and production sector mostly use natural refrigerant R-717 followed by R-134 A.

Commercial sector has become aware of the importance of changing their refrigerants for more environmentally friendly gases, such are 1233zd (E), 1234yf, 1234ze (E), but their share in the total registered mass of 6,7 t is just 0,12%.

Recent scientific research has shown that there are environmentally friendly suitable alternatives for gases that need to be phase-down, and some of which are already present on the market as a commercial product.

Further survey should include refrigeration and air-conditioning equipment and refrigerants at residential sector and transport, mobile air-conditioning(MAC) sector and other sectors (foam, aerosol, solvents and fire suppression).

5. Acknowledgments

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