Energy 57 (2013) 788–795

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

GHG (Greenhouse Gases) emission inventory and mitigation measures for public district heating plants in the Republic of Serbia

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A R T I C L E I N F O

Article history:
Received 2 November 2011
Received in revised form
25 September 2012
Accepted 30 September 2012
Available online 26 October 2012

Keywords:
Greenhouse gas emissions inventory of Republic of Serbia
Public district heating plants
Revised IPCC methodology
Mitigation measures

A B S T R A C T

As a non-Annex I Party to the United Nations Framework Convention on Climate Change and Kyoto Protocol signatory, the Republic of Serbia has committed to develop GHG (Greenhouse Gases) emission inventory and prepare comprehensive program of mitigation measures at national level.

The paper presents results of 2000–2008 GHG emission inventory assembled for PDH (Public District Heating) sub-sector in accordance with revised IPCC (Intergovernmental Panel on Climate Change) Tier 1 methodology. Evaluation of proposed mitigation measures was performed based on 2012 and 2015 GHG emission projections, obtained for basic and four alternative scenarios, all characterized by the same energy demand but with different fuel mix used. The first alternative scenario addresses GHG emissions in case that solid fuel is substituted by natural gas. The second alternative scenario represents a sub-scenario of the first alternative scenario, with additional substitution of liquid fuel with locally available biomass. Third alternative scenario addresses emissions resulting from complete fuel switch from natural gas to liquid fuel oil, while the final alternative scenario considers the case when natural gas is the only energy resource used.

GHG emission trends in the period until 2015, examined in case of previously mentioned basic and four alternative scenarios, point out to the positive impact of fuel switch on GHG emission reduction and pathways for future implementation of proposed mitigation measures. Results obtained clearly quantified assumption that fuel substitution by locally available biomass could solve environmental problems, overcome problems associated with high prices of imported fuels, improve energy supply security and increase local employment.

1. Introduction

Republic of Serbia has signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC, hereinafter referred to as the Convention) and the Kyoto Protocol, being given the status of developing country (non-Annex I country). As such, Republic of Serbia is not obliged to quantify its GHG (Greenhouse Gases) emission reductions during the first commitment period, but is obliged to develop national GHG inventory and define modality of systematic analysis and reporting on mitigation measures conducted towards GHG emissions reduction.

One of the first steps towards fulfilling the specified tasks is preparation of Initial National Communication on GHG emissions [1], followed by other national communications assembled in the form of strategic national documents. The aim of these documents is to provide information on the status of implementation of the Convention, governmental efforts and foreseen actions that are deemed to be contributing to climate change mitigation, as well as to define national needs in adaptation to the changed climate conditions.

Preparation of comprehensive mitigation program on national level should be based on GHG emissions models adopted for the relevant sector (energy, transport, agriculture, waste and forestry), continuous improvement and adoption of models based on the analysis of GHG emission reduction capabilities, including various scenario costs assessment, as well as analysis of the overall potential for national GHG emissions reduction.

Development of appropriate projection model (scenario) and assessment of capabilities related to limitation of national GHG emissions is based on detailed analysis of GHG emissions in the preceding period (in total and by sector), anticipated changes in the overall emissions resulting from anticipated technological and

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http://dx.doi.org/10.1016/j.energy.2012.09.063

Nomenclature

AC^i	annual energy potential of fossil fuel consumed, TJ
m^i	annual consumption of fossil fuel, t
H^i_d	net calorific value, TJ/kt
EF_C	carbon emission factor, tC/TJ
OC^i	fraction of carbon oxidized, %
PR^i_s	sulphur content in the fuel, %
RA^i_s	sulphur content in the ash residue, %
PDH	Public District Heating
IPCC	Intergovernmental Panel on Climate Change
GHG	Greenhouse Gases

socio-economic development in the projection period and analysis of national and international legislation and strategic documents.

The largest potential for GHG emission reduction in Serbian energy sector in the period until 2015 represents the energy efficiency increase [2] (retrofit of existing energy generation capacities) and more intensive use of renewable energy sources [3]. The indicated measures represent two out of five priorities specified in the Strategy of Energy Sector Development in the Republic of Serbia until 2015. The key barriers for implementation of energy efficiency programs are the state energy prices and price volatility, primarily observed from the relation between electricity and fossil fuel prices. Furthermore, concern for the social welfare has always taken priority over the energy (primarily electricity) price policy in the Republic of Serbia, which appears to be quite discouraging for implementation of energy efficiency programs.

PDH (Public District Heating) sub-sector could play significant role in fossil fuels consumption reduction and thus reduction of GHG, SO_2 and NO_x emission [4–6]. However, PDH sub-sector in Serbia is facing the problems of heat capacity shortage due to continuous increase in heating demand and limited capacity of heat distribution network, since cogeneration plants are usually located far away from urban district heating consumers.

Centralized heat and hot water supply systems operate in 50 Serbian cities. However, only 14% of total building floor area (including residential, commercial, institutional and other buildings) is heated by PDH facilities. Around 12% of total floor area is heated by local boilers (in-house central heating systems), 14% is heated by electricity (thereby consuming 24% of total annual household electricity consumption), 10% by individual natural gas systems and 50% of the floor area (mainly residential houses) is heated by the means of solid fuel fired stoves (burning coal, firewood, agricultural biomass, waste, etc.), characterized by small energy conversion efficiency and pronounced local pollution problems [2].

