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FINAL REPORT ON INVENTORY OF SECTORAL GREENHOUSE GAS EMISSIONS (DISTRICT-HEATING SECTOR OF UKRAINE)

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Introduction

In June 1992, more than 150 countries signed the Framework Convention on Climate Change (FCCC) at the Earth Summit in Rio de Janeiro. The Convention entered into force in 1994 after 50 signatories had officially ratified the agreement. The FCCC requires signatories to prepare inventories of their greenhouse gas emissions and sinks. Ukraine, the 11th largest emitter of greenhouse gases, has also signed the FCCC and has agreed to stabilize its emissions at their 1990 level. While Ukrainian emissions are currently well below their 1990 level, Ukraine's ability to compile reliable emission inventories and monitor those emissions is limited. The organization of statistical data, for example, makes it extremely difficult to prepare transparent, IPCC-compatible inventories. Likewise, lack of familiarity with international greenhouse gas inventories at the local level, where data are initially collected, also affects the accuracy of the final data. Ukraine submitted its first draft inventory to the FCCC Secretariat in the fall of 1999, and Ukrainian experts feel that much still needs to be done to improve the inventory of emissions. Monitoring and reporting greenhouse gas emissions are both key elements of compliance with the FCCC. If Ukraine cannot accurately report on its emission levels, it may ultimately fall out of compliance.

Through work sponsored by the U.S. Environmental Protection Agency, the Pacific Northwest National Laboratory requested the Agency for Rational Energy Use and Ecology to perform the greenhouse gases inventory in the district-heating sector of Ukraine.

The main aim of this project is to improve the capacity of Ukraine to monitor and report the emissions of the three primary greenhouse gases, carbon dioxide (CO_2), methane (CH_4), nitrous (N_2O), and other as necessary. This work fulfills the following objectives:

- *Increase Ukrainian monitoring and reporting capabilities.* Rigorous measurement and reporting of greenhouse gases is necessary for Ukraine to implement the United Nations Climate Change Convention.

- *Foster credible and meaningful emissions reductions targets.* Efficient and cost-effective monitoring systems will attract climate-related investment in economies in transition by addressing investors concerns about compliance. A successful monitoring system could also serve as a preliminary step for introducing emission quotas on a national or regional basis.

In the framework of fulfilling the inventory, the 'Proposals to a concept of the Ukrainian National GHG Inventory System' [3] and 'Report on Adaptation of IPCC Guidelines and Software to Conditions of Ukrainian District-heating Sector' [13] were developed. The district-heating sector is defined [3] as one of the priority sectors for a detailed greenhouse gases (GHG) inventory in Ukraine.

The provision of district heat is a technologically complex operation that involves the production, transmission, and consumption of heat energy. District heat consumers include buildings in the residential and public sectors, and industrial facilities. The source of GHG emissions in the district-heating sector is fuel combustion (mainly combustion of natural gas, but also coal and mazut) in boiler plants that are owned by the Ministry of Fuel and Energy, communal property enterprises, and others, mainly industrial enterprises.

This report gives provides:

- a characterization of the district-heating sector;

- outlines methods for a detailed GHG emissions inventory and issues for the primary data needed to prepare and calculate the inventories;
- proposes a model for automating the calculations and preparing the primary data;
- contains the estimated GHG emissions for Ukraine's 28 largest cities and Ukraine as a whole based on data of from statistical reports and a survey.

1. Characterization of the object of inventory

1.1. Justifying the choice of the object of inventory

The report 'Proposals to a concept of the Ukrainian National GHG Inventory System' [3] suggested terms for inventorying and categorizing the key sources of GHG emissions in order to provide Ukraine the opportunity to participate in the international activities for climate change mitigation. In accordance with 'Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories' [2] the key source categories of GHG emissions include the economic sectors, which, with 90% probability, account for 95% of cumulative GHG emissions.

The sequence of the detailed GHG emissions inventory was established according to the general rank of the key source categories that were defined [3], considering the shares of these sources in total emissions and trends in GHG emissions.

The highest general rank and, correspondingly, the highest priority in the inventory is given to fuel combustion in the power (heat and electricity) sector. This is followed by fuel combustion in the residential sector, production of pig iron and steel, industry and construction, coal mining, and other sectors.

This report considers the results of the GHG inventory in the district-heating sector, which is the largest source of GHG emissions in the housing sector of Ukraine. District-heating is defined [14] as heat supply to the consumers through a common heat network. District heat consumers include buildings in the residential and public sectors, and industrial facilities.

The public sectors [10] include heat consumption in secondary and higher education facilities, health care institutions, sport and trade institutions, catering enterprises, nursery schools, hotels, military divisions, etc., as well as heat consumption for the communal and cultural-household needs of all enterprises, institutions and organizations.

The source of GHG emissions in the district-heating sector is fuel combustion (mainly combustion of natural gas, but also coal and mazut) in boiler plants that are owned by the Ministry of Fuel and Energy, communal property enterprises, and others, mainly, industrial enterprises.

1.2. Characteristics of District-Heating Sector

Depending on location of the energy sources and consumers, heat supply systems are split into decentralized and district. In decentralized systems, heat sources are located near consumers so that heat is supplied without an intermediate link (i.e. heat networks). In district-heating systems, more distance separates energy sources and customers, and heat is supplied through heat networks.

District-heating is a unified and technologically complex system that involves heat production (CHP, boiler plants), its transportation (heating networks, pump stations, sectional units, group heat substations (GHS)) and energy consumption (built-in heaters for hot water supply, individual heat substations (IHS)), and heat supply systems that include radiators and control systems.

