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Overview of the methane emissions from domestic wastewater in the Republic of Serbia

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ABSTRACT

In this paper, methane emissions from domestic wastewater were estimated using 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines. Wastewater can produce methane if it is handled anaerobically. According to the 2006 IPCC Wastewater model, methane emission is a function of the amount of generated organic waste and an emission factor that characterizes the extent to which this waste generates methane. The amount of degradable organic fraction in wastewater represents the main factor in determining the quantity of methane production. In this study, the population was divided into two areas, urban and rural. A survey was conducted in order to determine the number and type of wastewater treatment plants. At the current state, 38 wastewater treatment plants are in operation. Country-specific methane emissions from closed sewers, stagnant open sewers, septic tanks, and latrines combined are estimated to be about 22,000 tons per year.

Keywords: Domestic wastewater; Methane emissions; IPCC guidelines

1. Introduction

Increases in greenhouse gases (GHG) as a result of human activity directly led to the rise in the average temperature of Earth's atmosphere and oceans causing global warming. These gases obstruct the radiation of heat from the Earth back into the atmosphere, resulting in increased temperatures on the Earth's surface. The key GHGs of concern are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). They are emitted continually from various anthropogenic sources. Since the beginning of the industrial revolution in 1750, the atmospheric concentration of these three gases has increased by 39, 158, and 19%, respectively [1]. Global anthropogenic GHGs from different sectors are given schematically in Fig. 1. The waste and wastewater sectors contribute 2.8% of the total anthropogenic GHG emissions [2]. The newest Intergovernmental Panel on Climate Change (IPCC) study determined that methane in the Earth's atmosphere is considered the second most important GHG after carbon dioxide, with a global warming potential of 28 compared to carbon dioxide over a 100-year period [3]. This means that a methane emission will have 28 times the effect on temperature of a carbon dioxide emission of the same mass over the following 100 years. Methane is also the second most abundant GHG, accounting for 14% of global GHG emissions

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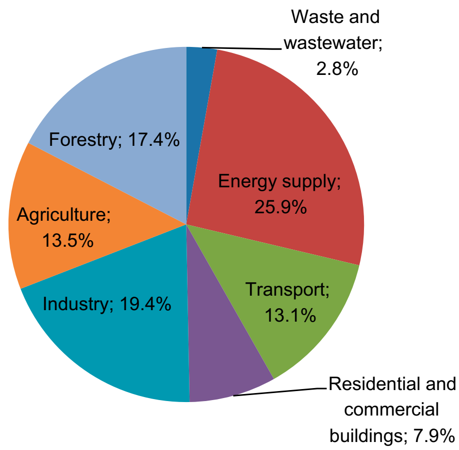

Fig. 1. Global anthropogenic GHG emissions from different sectors [1].

[4]. Global anthropogenic methane emissions from different sectors are given schematically in Fig. 2. It can be seen that wastewater sector contributes 9% of total anthropogenic methane emissions [5]. Globally, about 60% of total methane emissions come from human activities [2]. El-Fadel and Massoud reported that methane emitted from the wastewater sector contributed 11.4% of the total anthropogenic methane emission in 2001 [6]. In 2010, the estimated global methane emissions from municipal wastewater accounted for 6% of total global methane emissions, or approximately 512 $MtCO_2$ eq [7].

Wastewaters are the quantities of water which, after being used, are carried to the treatment plant or are discharged in underground or surface waters. Atmospheric water is not included in the quantities of wastewater. Today more than two-thirds of Europe's population lives in cities which is a result

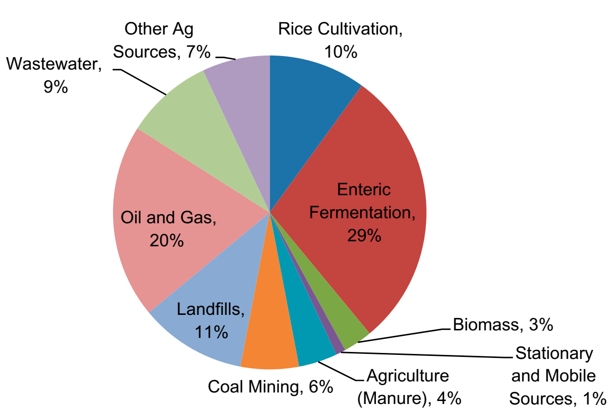

Fig. 2. Global anthropogenic methane emissions from different sectors, 2010 [5].

