Carbon footprint of reservoirs in Bucharest

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Abstract. The paper presents the carbon footprint of the 10 reservoirs on Colentina river in Bucharest. There were presented entry data and hypotheses used by G-res tool who was applied for determining GHG emissions of these reservoirs. Therefore, we now have a good picture about their contribution to the overall GHG emissions in Bucharest.

1 Introduction

Used since ancient times, the regulation of water courses and the creation of lakes, with numerous benefits for the population - irrigation, water supply, navigation, flood protection, hydroelectricity, recreation - are common both in and near cities and in remote, hard-to-reach areas. Today few rivers are untouched by human activities.

The creation of freshwater reservoirs by damming rivers results in changing the characteristics of the aquatic system from a flowing to a static, lentic system. These lentic systems are characterized by active carbon exchange from one species to another, mineralization at different end products, enhanced sedimentation, gas emissions at the air-water interface.

Concerns about climate change generated research to determine the contribution of natural or anthropogenic lakes to greenhouse gas emissions, the variation of this contribution in different regions of the world and under different environmental conditions, to determine the ecological footprint of newly created or existing reservoirs [1-3].

As a result, numerous studies in recent years confirm that inland waters, regardless of their type - stream/river, pond/lake/reservoir - represent an important component of the total greenhouse gas (GHG) emissions budget [4-12].

Estimating greenhouse gas emissions from lakes is a complex problem, and recent research has developed tools and methodologies, as G-res, to assess it [1-3, 13-17]. Basically, all the methodologies are based on measurements of GHG emissions from reservoirs in different climate zones. The reported results highlight the importance of certain characteristics of reservoirs/watercourses and their catchments, e.g. climate, reservoir age and depth, watershed lithology and land cover, water quality – pH, dissolved oxygen, TN, TP, trophic state, and so on [18-21].

In this paper, GHG emissions related to the cascade of reservoirs on the Colentina River, in Bucharest area, are evaluated by using G-res tool.

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2 Materials and methods

2.1 G-RES tool

Available online, for free, G-res allows users to determine GHG emissions of natural or artificial lakes and reservoirs. It also presents the advantage of performing the allocation of GHG emissions from reservoirs between the different uses, as well as the estimation of the possible emissions associated with different unrelated anthropogenic sources.

It can be used for the study of existing lakes or for those expected to be created and considers the emissions due to the construction works performed. As input data, values related to the climate, the age of the reservoir, solar radiation, the water uses, the land cover, the type of soil, the surface of the reservoir and the hydrographic basin, as well as the concentration of phosphorus in the reservoirs and the carbon content of the soil are required.

As a result, the emissions before and after the development are delivered, including the evolution over 100 years, the estimated lifetime of the reservoir, the emissions from non-anthropogenic sources (UAS), the emissions from the construction phase and the allocation of GHG emissions between the different uses of the reservoir [14].

2.2 Description of the study area

The Colentina River is a typical small, heavily meandering river of the countryside, which naturally often dries up in summer. It is part of the Argeș river basin and is a left tributary of the Dâmbovița River, which in turn is a tributary of the Argeș River [22, 23]. The river basin of Colentina River is presented in Figure 1 and some hydrographical and hydrological characteristics are presented in Table 1 [24].

Fig. 1. Colentina River hydrographic basin [25].

Table 1. Characteristics of the Colentina River [24].

Source Area	Dâmbovița county, Nucet village
Mouth	Dâmbovița, Cernica village
Altitude at the Mouth	52 masl
Altitude Difference	127 m
Catchment Area	643 km²
Length of Watercourse	101 km
Average Flow	0.60 m³/s – Colacu (upstream Bucharest) 2.39 m³/s – Cernica (downstream Bucharest)

Colentina is a river body of indigenous origin, which springs from the southern end of the alluvial cone at Târgoviște, in the village of Nucet, at an altitude of 179 masl. After crossing 101 km, of which 37.4 km are in the Bucharest area, it flows into the Dâmbovița

River. In its course, Colentina River collects the flows of two tributaries: Baranga stream, with a length of 31 km, and Crevedia stream, 30 km long. These tributaries together with their collector drain cover an area of 643 km^2.

The density of the hydrographic network in the Colentina basin is 0.25 km/km^2, below the national average. The sinuosity coefficient of the riverbed is of 1.56 and its slope is less than 1‰. In the middle and lower reaches the degree of meandering is very pronounced, leading to extremely low water velocities.