The Ministry of Fuel and Energy, municipalities, and industrial enterprises own and operate CHPs and boiler plants. When determining emissions from heat sources in the district-heating sector, the requirements included in the following documents were considered:

- IPCC Guidelines [1], according to which the energy module includes all GHG emission sources connected with fuel combustion for heat production;
- IPCC Guidelines [1-a], according to which energy sector emissions are included in GHG emissions from industrial processes, which take place simultaneously with the emissions from fuel combustion for energy processes (including heat production);
- State standard [14] that determines the notion of district-heating as heat supply to consumers through the common heat network;
- Recommendations for filling in form 1-TEP /10/, that includes statistical data from all energy supply enterprises, heat and electricity networks enterprises, and other enterprises, organizations, and institutions of all ministries and departments that own boilers and heat networks and supply consumers directly with heat and hot water.

Based on the analysis of the documents mentioned above, the district-heating sector included all CHPs and boiler plants included in the general statistical report on the heat supply (Form '1-tep'). This information provided that, in 2001, the 65,305 CHPs and boilers consumed 19,204.3 t.c.e. to produce 118,967,700 Gcal of heat.

District-heating companies owned by the Ministry of Fuel and Energy, communal/local district heating companies, oblast district-heating companies, and/or industrial heat sources supply heat to large cities. The smaller cities and municipalities are served by district-heating companies owned by the Ministry of Fuel and Energy.

It is typical for the large cities of Ukraine to use combined heat and power plants (CHPs) and large heat-only boiler plants as the main heat sources for municipal district-heating systems. The heat supply systems of these cities are characterized by a few large energy sources, long heating mains (over 500 km), sectionalized units, shutdown valves, pump stations, and group substations. The heating regions are organized and the system is configured to supply heat from one or a few large heat sources.

The heat networks may be linked by interregional mains to ensure that the system will function with a minimum of heat sources on the common heat network. The boiler plants serving the system, may be used as peaking sources to supplement the production from CHPs or as the main heat source of the region in periods of low demand. Water is the typical medium for transporting heat to residential and commercial buildings and steam is often used for industrial and manufacturing facilities.

A closed two-pipe heating systems is the predominate configuration used in Ukraine. In these systems, network water is used only as heat carrier. Domestic hot water may be obtained by using a heat exchanger installed at a GHS or IHS. Steam systems often provide for condensate recovery from consumers with the possible use of a condensate pump for remote customers.

Large cities also have large, medium, and small (individual) heat-only boiler plants distributed throughout the heating system. Medium and low-capacity CHPs may also be used. The heat supply systems of these cities are characterized by a relatively high concentration of heat consumers where the total length of the heat mains is 300-500 km. Due to this, there are fewer pump stations and CHPs, and control systems are usually absent. Low capacity group substations are not used in cases where heat is supplied from medium sized boiler plants. In these cases, four-pipe systems are prevalent to enable use of district hot water supply directly from boiler plants for domestic purposes and the heat networks are sometimes inter-connected at the mains.

The overall operation efficiency of district-heating systems depends on the operation efficiency of it's the components (heat sources, transportation systems and consumers). The structure of the district-heating system components is presented below:

Heat sources

- Heat generating equipment (CHPs and boilers that provide steam and hot water);
- Heat carrier preparation facilities (de-aeration plant and chemical water treatment unit);
- Heat carrier transportation equipment (networks, pumps, and re-circulation pumps);
- Fuel facilities (depends on fuel type – gas, mazut, solid fuel);
- Electric facilities and control systems.

Transport facilities

- Heat networks (mains and distribution networks);
- Sectional and dividing units;
- Distribution heat substations (controlling and group substations);
- Pump stations:
- Control systems.

Heat consumers

- Individual heat substations;
- Built-in boiler plants;
- Heating systems of buildings and constructions (heat substations and controls).

The main functions of heat sources are to produce the required heat flow with the specified performance factors with minimum energy consumption (fuel, electricity, water), chemical agents, and other costs.

The main functions of the transport facilities are to supply the required amount of heat to consumers with minimum electricity use for transportation, network water losses, and heat losses.

The main tasks at the consumers level are to create conditions for the total and the most efficient use of heat, and minimizing the flow of return heat.

Since heat energy supply sources (CHPs and boiler plants) consume energy (natural gas, mazut, and coal), the importance of efficient combustion and heat exchange equipment operation is paramount. The decrease of fuel consumption for heat generation is a priority as this directly results in the environmental improvement of the entire heat supply system. Further reduction in

fuel consumption at the boiler plant can be achieved by reducing heat losses that occur in the associated transportation and consumption elements.

As mentioned above, municipal DH systems may be characterized by autonomous heat supply for separate city regions (depending on the capacity of the connected consumers), from CHP or large boiler plants, to medium and small (individual) heat-only boiler plants.

Autonomous heat generation equipment may be large capacity hot water boilers (up to 180 Gcal/h) or steam-to-water heat exchangers used at CHP units. Medium and small heat generation boilers have over two dozen various boilers with capacity ranging from 0.07 to 100 Gcal/h.

The installed capacity of large boiler plants usually includes heat sources with capacities of over 65 Gcal/h, medium plants – have sources with capacity capacities from 10 to 65 Gcal/h, and small (individual) boiler plants – have sources with capacity capacities up to 10 Gcal/h. The large and medium plants have water boilers with the designation KVGM (capacity 10-100 Gcal/h), TVG-8M, KVG-6.5 (7.56), KV-G-4.56-150, and steam boilers designated as DE and DKVR (capacity 6.5, 10,16 and 20 t/h. These plants cover approximately 80% of the total load of district-heating systems. The water temperature at the output of the boiler house is about 150^0C and the return temperature to the boiler house is about 70^0C. The main fuel consumed by the large and medium boiler plants is natural gas with mazut as a reserve fuel only for the boiler plants with KVGM, PTVM, DE and DKVR boilers.