of urbanization that occurred between the 1950s and the 1980s. The increase in urban population has been typical of the former Yugoslavia too. The rapid population growth and industrial development has led to a growing need for water. The consequence of increasing the amount of used water led to an increase in wastewater. The construction of sewers has solved the problem at the source of wastewater, and it did not pay attention that the problem is just moved to another location. As a result, the biological, physical, and chemical values of the water resources have deteriorated, which, among other things, are used in the preparation of drinking water. Wastewater originates from a variety of domestic, commercial, and industrial sources. The characteristic of wastewater is self-purification which can be seen as the process of establishing the natural state of the water course. Self-purification of wastewater includes the physical and chemical processes that take place under the influence of organisms during decomposition of the organic compounds. To prevent pollution of the recipient by direct discharge of wastewater, the wastewater must be treated in a wastewater treatment plant. Treatment of wastewater means water purification from hazardous and harmful substances containing radio-nuclides, thus making water innocuous for further use. Wastewater may be treated onsite (uncollected), sewered to a centralized plant (collected), or disposed untreated nearby or via an outfall.

Centralized wastewater treatment methods can be classified as primary, secondary, and tertiary treatments. Primary treatment is a treatment of wastewater by a physical and/or chemical processes involving collecting of suspended solids, or other process in which the BOD_5 of the incoming wastewater is reduced by at least 20% before discharge and the total suspended solids of the incoming wastewater are reduced by at least 50%. Secondary treatment is a treatment of wastewater by a process generally involving biological treatment with a secondary settlement or other processes, resulting in a BOD_5 removal of at least 70% and a COD removal of at least 75%. Tertiary treatment is a continuation of the secondary treatment of nitrogen and/or phosphorous and/or any other pollutant affecting the quality or a specific use of water: microbiological pollution, color, etc. The following minimum treatment efficiencies define tertiary treatment: organic pollution removal of at least 95% for BOD_5 and 85% for COD, and at least one of the following: nitrogen removals of at least 70%, phosphorus removals of at least 80%, and microbiological removals achieving a fecal coliform density less than 1,000 in 100 ml.

Treatment and discharge systems can sharply differ between countries. The most common wastewater treatment methods in developed countries are centralized aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater.

Wastewater can produce methane if it is handled anaerobically. The amount of emitted methane depends mainly on the characteristics of WWTPs and environmental conditions. Wang et al. [8] published that the main factors influencing methane emissions are the dissolved oxygen concentration and water temperature. The study of STOWA [9] showed that the WWTPs with anaerobic digester produce higher methane quantity than WWTP without anaerobic digester. GWRC [10] reported that methane emission from WWTPs mainly originates from sewers and sludge handling.

There are several different methods for the estimation of methane emission from wastewater treatment systems. These include mathematical models, mass balances method, and experimental methods [11]. Experimental methods are based on trapping emitted gas by special equipment. Depending on device used for capturing emitted gas, several types of this method can be distinguished which include static-chamber techniques, dynamic-chamber techniques, and eddy covariance techniques. The basic concept of the mass balance method is breaking up complex system of treatment into several operation components. Within each operation component, the general concept of the law of conservation of mass is employed for estimating methane emission taking into account input, output, and transformation of matter. Daelman et al. [12] used this method to evaluate methane emission in WWTPs in Kralingseveer, Netherlands. Mathematical models use linear equations for the calculation of methane emissions. The main factors which influence methane production are organic matter and emission factor. Different models may result in different outcomes. The most widely used mathematical model is the model developed by IPCC with respect to the Kyoto protocol. Nairum and Towprayoon [13] estimated methane emissions from domestic wastewater in Thailand using revised 1996 IPCC guidelines and 2006 IPCC guidelines. They reported that methane emission results using the revised 1996 IPCC guidelines were higher than results when using 2006 IPCC guidelines. Xing et al. [14] used 2006 IPCC guidelines for measuring methane emissions from domestic and industrial sewage treatment in China for the period of 2000–2009. El-Fadel and Massoud [6] estimated methane emission in Lebanon using IPCC methodology and compared with estimations obtained using other methods in 2000. Also, they gave a prediction up to year 2040. Doorn and Liles [15] estimated global and country-specific methane emissions. These authors reported that global methane emissions from latrines, septic sewage tanks, and stagnant, open sewers are estimated to be 29 Tg/yr. According to them, the most significant source of methane is latrines in rural areas in China and India, accounting for roughly 12 Tg/yr.