According to the reference strategy implementation document [2], decrease in GHG emissions originating from Serbian PDH sub-sector should be achieved through implementation of the following measures:

a) *Increasing energy efficiency of heat distribution systems*. EU Directive on energy end-use efficiency and energy services adopted in 2006 has set a 9% energy efficiency improvement target for the period 2008–2016. In addition, EU energy-climate package “20-20-20” has defined an objective to achieve 20% energy efficiency increase by 2020. Implementation of energy efficiency improvement measures requires financial support from local and state governments and sufficient efforts in order to meet all regulatory and administrative requirements and assemble necessary documentation required for the measures proposed [7];
b) *Introducing contemporary technical solutions characterized by highly efficient performance* (combined heat and power generation i.e. cogeneration units with combined gas–steam cycle). A simple model which renders a quantitative analysis of investment viability associated with cogeneration plant construction, addressing different power output levels, as well as energy market conditions and institutional measures, has been proposed [8].
c) *Decreasing specific energy consumption* by introducing heat consumption metering and payment for the energy actually consumed, together with implementation of latest information technologies, energy efficient building design solutions, in case of new buildings, or improved thermal insulation of refurbished buildings; strategic priorities also include reduction of electricity use for meeting space heating needs and connection of up to 180,000 new consumers to district heating systems until 2015;
d) *Further substitution of coal and heavy oil with natural gas and renewable energy sources, primarily biomass*. Effects of renewable energy on future development have been addressed in many papers [4,5,9]. Short and long term plans have been drawn up to fully utilize renewable energy technologies in municipal facilities worldwide [10–12], with completely new type of renewable energy based district heating system proposed [13]. A master techno-economic assessment of renewable energy sources (biomass) and their use for combined heat and power generation in Serbia was presented in [2] and [14], defining characteristics of Serbian renewable energy potentials and their utilization in decentralized energy generation. State of the art solutions like heat storage and heat pumps, that can also help increasing the share of renewables in heat generation, are not realistic to be implemented in such a poor economy as Serbian.

Inventory of GHG emissions originating from PDH sub-sector was developed based on the quantities of fossil fuels consumed by PDH in the Republic of Serbia in 1990, 1998 and in the period 2000–2008, as documented in the related study [15]. Data were obtained directly from public district heating companies, operating in 50 Serbian cities, which were asked to fill out a distributed questionnaire containing questions on GHG emission related information. Information collected were checked and, if needed, revised based on the available statistical 1990–2008 yearbook data of Statistical Office of the Federal Republic of Yugoslavia, the Statistical Office of Serbia and Serbian customs authorities. Data analysed and results obtained for 1990, 1998 and 2008 are partly presented in [16]. Data relevant to this paper do not include GHG emissions originating from boilers utilized outside the public, central heat and hot water distribution sector, neither to Combined Thermal Power/Heat Plants of the “Electric Power Industry of Serbia – EPS”.

Based on GHG emissions calculated using the in-depth information on characteristics of heat generation facilities and fuel consumption in the preceding period, mitigation measures for Serbian PDH sub-sector were proposed, analysed and evaluated.

2. GHG emission calculation methodology

Processes of production, transformation and use of fossil fuels for energy generation purposes are inevitably associated with emission of gases causing the greenhouse effect. In general, total GHG emissions from energy systems can be divided into emissions released during fossil fuel combustion and fugitive emissions. In this section, methodology for estimation of GHG emissions released by fossil fuel combustion is only discussed. The most significant

GHGs released during fossil fuel combustion include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as indirect GHGs such as nitrogen oxides (NO_x), carbon monoxide (CO), Non-Methane Volatile Organic Compounds – NMVOCs and sulphur oxide (SO_2). Fugitive emissions occur during fossil fuel exploitation, processing, transmission and storage. Release of CH_4, resulting from coal excavation and extraction, as well as transport and storage of crude oil and natural gas, is identified as the most significant fugitive emission member.

Total GHG emissions resulting from fossil fuels combustion in PDH sub-sector were calculated in accordance with revised IPCC (Intergovernmental Panel on Climate Change) methodology for preparation of GHG emission inventory, with fugitive emissions not taken into account. This methodology defines standard values of pollutant emission factors for each different type of fossil fuel. Standard recommended net calorific values and emission factors of domestic and imported solid, liquid and gaseous fuels are presented in Table 1.

Carbon dioxide (CO_2) is the most common greenhouse gas generated by human activities, accounting for about 60% of the increase in GHG emissions when compared to pre-industrial times. By far the largest source of CO_2 emissions represents carbon oxidation process occurring during fossil fuel consumption and accounting for 70–90% of total anthropogenic CO_2 emissions. During fossil fuel combustion, most of the carbon contained in the fuel is emitted as CO_2 generated during the fuel combustion process. Some carbon is released as CO, CH_4 or non-methane hydrocarbons, which oxidize in the atmosphere to CO_2 over the period of few days up to 10–11 years.