The small boiler plants use KBHG-2.5, KBN-Gn-3,15M, TVG-2.5, KSVa (capacity 0.25-3.0 MW), “Drozd” (capacity 2.9 MW), “Grach” (capacity 5.2 MW), and NIISTU-5 (capacity 0.63 Gcal/h) water boilers, and E-1-0.9, and DKVR –2.5/13 steam boilers. The supply temperature of these boilers is 115-170^0C. The main fuel consumed by the small boiler plants is natural gas, although mazut and solid fuel are used in some regions.

The performance characteristics of the types of water boilers are presented in Tables 1and 2.

Table 1. Performance characteristics of the most often used large and medium capacity water boilers

Characteristics	Units	KVGM-30	PTVM-30	TVG-8M	TVG-4p	KVG-6.5	KVG-4.56-150
Thermal performance	Gcal/h	30	40	8.3	4.3	6.5	4
Performance factor	%	91.8	91.5	91.5	90.5	91	91
Specific fuel consumption	kg/Gcal	155.6	156.1	156.1	157.9	157.0	157.0
Water consumption	m^3/h	370	500	104	54	81	49.4
Water pressure	MPa	2.5	2.5	1.4	.4	1.6	1.6
Outlet water temperature	^{0}C	150	150	150	150	150	150
Inlet water temperature	^{0}C	70	70	70	70	70	70
Gas consumption	m^3/h	4,125	5,500	1,100	560	850	560
Gas pressure	kPa	40	40	25	25	25	25

Table 2. Performance characteristics of the main types of small capacity water boilers

Characteristics	Units	KBN-Gn-3.15	VK-21	TVG-2.5	"Drozd"	KBN-G-2.5	Kva-1.0
Thermal performance	Gcal/h	2,7	1.72	2.5	2,5	2.5	0,86
Performance factor	%	94	92	89	95.2	93	91
Specific fuel consumption	kg/Gcal	152.0	155.3	160.5	150.1	153.6	157.0
Water consumption	m^3/h	60	31	56	55	100	35
Water pressure	MPa	0.6	0.6	0.6	0.6	0.6	0.6
Outlet water temperature	^0C	115	115	115	115	95	95
Inlet water temperature	^0C	60	60	70	70	50	60
Gas consumption	m^3/h	350	200	336	310	322	112
Gas pressure	kPa	3	20	20	25	3	3

The main elements of the transport facilities are the heat networks comprised of the transmission and distribution networks, and heat substations. The general structure of the municipal district heat networks is a tree-type heat distribution scheme. A two-pipe system is most commonly used (delivery and return lines) to deliver heat for heating, ventilation and domestic hot water. Heating and ventilation systems are directly connected to the two-pipe water heating networks, and hot water is indirectly supplied through heat exchangers installed in the heat substations of the buildings.

A four-pipe system is used in some cities, as in Zaporizhzhya, where two-pipe (delivery and return) provide heating and ventilation, and two pipelines (delivery and re-circulating) provide hot water supply.

Functionally, heat networks are separated into mains and distribution networks. Mains in the larger cities are two-pipe pipelines with diameters of DN 450-1,200 mm and in the majority of medium and small cities the pipelines have diameters DN 250-500 mm. Distribution networks (prior to group substations) are two-pipe heat pipelines with diameters DN 150-450 mm, and distribution networks with a CHP are basically four-pipe heat pipelines with diameters DN 50-125 mm.

The majority of heat networks are generally laid in underground non-accessible concrete ducts, although the networks are laid in tunnels and accessible ducts in some regions. All heat networks are insulated regardless of the heat carrier temperature, location (above or below ground), and accessibility. The insulation most often used for the existing heat networks is mats made of mineral cotton.

The main functions of the insulation are to reduce energy losses during transportation by the maximum amount possible. Average annual heat losses do not exceed 5-7% for insulation in satisfactory condition.

Heat consumers are connected to the heat networks through individual heat substations (IHS) or group substations (GHS). IHSs are obligatory for every consumer (building) regardless of the availability of group substations, which connect two or more buildings to the network. The typical GHS includes a block of heaters for hot water supply and heating under the autonomous scheme, group network water mixing equipment, a de-aeration unit for hot water supply, and feed pumps for the network and cold water return. The typical IHS includes mixing equipment (hydro-elevator or other appliance), and a block of heaters for hot water supply.

2. Methodology for Emission Determination

Gases emitted during combustion include those having a direct greenhouses effect such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The quantities of GHG emissions are calculated in accordance with the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' [1], with consideration of the Guidelines [6] and results of the inventory in the energy sector of Ukraine [4]. GHG emissions are calculated by the following equation:

Emissions = (data on the combusted fuel) × (conversion factor for carbon emissions and oxidized carbon fraction (for CO_2) or emissions factors of other greenhouse gases).

The main fuel types in the district-heating sector are natural gas (about 90%), black coal (7%) and mazut (2%). The remaining 1% is accounted for oil, gas condensate, peat, firewood, coke, and light oil. The calculations show that GHG emissions from the three main fuel types (natural gas, black coal and mazut), exceed 99% of total district-heating sector GHG emissions.

Since Russia supplies most of the natural gas and liquid fuel, the GHG emissions and natural gas oxidizing factors recommended by the guidelines [6] for use in Russia were accepted for this report. The GHG emissions and solid fuel oxidizing factors as recommended in the guidelines [1] were used for coal.

Methane (CH_4) and nitrous oxide (N_2O) emissions, also produced during fuel combustion, depend on the fuel, emissions treatment technology, operation and maintenance, and age of the equipment. A precise estimate of these emissions requires additional data, but, given the low quantity of these emissions, approximate estimates are calculated.

Table 3 presents the recommended GHG emissions factors for GHG inventories in the district-heating sector of Ukraine for coal, natural gas and petroleum products that were used in this work.