This paper is structured as follows. In the next section, a methodology for estimating methane emissions from domestic wastewater is described. This is followed by Section 3, where collected data will be shown. Section 4 is dedicated to emission factors which will be used in calculation. Finally, in Section 5, results and a brief discussion are provided.

2. Methodology for estimating methane emissions from domestic wastewater

The aim of this research was to estimate methane emissions from domestic wastewater based on the methodology outlined in the 2006 IPCC Guidelines [16].

Methane emission is a function of the amount of organic waste generated and an emission factor that characterizes the extent to which this waste generates methane. The general equation to estimate methane emissions from domestic wastewater is:

$$\mathrm{CH_4\,Emissions} = \left[\sum_{i,j}\left(U_i \times T_{i,j} \times \mathrm{EF}_j\right)\right] \times (\mathrm{TOW} - S) - R \tag{1}$$

The emission factor for a domestic wastewater treatment and discharge pathway and system (EF_j) is a function of the maximum methane-producing potential (B_o), and the methane correction factor (MCF) for the wastewater treatment and discharge system, as shown in Eq. (2):

$$\mathrm{EF}_j = B_o \times \mathrm{MCF}_j \tag{2}$$

The total amount of organically degradable material (TOW) in the domestic wastewater is calculated using Eq. (3):

$$\mathrm{TOW} = P \times \mathrm{BOD} \times 0.001 \times I \times 365 \tag{3}$$

3. Activity data

3.1. Fraction of population income group (U) and population (P)

According to the classification of the local administration organizations in the Republic of Serbia, the country was divided into five categories, namely the Belgrade region, Vojvodina region, Sumadija and west Serbia region, south and east Serbia region, and Kosovo and Metohija region. Regions are further divided into municipalities, which makes 168 municipalities in the Republic of Serbia. Since 1999, the Kosovo and Metohija region has officially been administered by UNMIK as per UNSC Resolution 1,244 of the United Nations. According to the 2011 Census of Population, the Republic of Serbia has a population of 7,186,862 (excluding the Kosovo and Metohija region). The Sumadija and west Serbia region has the highest population of 2,026,751, followed by Vojvodina region of 1,922,093, Belgrade region of 1,649,121 and south and east Serbia region of 1,588,897. The 2006 IPCC Guidelines methodology recommends using fractions of population in three income groups for methane emissions from domestic wastewater because availability and choice of sewage disposal system are dependent on income and population density. These income groups are rural, urban high income and urban low income. In the Republic of Serbia, the income groups were not classified in this way; however, the population was divided into two areas, urban and rural. The population data were collected from the 2011 Census of Population [17].

3.2. Degree of utilization of treatment or discharge pathway or system (T)

The division of population was made due to the differences in their respective wastewater pathways or systems. The degree of utilization of treatment or discharge pathway or system (*T*) for each income group is different in each municipality. The degree of utilization of treatment or discharge pathway or system represents a percentage of population which is served by each wastewater treatment system. These treatment systems were classified as closed sewer, open stagnant sewer, septic tank, and latrine. The domestic wastewater collected by sewer is treated in centralized wastewater treatment plant or discharged directly into recipient. The septic tank was used to treat domestic wastewater onsite. For rural areas, some parts of the wastewater were treated onsite by latrine.

It was assumed that the urban population is served by sewer and septic tank. Another assumption was made for rural population, that besides sewer and septic tank some percentages use latrines. The *T* value of the sewer for urban population was found from the fraction of population connected to sewer. The *T* value of the septic tank for the urban population was calculated from the fraction of the urban population that is not connected to sewer. The *T* value of the sewer for rural population is found in the same way as it is done for urban population. These values are obtained from the 2011 Census of Population [18]. Because of the fact that septic tanks and latrines are classified in the same category in the 2011 Census of Population, it is assumed that 30% of the rural population treats wastewater in latrines and the rest in septic tank.