Data recorded at the Cernica hydrometric station show that a mean flow of 2.39 m^3/s is transited through the Colentina River. During summer, and especially during dry periods, the lowest flows are recorded, up to 8-10 l/s. The average specific runoff calculated over the entire basin is 3.8 l/s/km^2. In rainy years, exceptional flood waves may occur, as happened in July 1975, when heavy rainfall recorded the historical maximum flow of 57.9 m^3/s (Colacu station). The low slopes and low flow velocity favored the creation of marshy areas, which had to be drained and transformed into reservoirs [26].

The general action plan for the hydraulic development of the Bucharest region was drawn up in 1932 by the engineer Nicolae Caranfil and included several stages:

- **Stage I**: Buftea reservoir; 18 months, completion September 1934,
- **Stage II**: Băneasa and Herestrău reservoirs; 5 months, completion June 1935,
- **Stage III**: Bilciurești dam on the Ialomița River and the Bilciurești - Ghimpați diversion; 18 months, completion November 1936. Floreasca reservoir, completion in September 1936,
- **Stage IV**: Tei reservoir (including the dam); 16 months, completion September 1937,
- **Stage V**: Fundeni reservoir; completion 1938-1939. Mogoșoaia-Băneasa channel; completion 1939-1940,
- **Final stage**: Pantelimon and Cernica reservoirs, with the capital's industrial port and the link with the Dâmbovița Argeș navigation channel, completion 1941-1950 [27].

By 1940 only 7 of the 15 reservoirs had been completed. The following ones were built from 1968 onwards, with some modifications to the original plans. In 1970 the whole series of reservoirs on the Colentina River was completed as they exist today.

Nowadays there are 15 reservoirs on the Colentina River, about 56 km long and a total head of about 49 m, with a total surface area of 1500 ha and a total live storage of 44 Mm^3, created by damming the river and draining the marshy/swampy riverbed. The dams are of the homogeneous earth dam type, with the upstream side covered with concrete slabs and the downstream side covered by grass. Of these reservoirs, 10 are in the territory of Bucharest, marked in Table 2 (Străulești to Dobroești), where water uses means: fish farming (F), irrigation (I), flood protection (FP), recreation (R).

Along the Colentina River there are no dykes. The flood defense infrastructure consists of 18 dams on the upstream side, which control the flow of the Colentina River, Figure 2.

On the tributaries there are about 20 dams more. The dams on the Colentina River are either for fish farming or for flood protection, starting from upstream: 2 dams (Ciocănești 1 and Ciocănești 2) with low attenuation volume are under the administration of the fishing companies; The other 16 dams are under the administration of NARW (National Administration Romanian Waters) (7) and the municipality of Bucharest (9). The largest, Buftea reservoir, located furthest upstream, has a large attenuation volume and controls most of the flood flow. All reservoirs belong to the Bucharest flood defense line [29].

During summer, reservoirs on Colentina River show the phenomenon of algal blooms due to the high concentration of phosphorus and nitrogen in the water, substances that enter the water through several pathways, including insufficiently treated domestic wastewater from upstream communities along the river or from the supplemental food offered to fish in reservoirs where fish farming is practiced [24].

Table 2. The 15 reservoirs on Colentina River [28].

Reservoirs	Surface [ha]	Max depth [m]	Volume [Mm^3]	Water uses*
Buftea	307	8	9.6	F, I, FP, R
Mogoșoaia	66	4	2	F, I, FD, R
Chitila	75	5	0.86	I, R, F, FP
Străulești	**39**	**5**	**0.7**	**F, I, FP, R**
Grivițta	**80**	**4**	**1**	**F, I, FP, R**
Băneasa	**40**	**3**	**0.6**	**F, I, FD, R**
Herăstrău	**77**	**5**	**1.5**	**F, I, FP, R**
Floreasca	**70**	**5**	**1.6**	**F, I, FP, R**
Tei	**80**	**4**	**1.9**	**F, FD, R**
Plumbuita	**55**	**4**	**0.9**	**F, I, FD, R**
Colentina	**29**	**5**	**0.6**	**F, I, FD, R**
Fundeni	**123**	**5**	**8**	**F, I, FD, R**
Dobroești	**120**	**2**	**2**	**F, I, FD, R**
Pantelimon	260	4	12.3	F, I, FD, R
Cernica	360	3	0.44	R, F, I, FD