Table 3. Factors for greenhouse gases emissions calculations

Factor	Emissions factors		
	Coal	Natural gas	Mazut
Share of carbon oxidized during combustion	0.98	0.995	0.99
Carbon emissions, t C/TJ	26.8	14.96	21.32
Methane emissions, kg CH_4/TJ	10	5	10
Nitrous oxide, kg N_2O/TJ	1.4	0.1	0.6

3. Primary data for the detailed GHG inventory in the district-heating system

3.1. Background

The GHG inventory provides three methods for calculating emissions associated with heat production [1, 6]:

- The balance method (1st level) uses data on the consumption of the main fuel types at the national or oblast level.
- The key source method (2nd level) uses data on fuel consumption in the branches and sectors of economic activity. This method enables calculation of emissions by key source categories located at the territory of a particular oblast or city;
- The enterprise method (3rd level) uses data on fuel consumption at the enterprises level.

The GHG inventory methods used to meet the meet the IPCC guidelines under the detailed approach are levels 2 and 3. Section 3.2 discusses the preparation of the preliminary data for constructing a detailed inventory of GHG's using the 2nd and 3rd levels.

The amounts of GHG emissions are established by multiplying the volume of each fuel type combusted for heat production by the corresponding ratio of GHG emissions and fuel oxidation that result during combustion. Where available, sectoral fuel consumption data enable inventories to be calculated at the national and oblast levels using the 2nd level method Confidentiality restrictions, enacted by the newly formed State Committee of Communal Sector (created in 2002), prevent the provision of more detailed data at the enterprise level, but this data may be obtained in the future through disclosure restrictions or directly from government institutions. Section 3.3 provides a brief discussion for calculating GHG inventories at the 3rd level using this more detailed data.

3.2. Primary data for calculating GHG inventories using the key source method

District-heating sector GHG emissions can be established by the quantity of fuel combusted in the boiler plants of the communal property enterprises, Ministry of Fuel and Energy facilities, and other enterprises for the production of heat energy.

All enterprises in Ukraine report consumption and/or production of fuel and energy resource according in the following three forms:

- 1-tep – "Report on heat supply";
- 4-mtp – "Report on balance and consumption of fuel and combustive-lubricating materials";
- 11-mtp – "Report on the results of fuel, heat and electricity consumption".

Form 1-tep contains information on the number of the boiler plants (with the distribution by overall capacity of the boilers installed in each boiler plant), number of the boilers in each plant, volumes of production and delivery (to consumers and other enterprises), off-site receipt of heat, heat consumption for own needs and losses (with distribution by three consumer categories – residential, public, and industrial), amount of fuel consumption (in tons of carbon equivalent) by urban and rural settlements, oblast centers, enterprises of the Ministry of Fuel and Energy, and enterprises of communal property) [10].

Form 4-mtp contains information on other fuels consumed by consumers' and suppliers' to include the quantity of combustive-lubricating materials in physical and heat value terms, fuel con-

sumption in the energy sector (including production of heat by boiler plants), consumption of combustive-lubricating materials for energy needs, for industrial production, agricultural works, and other activities, as well as fuel losses during extraction and production, treatment, processing, transmission and distribution at the oblast and state levels [11].

Form 11-mtp contains information on the consumption of fuel (in tons of carbon equivalent), heat and electricity for production, including heat production in the boiler plants with distribution and consumption by the residential and public sectors [12].

3.3. Primary data for calculating GHG inventories using the enterprise method

Calculation of GHG inventories using the enterprise method (3rd level) entails using an instrumental examination (audit) and/or a survey. The examinations can be performed in accordance with an environmental and/or energy audit [7,8] for comparatively small objects – separate boilers, boiler plants or enterprises. Surveys or special questionnaires may be used for large enterprises, cities and regions. Examples of such questionnaires are included to Annex 1. It is recommended to conduct the survey with the support of the interested Ministry or Department. In individual cases it is possible to use a combination of an examination and a survey.

4. Greenhouse gases inventory

4.1. Calculation model of the district-heating sector

The source of GHG emissions in the district-heating sector is fuel combustion (mainly combustion of natural gas, but also coal and mazut) in CHPs and boiler plants that are owned by the Ministry of Fuel and Energy, communal property enterprises, and industrial enterprises. The latter includes heat network enterprises that sell heat energy to consumers. In addition to the residential and public consumers[1] there are other consumers, which use heat for production needs.

The assessment of the GHG emissions in the boiler plants and CHPs can be made based directly on the data of the statistic reports [10-12]. It is much more difficult to determine the GHG emissions caused by fuel combustion for providing heat to individual consumer categories – residential sector, public sector and production needs. In this case it is necessary to use a special calculation model, which is considered in this section.

Figure 1 shows the scheme of the main heat flows (marked with arrows) from sources to consumers. This scheme is designed in conformity with the data contained in the form 1-tep. Heat exchange between enterprises may occur because not all boiler plants have sufficient capacity to meet their own demand. Such enterprises purchase heat energy at the source level and are included in “Other enterprises”.

[1] The public sectors [10] include heat consumption in secondary and higher schools, health care institutions, sport and trade institutions, catering enterprises, children nursery schools, hotels, military divisions, etc., as well as heat consumption for communal and cultural-household needs of all enterprises, institutions and organizations.

Annex 2 contains the electronic worksheet with calculations of fuel consumption in the boiler plants of the Ministry of Fuel and Energy, communal and other enterprises for heat production in the district-heating system of Ukraine based on the data from forms 1-tep and 4-mtp for 2001. This worksheet may be used for establishing the amounts of fuel consumption for the GHG inventory both at the 2nd and 3rd levels. For this purpose it is necessary to enter the data on production and deliveries of heat from the boiler plants of the corresponding enterprises into rows 7-17 of Table A.2, then enter the associated physical quantities of coal, furnace oil and natural gas consumption in rows 24-35.