3.3. Degradable organic material in wastewater (BOD)

The amount of degradable organic fraction in wastewater represents the main factor in determining the quantity of the methane production. It is commonly expressed in terms of BOD or COD. This means that under the same conditions, methane production increases with increasing BOD or COD content. Degradable organic material in wastewater could be estimated by multiplying BOD in domestic wastewater (g/l) and the volume of wastewater generation (l/capita/d). If BOD data are not available, the 2006 IPCC Guidelines recommends selecting a BOD default value from a nearby comparable country. At the moment, there are no data for BOD in domestic wastewater for each municipality, even though it has been foreseen by law. In this paper, the adopted value for BOD is 60 g/person/d [16].

3.4. Correction factors for additional industrial BOD discharge into sewers (I)

Industrial wastewater quantities are highly variable and depend on the type of the industry as well as the industrial process itself. This factor expresses the BOD from industries and establishments (e.g. restaurants, butchers, or grocery stores) that is co-discharged with domestic wastewater. The default factor suggested by the 2006 IPCC Guidelines for collected industrial wastewater is 1.25, and for uncollected is 1.00. The data for discharging industrial wastewater into domestic were collected from the Ministry of Energy, Development and Environmental Protection of the Republic of Serbia [19].

3.5. Wastewater treatment sector in the Republic of Serbia

In order to determine the number and type of wastewater treatment plants in the Republic of Serbia, a survey has been conducted. At this moment, 38 municipalities have wastewater treatment plant currently in operation: 8 of them are primary, 29 are secondary and 1 is tertiary. Two of them do not have the capacity for their current sewer. Sludge arises in all of the primary, secondary and tertiary stages of treatment. Sludge can produce methane if it degrades

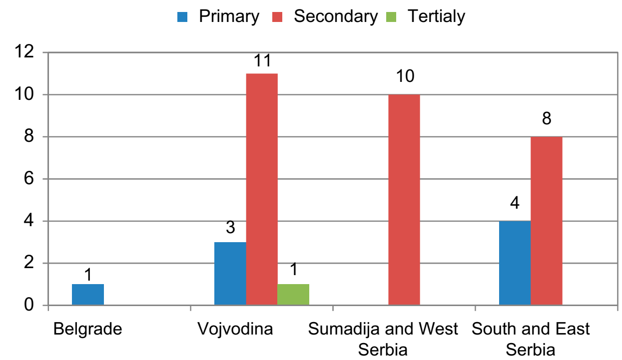

Fig. 3. Type of municipal wastewater treatment plants in the Republic of Serbia per regions.

anaerobically, and because of that sludge must be treated further before it can be safely disposed of. Methods of sludge treatment include aerobic and anaerobic stabilization (digestion), conditioning, centrifugation, composting, and drying. Data of sludge management are not available and therefore it is assumed to be disposed at solid waste landfills and the emission from domestic sludge is not included in this paper. Fig. 3 shows the type of municipal wastewater treatment plant in the Republic of Serbia per region.

4. Emission factors

Emission factors presume that the entire organic fraction removed anaerobically is converted to methane. These estimates oversimplify the complex process of wastewater decomposition and do not account for numerous factors including the extent of decomposition, nutrient limitations, biological inhibition, physicochemical interactions, and requirements for bacterial cell synthesis [7]. The methane emissions from wastewater were estimated based on activity data and emission factors. The activity data were described in the previous section. The emission factors were calculated by multiplying the maximum methane-producing capacity (B_o) and the MCF.

4.1. Maximum methane-producing capacity (B_o)

The maximum methane-producing capacity (B_o) is the maximum amount of methane that can be produced from a given quantity of organics in wastewater. The 2006 IPCC Guidelines suggest using country-specific data. If country-specific data are not available, it is recommended to use the value of 0.6 $kgCH_4$/kg BOD.

Table 1
The methane correction factor for wastewater treatment and discharge pathway

Type of treatment and discharge pathway	MCF value
River and lake discharge	0.1
Septic tank	0.5
Stagnant sewer	0.5
Latrine	0.1
Primary treatment	0.6
Secondary treatment	0
Tertiary treatment	0

4.2. Methane correction factor (MCF)

The MCF represents a fraction of a given degradable organic material in wastewater that will eventually degrade in an anaerobic process. It can be said that MCF is an indication of the degree to which the system is anaerobic. The MCF value depends on the type of discharge pathway and the type of technology used in centralized wastewater treatment plants. In the Republic of Serbia, all secondary wastewater treatment plants use activated sludge technology for wastewater treatment. MCF values used in this paper are shown in Table 1. Adopted values are suggested by 2006 IPCC Guidelines. Due to the fact that the MCF value for primary treatment is not recommended by the 2006 IPCC Guidelines, a value of 0.6 is adopted according to the study of Begak et al. [20]. This value is calculated for primary sedimentation tanks with depth within 1–5 m.