Quantities of fuel utilized for heat generation purposes, m^i [kt], may be used to define related energy potential of the fuel consumed, expressed based on the net calorific values Q_d^i [TJ/kt] (Table 1) of the fuel considered in accordance with the following expression:

$$AC^i = \sum_i m^i Q_d^i \tag{1}$$

Amount of CO_2 [Gg] released as a result of fossil fuel combustion is determined from the following expression:

$$EM^i_{CO_2} = \frac{AC^i \cdot EF_C}{1000} \cdot \frac{OC^i}{100} \cdot \frac{44}{12} \tag{2}$$

where AC^i is the energy potential of annually consumed quantity of fossil fuel, obtained in accordance with equation (1), EF_C is carbon emission factor (Table 1) and OC^i is the fraction of carbon oxidized during combustion of fuel considered (Tier 1 method recommends the following default values: 98% for all types of coal, 99% for all liquid fuels and 99.5% for natural gas).

Unlike relatively simple way of determining CO_2 emission, the amount of CH_4, N_2O, NO_x, CO and $NMVOC_s$ emitted during fossil fuel combustion depends on several factors: fuel type, combustion technology, operating conditions, technology and policy adopted for GHG emission control, equipment maintenance etc.

Due to lack of necessary data, the Tier 1 method defines emission EM_j^i [Gg] of each of the pollutants (CH_4, N_2O, NO_x, CO or $NMVOC_s$) separately, as a product of respective pollutant emission factor EF_j^i of the fuel used (Table 1) and energy potential of that fuel AC^i (where type of pollutant is indexed with "j" in subscript and type of fossil fuel combusted is indexed with "i" in superscript):

$$EM_j^i = \frac{EF_j^i \cdot AC^i}{10^6} \tag{3}$$

Sulphur dioxide does not fall into the category of primary GHG. It reacts in the atmosphere with a variety of photochemically produced oxidants forming sulphate aerosols. It is believed that formation of aerosols results in locally recurring effect of lowered average air temperature [17]. It is estimated that more than 70–80% of SO_2 released as a result of human activities is associated with coal combustion processes [18]. Due to the lack of precise information on sulphur content of fossil fuels, the IPCC methodology recommends the above presented equation (3) to be used for evaluating SO_2 emissions, whereby SO_2 emission factor in [kg/TJ] is to be obtained as follows:

$$EF^i_{SO_2} = 2 \cdot \frac{PR_S^i}{100} \cdot \frac{1}{Q_d^i} \cdot \left(\frac{100 - RA_S^i}{100}\right) \cdot \left(\frac{100 - AE_S^i}{100}\right) \cdot 10^6 \tag{4}$$

Equation (4) contains PR_S^i member which represents sulphur content of the fuel [%], while RA_S^i is sulphur content of ash residue [%], AE_S^i is percentage of sulphur removed from the process and Q_d^i is net calorific value of the fuel [TJ/kt].

Standard recommended sulphur content values of fossil fuels, PR_S^i, were adopted as follows: 2% for residual fuel oil and gas/diesel oil, 3.65% for other bituminous coal, 1.19% for sub-bituminous coal, 0.51% for dried lignite and 1% for lignite extracted from underground mines. Due to the small content of sulphur in natural gas, SO_2 emissions associated with natural gas combustion were deemed negligible and were not taken into account in analysis performed. Sulphur content of ash residue, RA_S^i, was adopted as follows: 7% for all solid fuels and 0.2% for all liquid fuels.

Table 1
Net calorific value Q_d^i and standard recommended emission factors EF_j^i of fuels considered.

Fuel:	Q_d^i	C	CH_4	N_2O	NO_x	CO	SO_2[a]	NMVOC
	[TJ/kt]	(tC/TJ)	(kg/TJ)					
Other bituminous coal	23.55	25.8	1.0	1.4	300.0	20	2882.8	5
Sub-bituminous coal	16.90	26.2					1309.7	
Lignite from underground mines	11.00	27.6					1027.6	
Dried lignite	18.10	26.7					862.4	
Gas/diesel oil	43.33	20.2	3.0	0.6	200.0	15	921.3	5
Residual fuel oil	40.19	21.1					993.3	
Natural gas (dry)	45.22[b]	15.3	1.0	0.1	150.0	20	–	5

[a] Based on equation (4).
[b] $Q_d^i = 34.0[MJ/m^3]/0.752[kg/m^3] = 45.22[TJ/kt]$.

3. Consumption of fossil fuels and related GHG emissions originating from PDH sub-sector in the period 2000–2008

Based on the data presented in the related study [15], an inventory of GHG emissions for the period 2000–2008 was assembled. Data on natural gas and liquid fuel consumption are summarized in Table 2, while data on the consumption of solid fuels are presented in Table 3.

At the end of last century, reduced use of fossil fuels for heat generation has been recorded in Serbia, primarily as a result of economic sanctions imposed by the UN. However, from 2000 onwards, fossil fuel consumption has been constantly increasing. At the same time, extensive fuel-switching measures have been carried out in PDH sub–sector, with coal and liquid fuel substituted by natural gas. Consequently, natural gas consumption has increased substantially [16] when compared to consumption in 1990 (by 212% compared to 1998 level and by 252% compared to 2008 consumption). On the other hand, consumption of liquid fuel

Table 2
Consumption of natural gas and liquid fuels used for heat production in PDH sub-sector.