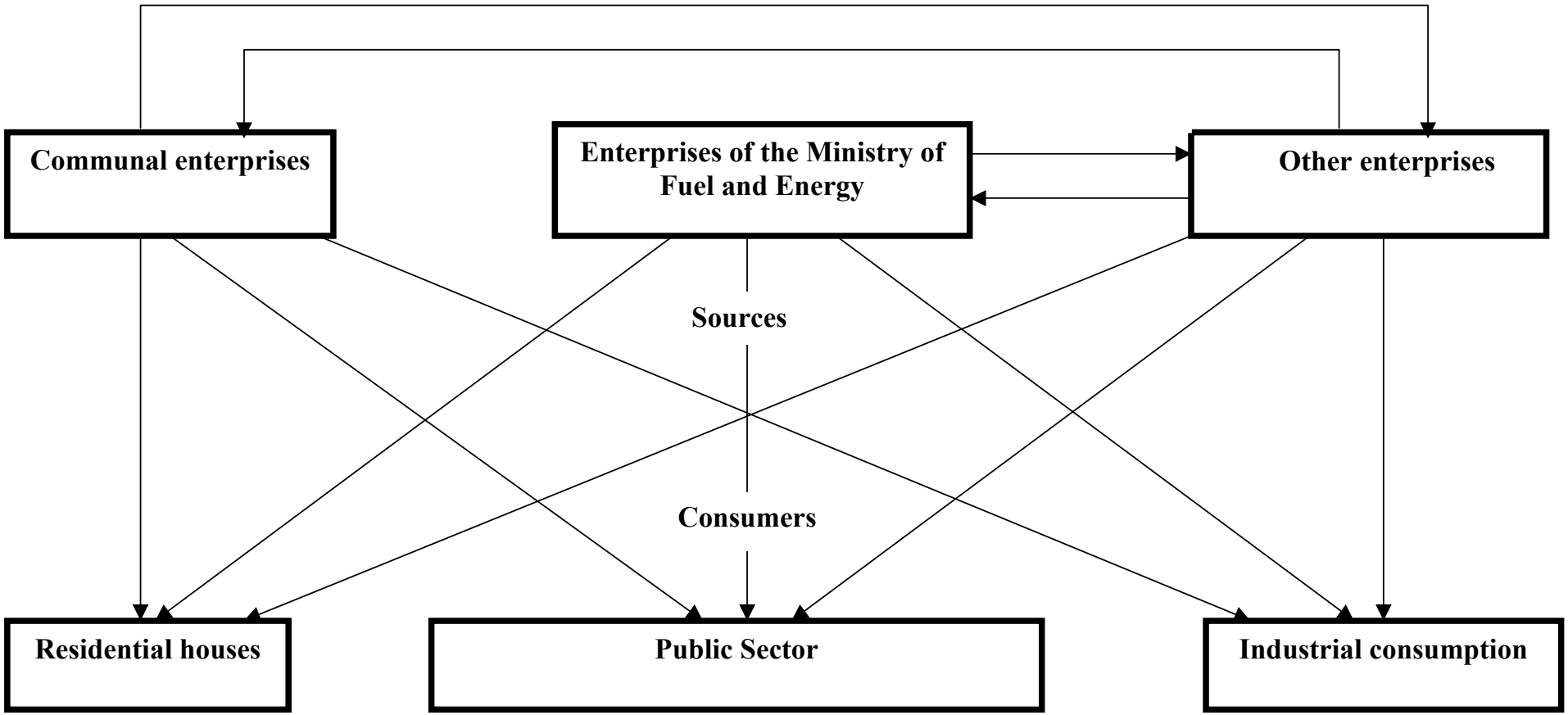

Figure 1. Scheme of heat flows in the district-heating sector

Figure 2 is an extension of figure 1 to show the volumes of fuel combusted in the district-heating sector for heat production. The nodes in figure 2 marks the volumes of heat and the connecting lines show the flows.