5. Results and discussion

The main activity data for estimating methane emission from domestic wastewater were the degree of urbanization, the degree of utilization of treatment or discharge pathway, and the number and type of wastewater treatment plants. The population at the municipality level is divided into urban and rural according to the 2011 Census of Population. Fig. 4 shows the population at the regional level. The Degree of urbanization in each municipality varies. The Belgrade region has the highest value of urban population with 81%, followed by the Vojvodina region with 59%, south andeast Serbia region with 53%, and Sumadija and west Serbia region with 47%. Fig. 5 shows the summarized results at the republic level. According to Fig. 5, 59.55% of the population lives in urban areas and 40.45% in rural areas.

The number of urban and rural populations connected to sewer varies at the municipality level too.

As can be seen from Fig. 4, the Sumadija and west Serbia region has 93% of the urban population connected to sewer, south and east Serbia region has 91%, Belgrade region has 89%, and Vojvodina region has 74%. The situation is quite different for the rural population. The Belgrade region has the highest value with 17%, Sumadija and west Serbia region 11%, south and east Serbia 10% and Vojvodina region only 6% of the rural population connected to sewer. Parts of the urban population without sewer were classified using septic tank for their wastewater treatment. Rural population without sewer was classified using septic tank and latrine. It is assumed that 30% of the rural population without sewer treats wastewater using latrines and the rest by septic tank. The values are shown in Fig. 4. At the republic level, 85.96% of the urban population is connected to sewer, and 9.98% of the rural population is connected to sewer (Fig. 6). The major recipient of domestic wastewater in the Republic of Serbia are rivers, followed by lakes, and a small amount of open stagnant sewers. Open stagnant sewers are commonly encountered in Vojvodina region.

Currently, 38 wastewater treatment plants are in operation. The Belgrade region has only 1 primary wastewater treatment plant which makes 0.15% of the whole region population. According to Fig. 7, 19.58% of the population treats wastewater onsite in septic tank, 5.7% onsite in latrine, and 74.57% discharges wastewater directly to recipient without treatment. In the Vojvodina region, 0.4% of the population treats wastewater with primary treatment, 8.83% with

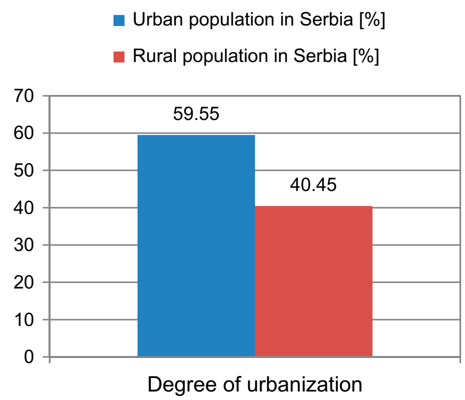

Fig. 5. Degree of urbanization in the Republic of Serbia at the republic level.

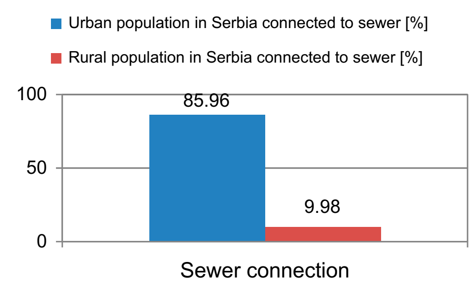

Fig. 6. Sewer connection in the Republic of Serbia at the republic level.