Year	Natural gas	Residual fuel oil	Gas/diesel oil
	[m^3]	[t]	[t]
1990	183,613,877	260,702	1349
1998	388,516,808	116,158	1516
2000	307,854,400	105,923	922
2004	484,560,931	118,346	689
2005	509,341,004	141,083	636
2006	491,971,479	140,547	800
2007	456,990,787	149,892	530
2008	463,539,345	149,875	574

and coal has decreased. Consumption of heavy fuel oil has reduced significantly in the period 1990–1998, dropping down to only 45% of the consumption recorded in 1990. In the period 1998–2008 consumption of liquid fuel oil decreased down to 58% of the consumption recorded in 1990. Consumption of other liquid fuels was small [16] and was not taken into account in the analysis performed and presented herein.

Table 3 presents data which illustrate a tendency towards reduced coal consumption when compared to 1990 coal consumption. Till 2008, the amount of lignite obtained from underground mines and consumed in thermal energy generation processes in the sub-sector of PDH was decreased down to 13.5% of the quantity consumed in 1990. Consumption of dried lignite has varied from year to year, primarily due to reasons associated with energy prices and local fuel market conditions. In recent years, consumption of dried lignite has stabilized at the 1990 consumption level. Consumption of sub-bituminous and other bituminous coals has reduced to 45% and 27% of 1990 consumption levels respectively.

Consumption of wood and biomass briquettes was small and was therefore not taken into account when assembling mass and energy budgets.

Table 4 presents data on fossil-fuel-derived energy consumed by PDH sub-sector in the period 1990–2008, as well as overall fossil-fuel-derived energy consumed by Serbian energy sector in 1990 and 1998. Total installed capacity of boilers utilized in PDH sub-sector reaches about 5500 MW.

Energy consumption in PDH sub-sector remained almost unchanged until 1998 [15] (a decrease of 1.4% compared to the base 1990), only to increase by 8.6% until 2008. Annual changes in PDH sub-sector energy needs resulting from specific annual climate conditions and annual increase in heated floor area connected to district heating (DH) system was accompanied by corresponding changes in annual fuel consumption.

A share of PDH sub-sector in total energy consumed by Serbian energy sector equalled 3.41% in 1990 i.e. 4.35% in 1998, afterwards remaining unchanged until 2008. Fuel mix consumed by PDH sub-sector in 1990 (Liquid fuels 46.4%, Solid fuels 26.2% and Gaseous fuels 27.4%) has gradually shifted to more environmentally friendly fuel mix recorded in 2004 (Liquid fuels 19.7%, Solid fuels 12.5% and Gaseous fuels 67.8%) and 2008 (Liquid fuels 24.5%, Solid fuels 11.7% and Gaseous fuels 63.8%).

Table 3
Consumption of solid fossil fuels in PDH sub-sector.

Year	Lignite from underground mines	Dried lignite	Other bituminous coal	Sub-bituminous coal
	[t]			
1990	200,845	9804	12,788	309,365
1998	41,812	14,734	2281	218,089
2000	40,207	14,975	18,149	177,634
2004	31,023	18,767	10,156	126,255
2005	30,967	23,269	15,434	141,763
2006	34,075	18,807	12,897	131,781
2007	27,179	10,508	14,146	127,259
2008	27,072	8588	3437	139,192

Calculated GHG emissions resulting from thermal energy generation based on fossil fuel combustion in PDH plants in Serbia in the period from 1990 to 2008 are presented in Table 5. In accordance with widely accepted approach, net emissions of CO_2, CH_4 and N_2O are cumulatively expressed through CO_2 equivalent emissions (CO_{2eq}), using global warming potentials values of 1 for CO_2, 21 for CH_4 and 310 for N_2O.

When compared to 1990 emissions, CO_2 emission recorded in 2008 were lower (reduced by 5.7%), in spite of increased fuel consumption and heat generation (increase of 8.6%), primarily as a result of fuel switching from coal and oil to natural gas. Increased natural gas share in total fuel consumption in 2008 has led to significant decrease in most GHG emissions when compared to 1990 emission levels. Thus, N_2O emissions decreased by 39.5%, NO_x emissions by 8%, CH_4 emissions by 11.4% and SO_2 emissions by 45.8%, while CO and NMVOC emissions increased by 17.4% and 8.8% respectively.

Fig. 1 presents changes in energy consumption and emitted CO_{2eq} attributed to PDH sub-sector in the period observed, relative to 2000 values. Consumption of fossil-fuel-derived energy in PDH sub-sector has been gradually increasing in the period considered, reaching the maximum in 2005 (increase of 40% when compared to 2000 level) and stabilizing at the level of +30% in the last two years of the period considered. GHG emissions (expressed as CO_{2eq} emissions) have also increased in the period examined, but at somewhat slower pace due to coal-to-gas fuel switching. Reduction of GHG emissions originating from PDH sub-sector, recorded in the period 2000–2008, would be even higher if liquid fuels have been substituted by natural gas as well.

Quantities of CH_4, N_2O, NO_x, CO, $NMVOC_s$ and SO_2 emitted in the period 2000–2008 are presented in Fig. 2, relative to the 2000 values. Fig. 2 clearly indicates that emissions are closely following the trend of increased fossil-fuel-derived energy consumption in the period examined, with an exception of N_2O and SO_2 emissions which have decreased compared to respective 2000 levels. The last is mainly attributed to fuel switching from sulphur-rich coal to natural gas (with zero sulphur content and lower N_2O emission factors) implemented in PDH sub-sector.