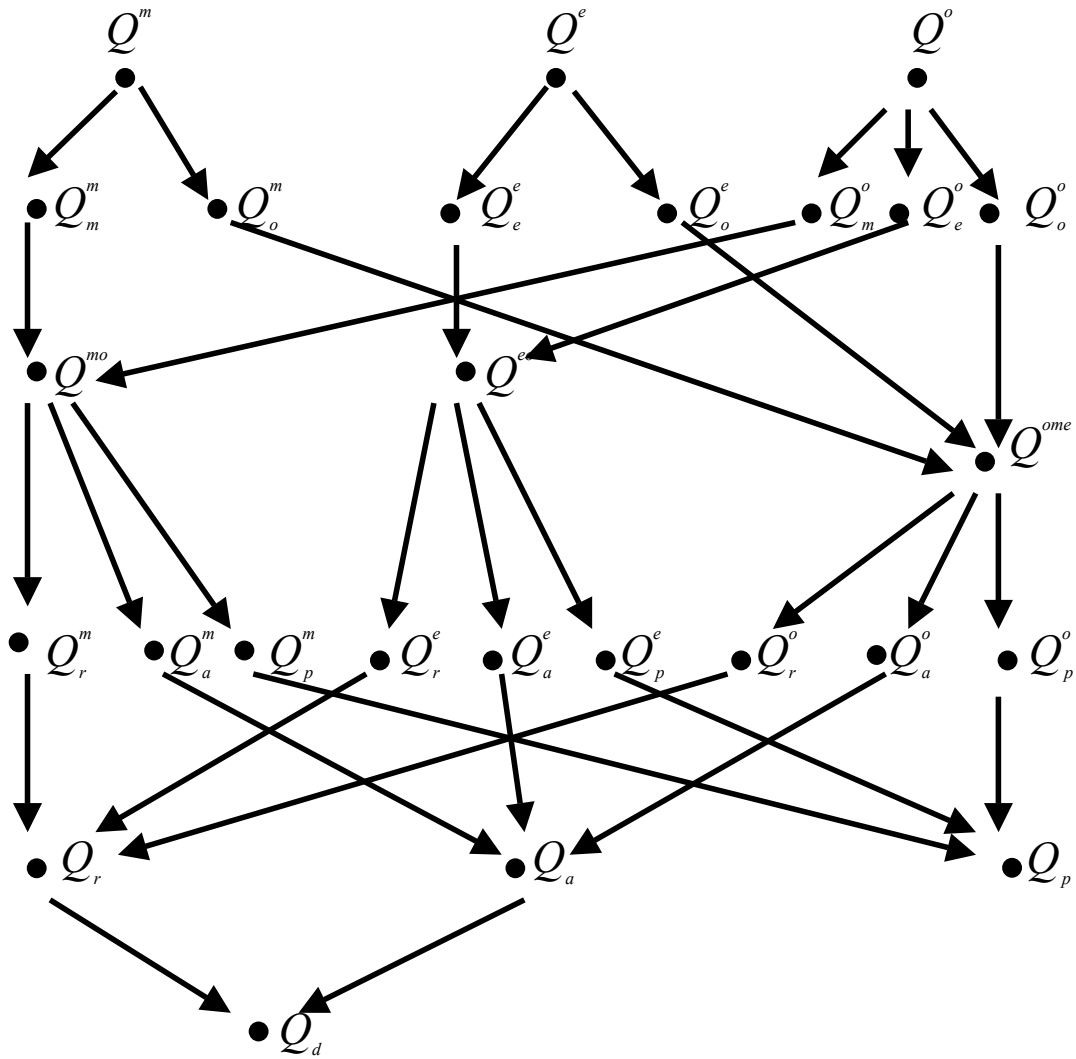

Figure 2. Oriented graph of the heat flows in the district-heating sector of Ukraine.

The list of symbolic notations used in this graph and the values of heat energy at its nodes are presented in Table 4.

Table 4. Symbolic notations and heat deliveries for the district-heating sector of Ukraine (based on the data of 1-tep form for 2001

Magnitude	Symbolic notation	Heat Delivered, thousand Gcal
Total heat delivered by the communal enterprises	Q^m	42,863.5
Heat delivered by the communal enterprises to their consumers	Q^m_m	42,141.8

Heat delivered by the communal enterprises to other enterprises	Q_0^m	721.8
Total heat delivered by the enterprises of the Ministry of Fuel and Energy	Q^e	26,704.6
Heat delivered by the enterprises of the Ministry of Fuel and Energy to their consumers	Q_e^e	22,312.3
Heat delivered by the enterprises of the Ministry of Fuel and Energy to other enterprises	Q_0^e	4,392.3
Total heat delivered by other enterprises	Q^0	45,359.7
Heat delivered by other enterprises to their consumers	Q_0^0	40,245.6
Heat delivered by other enterprises to communal enterprises	Q_m^0	6,925.7
Heat delivered by other enterprises to the enterprises of the Ministry of Fuel and Energy	Q_e^0	662.7
Heat delivered to the residential sector	Q_r	59,267.2
Heat delivered to the public sector	Q_a	24,897.8
Heat delivered to the district-heating sector	Q_d	84,165.0
Heat delivered for production needs	Q_p	20,927.9

Since the input fuel mix (coal, mazut, natural gas) is different for the production of heat for each sector, the volumes of fuel should be established for each sector separately. The formulas for estimating the volume of fuel by type (coal, mazut and natural gas) for generating the heat provided to meet municipal infrastructure, which includes the residential and public sectors, are presented below:

$$(1)\begin{cases} E_d^m = E_m\left(Q_m^m k_d^m + Q_0^m k_d^0\right)\Big/Q^m; \\ E_d^e = E_e\left(Q_e^e k_d^e + Q_o^e k_d^o\right)\Big/Q^e; \\ E_d^0 = E_0\left(Q_0^0 k_d^0 + Q_m^0 k_d^m + Q_e^0 k_d^e\right)\Big/Q^0; \end{cases}$$

where: E - volume of fuel combusted for heat production
Q - volumes of heat consumption;
k - share of fuel combusted in the boiler plants and CHPs of non-municipal enterprises for providing heat to meet municipal demands
m - index of the enterprises of the communal property;
e - index of the enterprises of the Ministry of Fuel and Energy ;
o - index of the other enterprises.
d - index of the municipal consumers.

The factors k_d^m , k_d^e, and k_d in the three formulas in (1) above, depict the ratio between heat consumption in the each of the three customer classes and the total heat generated; these are calculated using the formulas:

$$(2)\begin{cases} k_d^m = \left(Q_r^m + Q_a^m\right) \Big/ \left(Q_r^m + Q_a^m + Q_p^m\right); \\ k_d^e = \left(Q_r^e + Q_a^e\right) \Big/ \left(Q_r^e + Q_a^e + Q_p^e\right); \\ k_d^0 = \left(Q_r^0 + Q_a^0\right) \Big/ \left(Q_r^0 + Q_a^0 + Q_p^0\right). \end{cases}$$

where: p - index of production needs in the heat energy;
r - index of the residential consumers' needs;
a - index of the public sector's needs

The calculation model allows definition of the quantity of GHG emissions from fuel combustion for heat supply to the separate consumers of the district-heating sector. These consumers might include population, administrative sector (separately and together as shown below), as well as technological processes at the national and oblast level. This model may also be used to determine GHG emissions and their reduction from implementation of efficiency measures at the separate enterprises or boiler plants.

4.2. Greenhouse gases inventory in the district-heating sector of Ukraine

The primary data for calculating the inventory of GHG emissions for the district-heating sector of Ukraine using the method discussed above is presented in tables 5 and 6.