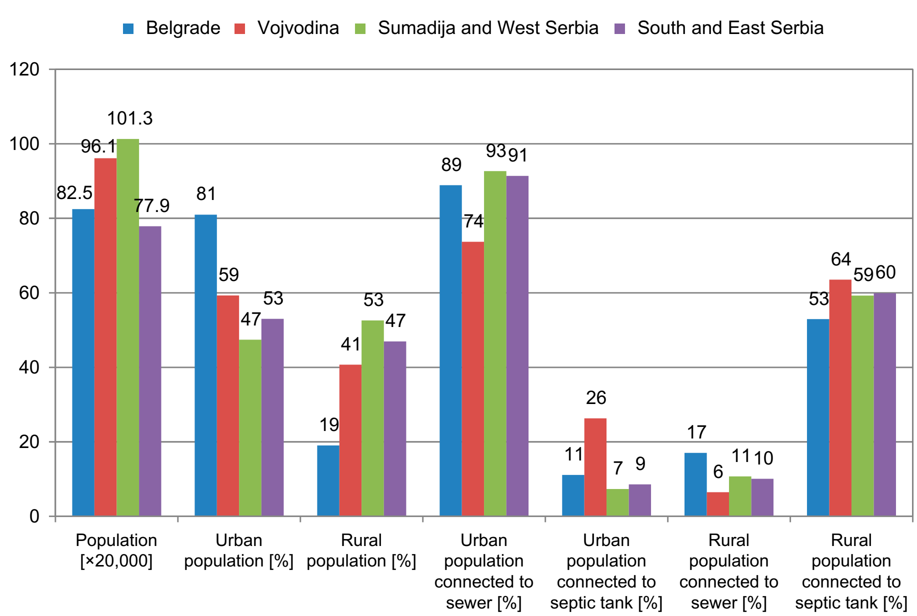

Fig. 4. Population, degree of urbanization and discharge pathways in the Republic of Serbia at the regional level.

secondary, 3.75% with tertiary treatment, 41.75% onsite in septic tank, 12.21% onsite in latrine, and 33.06% discharges wastewater directly to recipient without treatment. In the Sumadija and west Serbia region, 19.41% of the population treats wastewater with secondary treatment, 34.74% onsite in septic tank, 15.78% onsite in latrine, and 30.07% discharges wastewater directly to recipient without treatment. In the south and east Serbia region, 1.78% of population treats wastewater with primary treatment, 4.5% with secondary treatment, 33.27% onsite in septic tank, 14.01% onsite in latrine, and 46.45% discharges wastewater directly to recipient without treatment. Fig. 7 shows wastewater treatment status in the Republic of Serbia at the regional level. At the republic level, 0.53% of the population treats wastewater with primary treatment, 8.85% with secondary, 1.01% with tertiary treatment, 32.81% onsite in septic tank, 12.11% onsite in latrine, and 44.69% discharges wastewater directly to recipient without treatment. Wastewater treatment status in the Republic of Serbia at the republic level is shown in Fig. 8.

Methane emission estimation from domestic wastewater handling using the 2006 IPCC Guidelines for the year 2013 is 22,471 tons per year. The Belgrade region emits 4,284 tons of methane per year, Vojvodina region 7,067 tons per year, Sumadija and west Serbia region 6,027 tons per year, and south and east Serbia region 5,093 tons per year, which is 19, 31, 27, and 23%, respectively. The percentage contribution of discharge pathways to methane emissions at the republic and regional levels is shown in Fig. 9. As it can be seen from Fig. 9, the highest contribution to methane emission at republic level is by septic tank with 68.63%. This is due to the small sewering of the rural population. Observing methane emissions at the regional level (Fig. 9), it can be noticed that in each region methane emissions from septic tank is dominant. In the Belgrade region, it appears that the contributions of methane emissions from sewage and septic tank are approximately equal despite a large percentage of the urban population and large number of population attached to the sewer. The main factor that affects such large proportions of methane emissions from sewage is the lack of wastewater treatment plants. In other regions, methane emissions from the septic tank is in the range of 67–77% of the corresponding region. Although approximately one-third of the municipalities in the Vojvodina region have a wastewater treatment plant, methane emissions from sewage is the result of a lower percentage of urban population (59%) and discharging untreated wastewater into the open stagnant sewer. Sumadija and west Serbia region, which has the largest population and in which about one-fifth of the municipalities have a wastewater treatment plant, has the lowest emissions of methane from sewage. This is due to the fact that wastewater treatment plants are located in municipalities with a larger population of the region. In contrast, the south and east Serbia region has wastewater treatment plants located in municipalities with a smaller population which causes a greater amount of methane emission from sewage. In these two regions, the percentage of the rural population is approximately 50%.