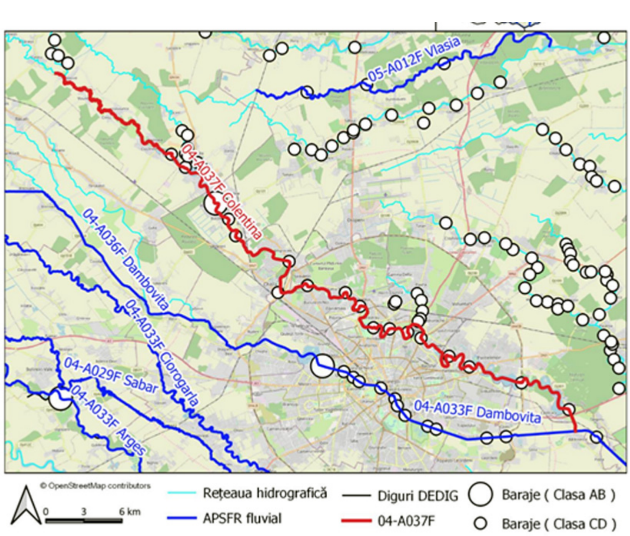

Fig. 2. Flood defense infrastructure of the Colentina River.

These reservoirs do not face serious problems of contamination with pollutants, but even after a brief analysis of some water parameters, the presence of pathogenic germs can be observed, which indicates that the water has been contaminated with human or animal faecal matter and shows the need to connect to the sewage network some marginal neighborhoods or small upstream localities. It also shows that the maximum permissible values for cadmium, copper and lead, heavy metals which can be a danger to human health if water is consumed directly from the river or if fish is eaten excessively, are exceeded, as they tend to accumulate in animal tissues and eventually end up in the human body.

At present, the water quality of the Colentina River's reservoirs is inadequate. This is due to the direct discharge of wastewater upstream from Bucharest into the Colentina River by industrial units and the population: Buftea (food industry, light industry, population, pollution consisting of nutrient inputs), Crevedia (poultry farm, population), Mogoșoaia (film industry, population). On the other hand, the reservoirs on the Colentina River have not been dredged for over 30 years, leading to the accumulation of large quantities of insalubrious sludge.

In this case study, only the 10 reservoirs included in the territory of Bucharest municipality were considered, and the entire Colentina river basin as the watershed. To apply G-res on only an equivalent reservoir, the 10 reservoirs were considered as forming a single water body, whose characteristics are obtained by summing volumes and surfaces and by averaging depths.

Regarding the population at the level of the hydrographic basin, 2 M inhabitants were considered for Bucharest and 1.5 M for the neighboring areas. As uses of this water body were considered: recreation - primary, flood mitigation - secondary and irrigation - tertiary, the degree of allocation of water volumes related to these uses being implicitly defined in the G-res.

As regards land cover, for Bucharest the values are those reported in the cadastral maps, while for the neighboring areas [30], where data were not available, they were estimated based on satellite maps. The centralization of these data is shown in Table 3.

Table 3. Data for land cover in the Colentina river basin.

Land cover in the catchment area	Bucharest 36.55%	Neighboring areas 63.45%	Total 100%
Croplands	11	50	30.5%
Grassland	2	5	3.5%
Forest	21	20	20.5%
Water bodies	4	4	4%
Bare areas	0	0	0
Settlements	61	20	40.5%
Wet areas	0.4	0.5	0.45
Drained Peatlands	0.6	0.5	0.55
Total	100%	100%	100%

2.3 Data used in G-res tool

To perform GHG emission analysis, G-res tool needs annual mean meteorological data (average monthly temperatures, average wind speed, and mean global horizontal radiance), which have been retrieved, for Bucharest area, from www.meteoblue.com, a meteorological free data service, Figure 3.

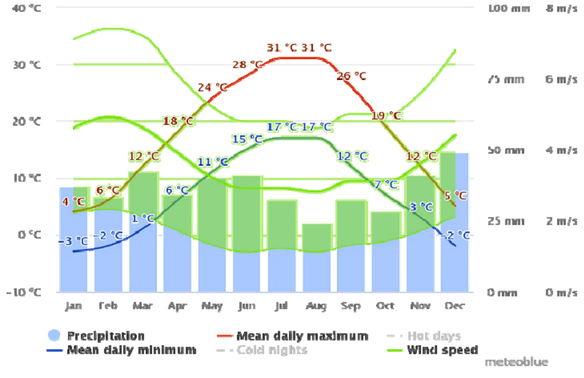

Fig. 3. Annual mean meteorological data for Bucharest area [31].