Table 5. Production and consumption of heat in Ukraine in 2001(based on form 1-tep of the statistic reports)

Indicator	Total heat supplied, thousand Gcal	Heat supplied to consumers, thousand Gcal			
		Total	including		
			residential consumers	public consumers	industrial needs
Total heat supply, Includes:	114,927.8	105,093.0	59,267.2	24,897.8	20,927.9
- Urban settlements	107,789.5	99,631.8	58,385.3	22,087.5	19,159.3
- Rural settlements	7,137.8	5,460.8	882.3	2,810.7	1,768.5
Heat supplied in oblast centers and the capital of AR Crimea	57,395.3	53,777.7	35,323.6	11,867.7	6,586.2
Heat supplied to Enterprises of communal property	42,863.5	42,141.8	28,436.4	12,260.3	1,444.9
Heat supplied to Enterprises of the Ministry of Fuel and Energy of Ukraine	26,704.6	22,312.1	15,795.5	3,723.1	2,793.8
Heat supplied to other enterprises	45,359.7	40,639.1	15,035.3	8,914.4	16,689.2

Table 5 is essentially a balance of heat delivery and consumption in Ukraine. The top three lines contain data on the total heat supplied to and consumed in urban and rural settlements. Additionally form '1-tep' presents the data (line 4) on heat consumption in the oblast centers and the capital of the autonomous republic of Crimea (AR Crimea). Lines 5 and 6 contain data on heat deliv-

ery by two of three main heat sources in the district-heating sector – enterprises of the communal property and enterprises of the Ministry of Fuel and Energy. The volumes of heat supplied to other enterprises were obtained by subtracting the data of line 5 and 6 from the total volume of heat supplied in line 1.

As mentioned in chapter 3, the quantities of fuel combusted for heat generation in the district-heating sector is presented in statistical forms 1-tep, 4-mtp and 11-mtp. The most detailed information on heat generation and distribution is presented in form 1-tep, which is considered the profile for the district-heating sector. However, 1-tep contains data only in tonnes of coal equivalent (t.c.e.) without identifying fuel type, so GHG emissions cannot be estimated directly from 1-tep.

At the same time, the consumption data by fuel (coal, mazut and natural gas) contained in forms 4-mtp and 11-mtp significantly differ due to differing sources of data. In practice, the State Statistic Committee of Ukraine prefers using data from form 4-mtp rather then 11-mtp.

Table 6 presents a summary of the data from 1-tep, 4-mtp, 11-mtp to show fuel consumption by fuel type in physical units and tons of coal equivalent by economic sector. The last 4 lines provide the estimated coal, mazut and natural gas combustion based on the data from 1-tep and 4-mtp. This synthesis used totals from 1-tep and the shares by fuel type from 4-mtp.

Table 6. Fuel consumption in boiler plants of Ukraine, 2001

Statistcal Report	Economic sector	Coal		Mazut		Natural gas		Total fuel consumption, thousand t.c.e
		thousand t	thousand t.c.e.	thousand t	thousand t.c.e.	mln m^3	thousand t.c.e.	
1-tep	Ukraine in total	Data not available (N/A)	N/A	N/A	N/A	N/A	N/A	19,204.3
	- communal property enterprises	N/A	N/A	N/A	N/A	N/A	N/A	6,924.5
	- enterprises of Ministry of Fuel and Energy	N/A	N/A	N/A	N/A	N/A	N/A	4,531.5
4-mtp	Ukraine in total	2,277.1	1,512.0	402.3	551.1	12,946.8	14,888.8	16,952.0
	- communal property enterprises	172.7	114.7	50.5	69.2	5,478.6	6,300.4	6,484.3
	- enterprises of Ministry of Fuel and Energy	18.2	12.1	19.4	26.6	2,381.2	2,738.4	2,777.1
11-mtp	Ukraine in total	1,683.7	1,118.0	516.5	707.6	14,611.8	16,803.6	18,629.2

	- communal property enterprises	124.6	82.7	68.7	94.1	6,279.7	7,221.7	7,398.5
	- enterprises of Ministry of Fuel and Energy	12.8	8.5	26.5	36.3	2,743.8	3,155.4	3,200.2
Synthe-sized Total from 1-tep and 4-mtp	Ukraine in total	2,579.6	1,712.9	455.8	624.4	14,667.0	16,867.0	19,204.3
	- communal property enterprises	184.4	122.4	53.9	73.9	5,850.6	6,728.2	6,924.5
	- enterprises of Ministry of Fuel and Energy	29.7	19.7	31.7	43.4	3,885.6	4,468.4	4,531.5
	- Other enterprises	2,365.5	1,570.7	370.2	507.1	4,930.8	5,670.5	7,748.3

t = metric tonnes and t.c.e. = tonnes of coal equivalent

Table 7 uses the synthesized data to develop estimates of the GHG emissions in the district-heating sector of Ukraine by major economic sector and fuel type.

Table 7. Greenhouse gases emissions in the district-heating sector of Ukraine, 2001.

Object of inventory	Fuel type	Volume of consumed fuel		CO_2, (Gg)	CH_4 (Mg)	N_2O (Mg)
		Physical units	1000 thousand t.c.e.			
Ukraine in total	Coal	2,579.6 thousand tons	1,712.9	4,565.13	474.05	66.37
	Mazut	455.8 thousand tons	624.4	1,402.11	183.02	10.98
	Gas	14,667.0 mln m^3	16,867.0	26,981.51	2,471.78	49.44
	Total	–	19,204.3	32,948.75	3,128.85	126.78
- communal property enterprises	Coal	184.4 thousand tons	122.5	326.33	33.89	4.74
	Mazut	53.9 thousand tons	73.8	165.80	21.64	1.30
	Gas	5,850.6 mln m^3	6,728.2	10,762.80	985.98	19.72
	Total	–	6,924.5	11,254.94	1,041.51	25.76
- enterprises of Ministry of Fuel and Energy	Coal	29.7 thousand tons	19.7	52.56	5.46	0.76
	Mazut	31.7 thousand tons	43.4	97.51	12.73	0.76
	Gas	3,885.6 mln m^3	4,468.4	7,147.98	654.83	13.10
	Total	–	4,531.5	7,298.05	673.01	14.62
- other enterprises	Coal	2,365.5 thousand tons	1,570.7	4,186.24	434.7	60.86
	Mazut	370.17 thousand tons	507.1	1,138.79	148.65	8.92
	Gas	4,930.84 mln m^3	5,670.5	9,070.73	830.97	16.62
	Total	–	7,748.3	14,395.76	1,414.32	86.40