Fig. 10 shows the percentage contribution of regional discharge pathways to total methane emissions. It can be seen that the greatest influence on the total methane emissions are from septic tank in the regions

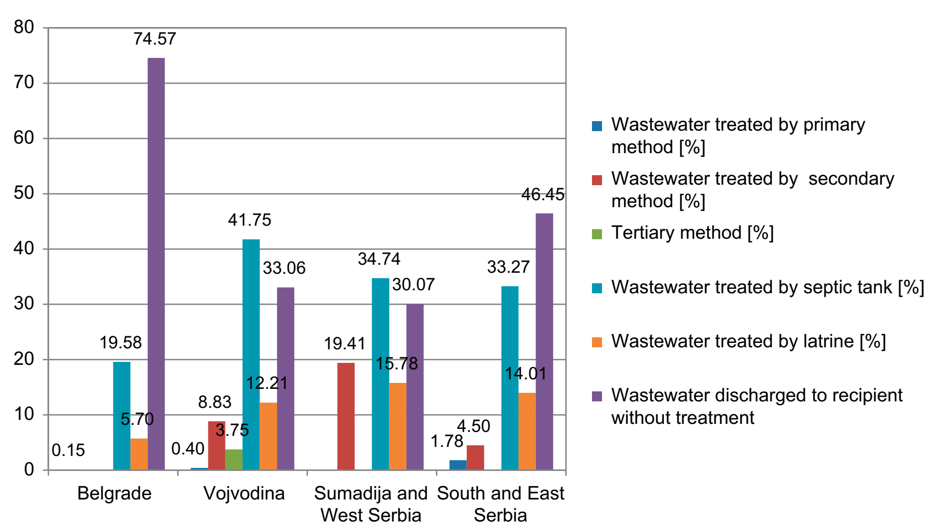

Fig. 7. Wastewater treatment status in the Republic of Serbia at the regional level.

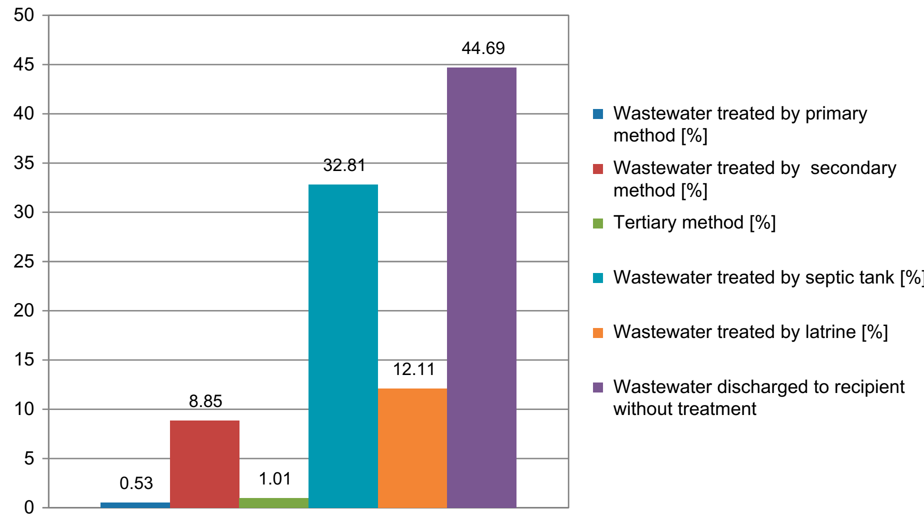

Fig. 8. Wastewater treatment status in the Republic of Serbia at the republic level.

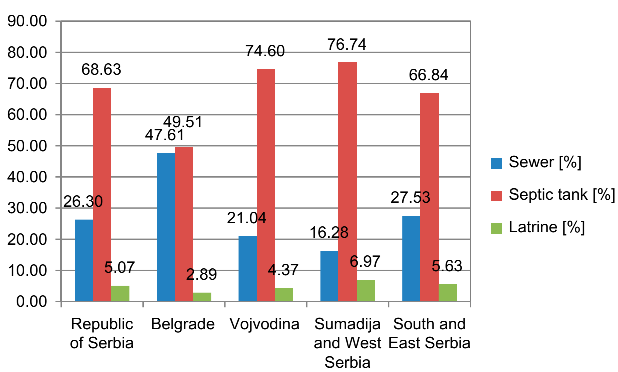

Fig. 9. Percentage contribution of discharge pathways to methane emissions at the republic and region level.