The share of GHG (CO_{2eq}) emissions resulting from natural gas combustion increased from 20.26% in 1990 to 54.28% in 2008 (Table 6), while the share of CO_{2eq} emissions associated with liquid fuel combustion decreased from 47.23%, as recorded in 1990, to 28.86%, as recorded in 2008 [16]. The share of solid fuel related CO_{2eq} emissions in total CO_{2eq} emissions originating from PDH sub-sector decreased from 32.51% in 1990 to 16.86% in 2008.

The share of GHG (CO_{2eq}) emission originating from PDH sub-sector in total national GHG emissions (from all sectors) equalled 2.13% and 2.30% in 1990 and 1998 respectively [1].

Uncertainty in GHG emission budget was determined in accordance with IPCC Guidelines. Table 6 presents an overview of major sources of GHG emissions in PDH sub-sector and related values of combined uncertainty calculated from the uncertainty of specific activity/the amount of fuel used and uncertainty of assumed fossil fuel emission factor.

4. Projections of future GHG emission originating from PDH sub-sector in the Republic of Serbia

Global reduction of GHG emissions and adoption of national mitigation measures by non-Annex I Parties to the Convention have been identified as the key objectives of UN Framework Convention

Table 4
Fossil-fuel-derived energy consumption in PDH sub-sector compared to fossil-fuel-derived energy consumption in Serbian energy sector (IPCC Source Category 1.A).

Year	PDH sub-sector [TJ]				Energy sector [TJ]				PDH in energy sector [%]			
	Total liquid	Total solid	Total gaseous	Total	Total liquid	Total solid	Total gaseous	Total	Total liquid	Total solid	Total gaseous	Total
1990	10,551	5945	6238	22,734	201,360	379,400	86,221	666,981	5.24	1.57	7.23	3.41
1998	4731	4479	13,230	22,410	108,988	333,509	72,872	515,428	4.34	1.34	18.16	4.35
2000	4297	4143	10,467	18,907								
2004	4786	3054	16,475	24,315								
2005	5698	3521	17,318	26,537								
2006	5683	3246	16,727	25,656								
2007	6047	2973	15,538	24,558								
2008	6048	2887	15,760	24,695								

on Climate Change [19]. Strategic priorities defined for Serbian energy sector [2] are: continued technological modernization of existing power plants/systems/resources in the energy sector, rational use of high quality energy sources, increase in energy production and distribution efficiency, introduction of new renewable energy sources and new energy-efficient and environmentally friendly energy generation technologies and devices/equipment. In addition, different measures and activities have been proposed [2,3] to be implemented in PDH sub-sector and buildings in order to achieve the goals defined:

- Reconstruction of boiler units and heat supply systems,
- Conversion of solid and liquid fuel fired boilers to natural gas fired boilers,
- Boiler plant modernization and automation,
- Introduction of new technologies for decentralized electricity and heat production; series of combined natural gas fired heat and power production facilities (CHP),
- Consistent implementation of JUS J5.600 (1987) and other related standards addressing design of new buildings and their thermal insulation,
- Transition from electricity-based space heating to other energy sources,
- Establishment of energy efficiency fund so as to be able to financially support improvement of thermal performance of existing residential buildings and other energy efficiency projects.

The overall floor area (residential, commercial and institutional buildings) heated by PDH systems in Serbia in 2008 year equalled app. 37,500,000 m^2, with related gross specific heat consumption of 182 kWh/m^2. According to available data [2], electricity is used to heat 14% of total floor area of residential buildings (as well as commercial/institutional buildings), mainly due to low electricity price when compared to the price of final energy derived from liquid/gas fossil fuels. The indicated electricity use accounts for ~24% of total residential annual electricity consumption. As the ratio of primary (lignite) energy utilized for power generation to final energy (electricity) consumed in the Republic of Serbia is very high (due to low efficiency of energy transformation processes of ~0.33 and high transmission and distribution loses), high electricity consumption for residential space heating is accompanied by high GHG emissions in energy generation sub-sector. Government policies are aimed at decreasing the use of electricity for residential space heating by extending the existing district heating network and financially supporting connection of new and current residential and commercial/institutional buildings to DH networks. It is expected that the number of district heating users (with average heated floor area of 66 m^2) will rise by 100,000 until 2012 and by additional 80,000 until 2015. The overall PDH heated floor area will rise to 44,100,000 m^2 and 49,380,000 m^2 accordingly.

It is estimated that efficiency of district heating system operation will improve by 7% until 2012 and by 12.5% until 2015. As a result, gross specific energy consumption will be reduced to 170.1 kWh/m^2 in 2012 and to 160.0 kWh/m^2 in 2015. Due to increased floor area heated by PDH (+17.6% by 2012 and +31.7% by 2015 compared to the heated floor area serviced in 2008) and increased PDH system operation efficiency, estimated annual heat demand will increase at a somewhat slower pace: by 9.3% in 2012 and by 15.2% in 2015 compared to energy consumption in 2008.

Analysis of PDH sub-sector related GHG emissions were performed for basic and four alternative scenarios. Basic scenario relates to the assumption that thermal energy demand to be met by PDH sub-sector will increase by 10% till 2012 and by 15% till 2015 compared to 2008, adopted as the base year, while the fuel mix will remain unchanged. In all four alternative scenarios thermal energy

Table 5
Annual GHG emission originating from PDH sub-sector.