As regards the other data needed by G-res tool, the values used are presented in Table 4.

Table 4. Reservoir and catchment information used in G-res.

Reservoir Information	
Country	Romania
Longitude of Dam	44◦26′7” N
Latitude of Dam	26◦6′10” E
Climate Zone	Temperate
Water Uses	Recreation, flood control, irrigation
Impoundment Year	1970
Reservoir Area	7.13 km^2
Reservoir Volume (Multiannual Average)	0.0185 km^3
Water Level (m above sea level)	70 masl
Maximum Depth	5 m
Mean Depth	4.2 m
Soil Carbon Content Under Impounded Area	0.8 kg C/m^2 [20]
Annual Wind Speed at 10 m	4 m/s
River Length Before Impoundment (m)	37.4 m
Reservoir Mean Global Horizontal Radiance	3.24 kWh/m^2/d [31]
Mean Annual Air Temperature	13 °C [31]
Catchment Information	
Catchment Area	643 km^2
Population in the Catchment	3500000
Catchment annual runoff	700 mm/year [31]
Community wastewater treatment	Secondary
Industrial wastewater treatment	None
River Area Before Impoundment	0.2 km^2

3 Results and discussion

Based on the data provided, G-res computes not only the GHG footprint, but also some characteristic elements of the equivalent reservoir, as follows: Littoral area = 16.015%, Water residence time = 0.14 year and Annual discharge from Main Intake = 14.3 m^3/s.

The values of net GHG footprint for Colentina reservoirs, including the 95% confidence interval, are presented in Figure 4, while Figure 5 presents the net GHG emissions contributions for each equivalent reservoir water uses (services). The results are comparable to those reported in the literature [12, 20, 32].

The emission factors depend on the land type and use, and the data used in this simulation are presented in table 3. Under these assumptions, the landscape CO_2 emission rate for the Bucharest reservoirs for the pre-impoundment stage are 23 gCO_2e/m^2/year, which means 344 tCO_2e/year.

The values of CO_2 and CH_4 for the post-impoundment stage are:

- CO_2 release rate = 181 gCO_2e/m^2/year,
- CH_4 release rate = 121 gCH_4/m^2/year.

Thus, for post-impoundment stage, results a CO_2 emission rate for the Bucharest reservoirs of 302 gCO_2e/m^2/year.

Table 5 presents the CH_4 emissions from the reservoir associated with other anthropogenic sources. Given the fact that the water residence times is less than one year - very low, the CH_4 emissions associated with other anthropogenic sources is high and has an important share from the total CH_4 emission of post-impoundment.

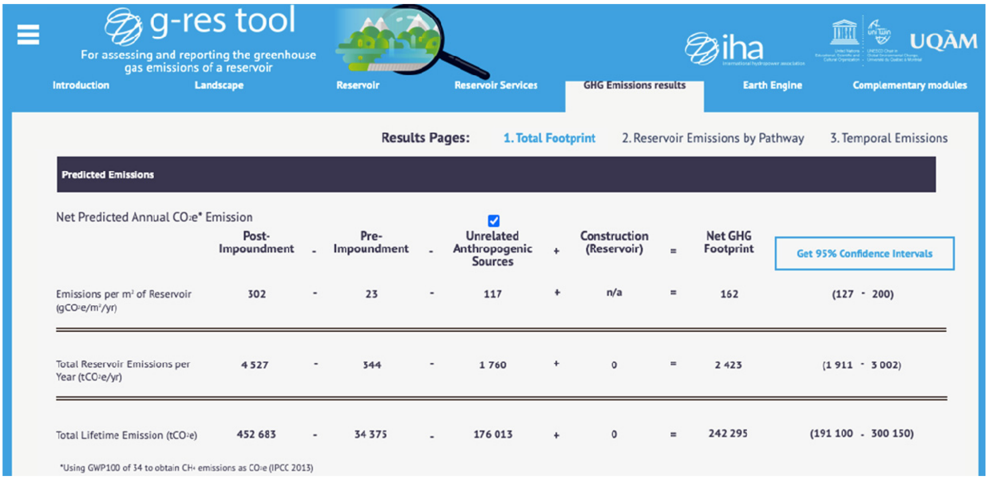

Fig. 4. Net GHG footprint for the equivalent reservoir (Colentina reservoirs).