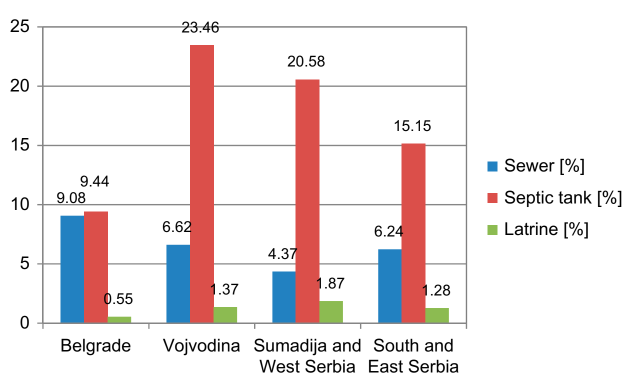

Fig. 10. Percentage contribution of discharge pathways to total methane emissions on regional level.

of Vojvodina, Sumadija and west Serbia, and south and east Serbia with 23.46, 20.58, and 15.15%, respectively. It can be concluded that the increase in the number of urban and rural populations connected to sewer can significantly reduce methane emissions.

The three largest cities in the Republic of Serbia, Belgrade, Novi Sad, and Nis with populations of 1,334,773, 339,358, and 244,459, respectively, at this moment do not have a centralized wastewater treatment plant. In these cities, 26.8% of population of the Republic of Serbia lives, 23.89% of the urban population and 22.4% of the population connected to sewer. They emit 4,549 tons of methane per year, which is 20.24% of the total methane emission from domestic wastewater.

6. Conclusions

An increase in the concentration of GHGs in the Earth‘s atmosphere as a result of human activity has a direct impact on the global warming effect. The wastewater sector contributes 9% of total anthropogenic GHG emissions. Methane is one of the GHGs of concern with a global warming potential of 28 compared to carbon dioxide over a 100-year period. According to available data from the literature, about 60% of total methane emissions come from human activities.

This paper represents an attempt to estimate methane emissions from domestic wastewater using the 2006 IPCC Guidelines. The highest percentage of population connected to the sewer is located in narrow urban areas, while in rural areas this percentage is generally very low. Industrial facilities located in urban areas discharge wastewater mainly in the municipal sewer system, usually without pretreatment. At the present state, 65% of municipalities discharge industrial wastewater in sewer. Currently, 38 centralized wastewater treatment plants are in operation. At this moment, 41 municipalities have projects for the construction of these facilities, and projects are in various stages of development, from conceptual designs to the general project. The rest of the municipalities without wastewater treatment plant have no plans for the construction of wastewater treatment plants. The alarming fact is that the three largest cities in the Republic of Serbia, Belgrade, Novi Sad, and Nis, which collectively account for 26% of the population of the Republic of Serbia, do not have wastewater treatment plants.

The estimated amount of methane emission from domestic wastewater is 22,471 tons per year. The highest contribution to methane emission comes from septic tank, which is almost 70%. Increasing the number of people connected to the sewer and construction of facilities for wastewater treatment will result in the reduction in methane emissions, thus improving the quality of water in recipients and the environment.

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List of symbols

CH_4 emissions	—	methane emissions in the inventory year, kg CH_4/yr
TOW	—	total organics in domestic wastewater in the inventory year, kg BOD/yr
S	—	organic component removed as sludge in the inventory year, kg BOD/yr
U_i	—	fraction of population in income group i in the inventory year
$T_{i,j}$	—	degree of utilization of treatment/discharge pathway or system, j, for each income group fraction i in the inventory year
i	—	income group: rural, urban high income and urban low income
j	—	each treatment/discharge pathway or system
EF_j	—	emission factor, kg CH_4/kg BOD
R	—	amount of methane recovered in the inventory year, kg CH_4/yr
B_o	—	maximum methane production capacity, kg CH_4/kg BOD
MCF_j	—	methane correction factor (fraction)
P	—	country population in the inventory year, person
BOD	—	country-specific per capita BOD in the inventory year, g/person/d
0.001	—	conversion from grams BOD to kg BOD
I	—	correction factor for additional industrial BOD discharged into sewers

Abbreviations

BOD_5	—	biological oxygen demand after 5 d
COD	—	chemical oxygen demand

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