Year	Emission from PDH sub-sector [Gg]							
	CO_2	CH_4	N_2O	NO_x	NMVOC	CO	SO_2	CO_{2eq}
1990	1714	0.044	0.015	4.822	0.114	0.402	18.643	1720
1998	1523	0.032	0.010	4.268	0.112	0.425	10.598	1527
2000	1308	0.028	0.009	3.680	0.095	0.357	10.730	1311
2004	1576	0.034	0.009	4.340	0.122	0.462	9.200	1579
2005	1736	0.038	0.010	4.790	0.133	0.502	10.930	1740
2006	1677	0.037	0.009	4.590	0.128	0.483	10.470	1680
2007	1612	0.037	0.009	4.430	0.123	0.461	10.610	1615
2008	1616	0.039	0.009	4.440	0.124	0.472	10.110	1620

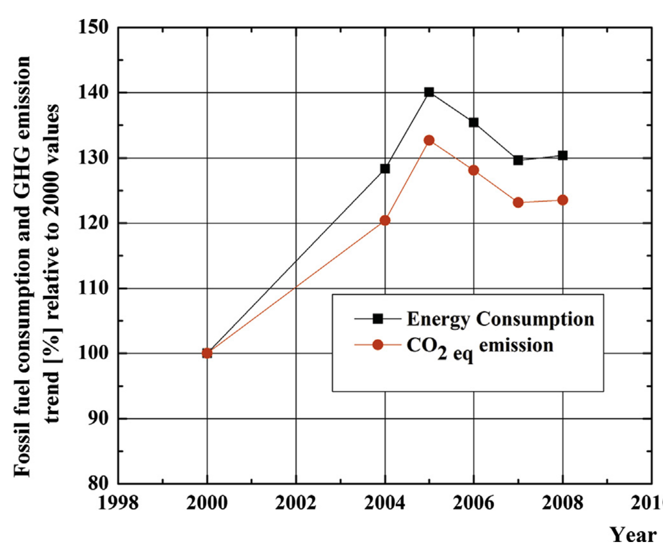

Fig. 1. Energy consumption and CO_{2eq} emission in the period 2000–2008.

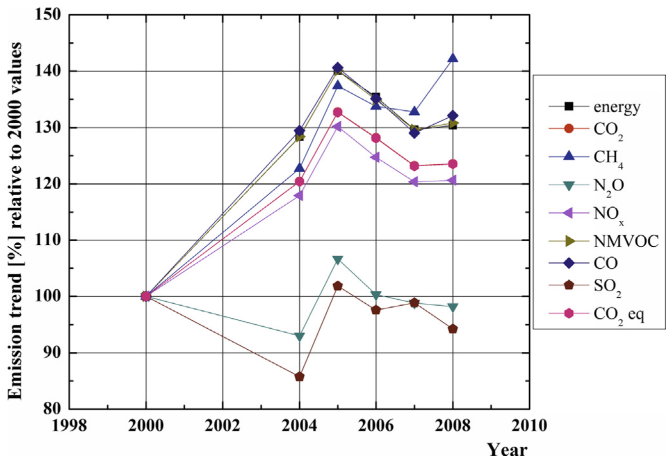

Fig. 2. CH_4, N_2O, NO_x, CO, SO_2 and NMVOCs emissions in the period 2000–2008.

demand to be met by PDH sub-sector remains the same as in the basic scenario, while the fuel mix is altered from one scenario to the other:

- The first alternative scenario (I) predicts a change in GHG emissions relative to the base year as a result of solid fuel substitution by natural gas;
- The second scenario (I/B) predicts a change in GHG emissions relative to the base year as a result of solid fuel substitution by natural gas and partial substitution of liquid fuel by biomass;
- Third scenario (II) represents a hypothetical case assuming that total necessary amount of natural gas is substituted by heavy fuel oil (this is not even a realistic scenario, but is addressed in order to examine environmental impact in a situation when natural gas supplies are cut-off, as it happened in winter 2008/2009 due to Russia–Ukraine crisis);
- Final alternative scenario (III) represents a hypothetical case when all energy needed to meet PDH sector demand is generated only by natural gas combustion.

Table 7 presents projection of fossil-fuel-derived energy consumed in PDH sub-sector according to different scenarios. Calculations of 2012 and 2015 GHG emissions were performed according to IPCC methodology, with results obtained and presented in Table 8.

Fig. 3 shows calculated GHG emissions originating from PDH sub-sector, as obtained for different scenarios and expressed relative to 2008 CO_{2eq} emission level.

In case of basic scenario, characterized by unchanged fuel mix, increase in GHG emissions is proportional to the increase in energy demand.

In case of partial fuel switching from coal to "environmentally friendly" natural gas (scenario I), a slower increase in GHG emissions (compared to the basic scenario) is expected until 2012, when 100% coal substitution by natural gas is planned to take place. Starting from 2012, fuel switch will have no effect on GHG emissions, meaning that increase in GHG emissions shall be higher than in the period that has preceded.