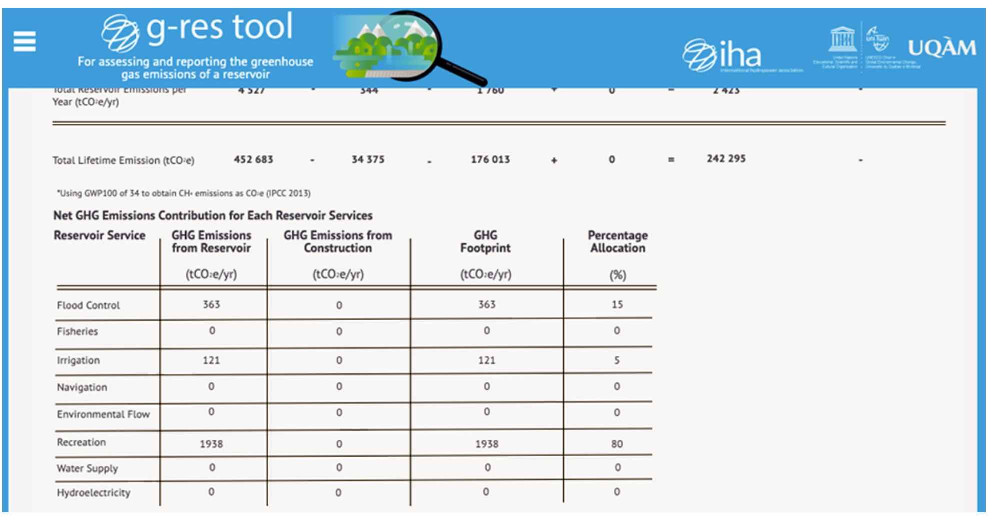

Fig. 5. Net GHG emissions contributions for each equivalent reservoir water uses (services).

Table 5. CH4 values associated to other anthropogenic sources.

Water Residence Time (year)	0.1
Reservoir CH_4 Emissions ($gCO_2e/m^2/year$)	120.8
Estimated CH_4 Release due to UAS ($gCO_2e/m^2/year$)	117.3
- due to land use ($gCO_2e/m^2/year$)	25.4
- due to sewage ($gCO_2e/m^2/year$)	91.9

Net reservoir footprint and CO_2 and CH_4 emission compared to reservoirs from same climate are presented in Figure 6 and Figure 7. As it can be seen in Figure 6, the Net reservoir footprint for Bucharest reservoirs, 162 $gCO_2e/m^2/year$ (Figure 4), is not very high compared to reservoirs from same climate. The small black arrow which indicates the position of the Bucharest reservoirs is placed on the beginning of the curve, and the values obtained for the reservoirs contained in the G-res Tool library range from 0 to over 3000 $gCO_2e/m^2/year$, the most frequent values being between 100 and 600 $gCO_2e/m^2/year$. Related to CH_4 post-impoundment emissions, no degassing is considered since the

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equivalent reservoir is shallow and the thermocline level is not known. As a result, only diffusive and bubbling mechanisms are considered, representing 85% and 15% respectively.

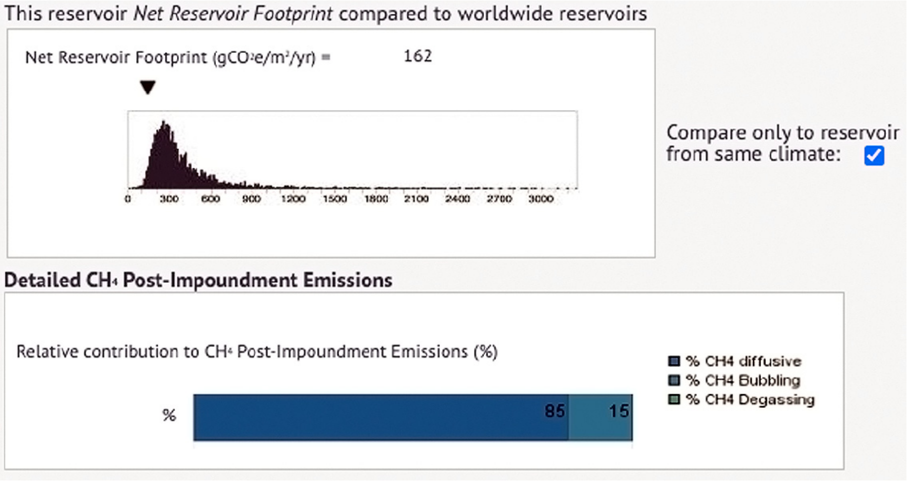

Fig. 6. Net reservoir footprint of the equivalent reservoir compared to reservoirs from same climate and detailed contribution to CH_4 post-impoundment emissions.