In case when liquid fuel and coal are fully replaced by "environmentally friendly" natural gas (scenario III), GHG emission decrease until 2012, reaching the level of 93.7% of 2008 GHG emissions. In the period from 2012 to 2015, increased energy demand i.e. increased natural gas consumption in PDH sub-sector shall cause an increase in GHG emissions, but with emissions still staying below 2008 emission level (97.9%).

Scenarios I and III clearly indicate a strong positive impact of fuel switch (switching from coal and liquid fuel, characterized by higher carbon emission factors, to natural gas with lower carbon emission factor) on GHG emission reduction. The indicated mitigation measure has been successfully implemented in Serbia in the previous period, with implementation planned to be continued in the future, in spite of the fact that high prices of

Table 6
Key sources and combined uncertainty of calculated CO_{2eq} emissions originating from PDH sub-sector, as obtained for 1990, 1998 and 2008.

Year		1990			1998			2008		Uncertainty	
Key source category		CO_{2eq} [Gg]	Level [%]	Cumul. [%]	CO_{2eq} [Gg]	Level [%]	Cumul. [%]	CO_{2eq} [Gg]	Level [%]	Cumul. [%]	[%]
CO_2 emissions from PDH	Gas/diesel oil	4.3	0.25	47.23	4.9	0.32	24.00	1.8	0.11	28.86	7
	Residual fuel oil	808.0	46.98		361.6	23.68		465.9	28.75		7
	Other bituminous coal	27.92	1.62	32.51	4.98	0.33	27.71	7.5	0.46	16.86	7
	Sub-bituminous coal	492.2	28.62		346.9	22.72		221.5	13.66		12
	Dried lignite	17.0	0.99		25.6	1.68		14.9	0.92		7
	Lignite from underground mines	21.9	1.27		45.6	2.99		29.5	1.82		7
	Natural gas	348.5	20.26		737.4	48.29		879.7	54.28		7

Table 7
Projection of fossil-fuel-derived energy consumption in PDH sub-sector according to different scenarios.

Year/Scenario	Total energy [TJ]	Liquid fuel [%]	Solid fuel [%]	Natural gas [%]	Liquid fuel [TJ]	Solid fuel [TJ]	Natural gas [TJ]
2008	24,695	24.5	11.7	63.8	6048	2887	15,760
2012 – basic	27,165	24.5	11.7	63.8	6652.9	3175.8	17,336.3
2015 – basic	28,399	24.5	11.7	63.8	6955	3320	18,124
2012 – I	27,165	24.5	0	75.5	6652.9	0	20,512.1
2015 – I	28,399	24.5	0	75.5	6955	0	21,444
2012 – I/B	27,165	16.7	7.8[a]	75.5	4531.7	2121.2[a]	20,512.1
2015 – I/B	28,399	16.7	7.8[a]	75.5	6955	2217.5[a]	21,444
2012 – II	27,165	88.3	11.7	0	23,989.2	3175.8	0
2015 – II	28,399	88.3	11.7	0	25,079	3320	0
2012 – III	27,165	0	0	100	0	0	27,165
2015 – III	28,399	0	0	100	0	0	28,399

[a] Biomass.

Table 8
Projection of GHG emissions according to different scenarios.

Year/Scenario	GHG emission [t]							
	CO_2	CH_4	N_2O	NO_x	NMVOC	CO	SO_2	CO_{2eq}
2008	1,616,328	39.66	9.25	4440	123.48	471.66	10,110	1,619,967
2012 – basic	1,777,961	40.47	10.17	4884	135.82	510.03	10,896	1,781,963
2015 – basic	1,858,777	42.31	10.63	5106	142.00	533.21	11,391	1,862,962
2012 – I	1,654,443	40.47	6.04	4407	135.82	510.03	6607	1,657,166
2015 – I	1,729,645	42.31	6.32	4608	142.00	533.21	6907	1,732,492
2012 – I/B	1,491,974	34.11	4.77	4619	135.82	520.64	4501	1,494,169
2015 – I/B	1,559,800	35.66	4.99	4830	142.00	544.31	4706	1,562,095
2012 – II	2,138,098	75.14	18.84	5750	135.82	423.35	28,116	2,145,516
2015 – II	2,235,284	78.56	19.70	6012	142.00	442.59	29,394	2,243,039
2012 – III	1,516,310	27.16	2.72	4074	135.82	543.29	0	1,517,723
2015 – III	1,585,233	28.40	2.84	4260	142.00	567.99	0	1,586,710

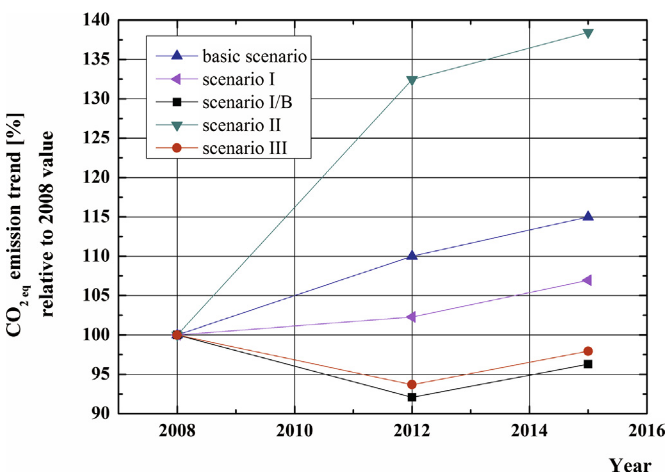

Fig. 3. GHG emission projections until 2015 according to the scenarios.

imported natural gas (especially compared to prices of domestically excavated lignite and related electricity produced) represent serious obstacles to faster and broader implementation of the measure addressed.

On the contrary, scenario II shows high increase in GHG emissions as a result of fuel switching to liquid fuel (in case of switching to coal, GHG emissions would be much higher), as examined for hypothetical case of natural gas supply cut-off (that actually happened in winter 2008/2009 due to Russia–Ukraine crisis) or in case of much higher price disproportion (especially disproportion between electricity price and fuel-to-energy price associated with natural gas use). In order to be able to overcome potential problem of natural gas supply cut-off, besides new alternative gas supply pipeline, first underground natural gas storage in Serbia is being completed.

By partially switching from liquid fuel to CO_2-neutral biomass (scenario I/B compared to alternative scenario I), related GHG emissions expected in 2012 and 2015 would be the lowest among all analysed scenarios. Substitution of fossil fuels (imported liquid and gaseous fuels) by locally available biomass and its use in PDH systems has been identified as the best option for solving environmental problems (reduction of SO_2 and GHG emissions) and increasing both energy security and local employment rate.

5. Conclusion

Presented data related to fossil fuels consumption in PDH sub-sector in Serbia in 1990, 1998 and in the period 2000–2008 and results of associated GHG emission calculation were used to develop different scenario and evaluate proposed mitigation measures.

Starting from 1990, consumption of fossil-fuel-derived energy in PDH sub-sector remained almost at the same level until 1998 (a decrease of only 1.4% compared to the base year of 1990 i.e. 22,734 TJ), only to be increased by +8.6% until 2008. The share of PDH sub-sector in total energy consumed by the energy sector equalled 3.41% in 1990 and 4.35% in 1998, remaining at the same level during the entire period until 2008. Fuel mix consumed by PDH sub-sector in 1990 (Liquid fuels 46.4%, Solid fuels 26.2% and Gaseous fuels 27.4%) has gradually shifted to more environmentally friendly fuel mix recorded in 2004 (Liquid fuels 19.7%, Solid fuels 12.5% and Gaseous fuels 67.8%) and 2008 (Liquid fuels 24.5%, Solid fuels 11.7% and Gaseous fuels 63.8%).

GHG emissions originating from PDH sub-sector in 2008 decreased by 5.8% compared to the base year (1990 i.e. 1720 Gg $CO_{2eq.}$) in spite of increased fossil fuel consumption (by 8.6%), which mainly came as a result of fuel switching from coal and oil to natural gas. Increased natural gas share in total fuel consumption in 2008 has led to significant decrease in most GHG emissions when compared to 1990 emission levels.

Potentially high GHG emission reduction in PDH sub-sector in Serbia could be achieved through: a) further substitution of coal and oil with natural gas and/or biomass, b) improvement of district heating system performance efficiency, which shall lead to reduced specific heat consumption and c) implementation of modern technological solutions (combined heat and power generation i.e. cogeneration units with combined gas–steam cycle).

Efficiency of district heating systems is expected to improve by 7% until 2012 and by 12.5% until 2015. As a result, gross specific energy consumption will be reduced to 170.1 kWh/m^2 in 2012 and 160.0 kWh/m^2 in 2015. Due to increased floor area heated by PDH (+17.6% by 2012 and +31.7% by 2015 compared to the heated floor area serviced in 2008) and increased efficiency of PDH system performance, estimated annual energy demand will increase at a somewhat slower pace: by 9.3% in 2012 and by 15.2% in 2015 compared to energy consumption in 2008.

Analysis of GHG emissions attributed to PDH sub-sector up to 2015 in case of basic and four alternative scenarios points out to highly positive impact of fuel switching on GHG emission reduction (switching from coal and liquid fuel characterized by higher carbon emission factors to natural gas with lower carbon emission factor). The indicated mitigation measure has been successfully implemented in Serbia in the previous period, with implementation planned to be continued in the future, in spite of the fact that high prices of imported natural gas (especially compared to prices of domestically excavated lignite and related electricity produced) represent serious obstacles for faster and broader implementation of the measure addressed.

Substitution of fossil fuels (imported liquid and gaseous fuels) by locally available biomass and its use in PDH systems has been identified as the best option for solving environmental problems (reduction of SO_2 and GHG emissions), as well as overcoming problems associated with high prices of imported fuels, improving energy security and increasing local employment rate.

On the contrary, scenario that assumes fuel switching to liquid fuel (and especially in case of fuel switch to coal, when GHG emissions would be even higher), examined for hypothetical case of natural gas supply cut-off (as it happened in winter 2008/2009 due to Russia–Ukraine crisis) or in case of much higher price disproportion (especially disproportion between electricity price and fuel-to-energy price associated with natural gas use) is determined to be associated with high increase in GHG emissions. In order to be able to overcome potential problem of natural gas supply cut-off, besides new alternative gas supply pipeline ("South Stream" gas supply line), first underground natural gas storage in Banatski Dvor, Serbia, is being constructed.

Acknowledgements

The authors would like to express their appreciation for the efforts of the Ministry of Education and Science of the Republic of Serbia in supporting and promoting this work through scientific projects referenced III42010 and TR33050.

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