Figure 7 presents in detail CH_4 and CO_2 emissions for Bucharest reservoirs in contrast with reservoirs from same climate. In terms of CH_4 diffusive emissions, the reservoir is placed in the first third of the descending branch/curve, while the bubbling emissions is in the high values area. CO_2 diffusive emissions place the reservoir in the first third of the descending branch/curve, as well.

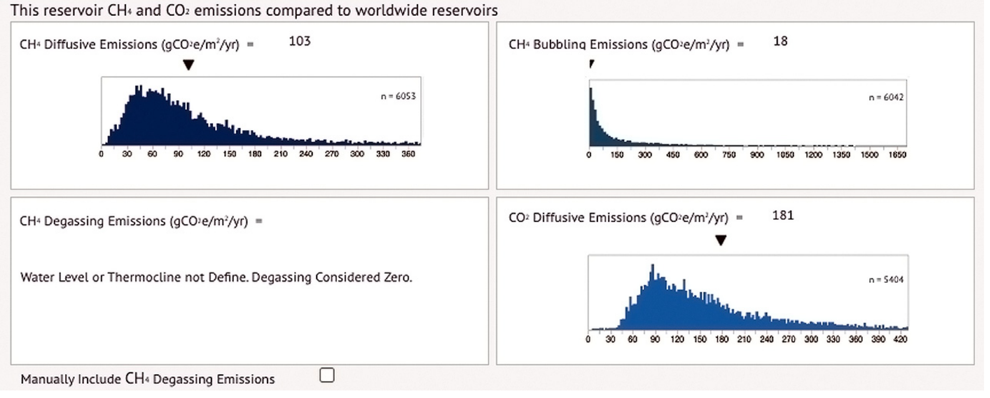

Fig. 7. CH_4 and CO_2 emissions of the equivalent reservoir compared to reservoirs from same climate.

Finally, the temporal variation of GHG by emission pathways of the analysed equivalent reservoir is presented in Figure 8.

According to the simulation values, GHG intensity exponentially decreased (Figure 8), at this date (50th year) representing just approximately 11% (~200 gCO_2e/m^2/year) from the initial value (the one from the completion, just after the damming of the water course, i.e. 1970).

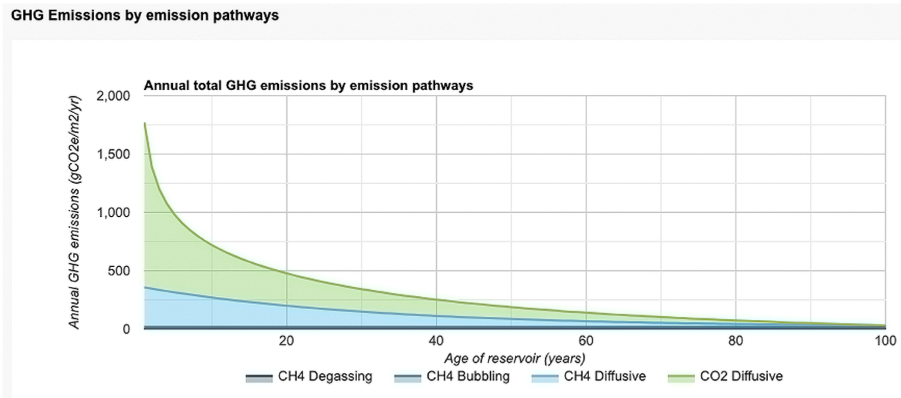

Fig. 8. Temporal variation of GHG by emission pathways.

4 Conclusions

This paper determined carbon footprint related to the 10 reservoirs on Colentina river in Bucharest, considered in the analysis by means of an equivalent reservoir, using GHG Reservoir Tool (G-res).

There were presented entry data, hypotheses, and the use of G-res tool, applied for determining GHG emissions of the equivalent reservoir. Thus, we now have a good picture of the 10 reservoirs on Colentina river contribution to the overall GHG emissions in Bucharest.

According to these results we can appreciate that, at this moment, the 10 reservoirs on Colentina river in Bucharest do not have a substantial contribution to GHG emissions, and in the next 25-30 years they will reach emissions comparable to those obtained for the undeveloped version of the Colentina river. As a result, in our opinion, these reservoirs represent a plus both in terms of providing adequate recreational spaces for the population, and increased benefits to the microclimate and population of Bucharest.

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