The following information can be drawn from the data in Table 7:

- nearly all of the GHG emissions in Ukraine's district-heating sector are made by carbon dioxide (99,6% of total emissions equal to 33.05 million t of CO_2-equivalent)[3]. Given that, further discussion focuses only on carbon dioxide emissions;
- 13,8% of GHG emissions are from coal combustion, while the share of heat produced from coal is only 8,9% of total deliveries[4];
- industrial boiler plants are the source of the largest share of GHG emissions (43.7%). This is explained by the fact that industrial boiler plants provide the largest share of delivered heat (40%) and as well as by the significant share of coal (20%) combusted in these plants.

Taking a step down, fuel consumption and GHG emissions were estimated for heat supplied to serve the population living in Ukraine's municipalities using the data from Table 6 and the calculation method described in section 4.1. Table 8 presents the quantities of fuel combusted in boiler plants by type of fuel and ownership for the provision of heat to meet municipal demands.

Table 8. Volumes of fuel combusted in boiler plants by type of fuel and ownership for heat supplied to Ukraine's municipalities, 2001.

Economic sector	Total fuel consumption, thousand t.c.e	Coal, thousand t	Mazut, thousand t	Natural gas, mln m^3
Ukraine in total	15,456.21	1,745.36	319.56	12,051.73
- communal property enterprises	6,643.88	176.95	51.74	5,613.47
- enterprises of Ministry of Fuel and Energy	3,755.61	24.61	26.24	3,220.28
- other enterprises	5,056.72	1,543.80	241.58	3,217.98

Table 9 contains the estimated GHG emissions in the district-heating sector for providing heat to meet municipal needs based on the fuel consumption data in Table 8.

Table 9. Greenhouse gases emissions from fuel combustion for heat supply to the municipal infrastructure of Ukraine, 2001

Object of inventory	Fuel type	Volume of consumed fuel		CO_2 (Gg)	CH_4 (Mg)	N_2O (Mg)
		Physical units	Thousand t.c.e.			
Ukraine in total	Coal	1,745.36 thousand tons	1,158.92	3,088.78	320.74	44.90
	Mazut	319.56 thousand tons	437.80	983.02	128.32	7.70
	Gas	12,051.73 mln m^3	13,859.49	22,170.44	2,031.04	40.62
	Total	–	15,456.21	26,242.24	2,480.10	93.22
- including communal property enterprises	Coal	176.95 thousand tons	117.50	313.15	32.52	4.55
	Mazut	51.74 thousand tons	70.89	159.17	20.78	1.25
	Gas	5,613.47 mln m^3	6,455.49	10,326.58	946.02	18.92
	Total	–	6,643.88	10,798.90	999.32	24.72

[3] Assessment was made using the following conversion factors into CO_2 equivalent: for methane emissions – 21t of CO_2 equivalent per 1 t of methane and for nitrous oxideemissions – 310t of CO_2 equivalent per 1 t nitrous oxide.
[4] The assessment was made using the data on the amount of fuel combustion in c.e.

- enterprises of Ministry of Fuel and Energy	Coal	24.61 thousand tons	16.34	43.56	4.52	0.63
	Mazut	26.24 thousand tons	35.95	80.72	10.54	0.63
	Gas	3,220.28 mln m^3	3,703.32	5,924.04	542.70	10.85
	Total	–	3,755.61	6,048.32	557.76	12.12
- other enterprises	Coal	1,543.80 thousand tons	1,025.08	2,732.06	283.70	39.72
	Mazut	241.58 thousand tons	330.96	743.13	97.00	5.82
	Gas	3,217.98 mln m^3	3,700.68	5,919.82	542.32	10.85
	Total	–	5,056.72	9,395.02	923.02	56.38

Eighty-three percent of total district heat in Ukraine is supplied to Ukraine's municipalities infrastructure, which accounts for 80% GHG emissions from district-heating systems. Given this large share, the conclusions drawn from the data in Table 9 are similar to those from the data in Table 7. The share of heat produced from natural gas amounts to 90% of the total amount of delivered heat and over 84% of GHG emissions.

4.3. Greenhouse gases inventory in the district-heating sector of the 28 largest cities in Ukraine

One of the tasks of the detailed GHG inventory is to determine the priority objects (geographic level) for implementing energy efficiency measures. For this purpose, the GHG inventory in the district-heating sector of Ukraine should be more detailed than in Ukraine as a whole or at the level of separate oblasts. However, data for estimating GHG inventories at the municipal level, with the exception of Oblast centers, is not available as legislation prohibits the provision of such data on confidentiality grounds. The exception is that heat production and consumption can be obtained from the form '1-tep'.

To determine the object for such an inventory, we will examine the data in table 10, obtained from the form 1-tep, on Ukraine's district-heating operation.

Table 10. – Indicators of operating boilers plants in Ukraine, 2001 (based on data from 1-tep)

#	Indicator	Number of enterprises that submitted reports	Number of boiler plants	Number of boilers	Consumption, thousand t.c.e	Specific fuel consumption, kg t.c.e/ Gcal
1	Total Ukraine	8,214	26,203	65,305	19,204.8	167.1
2	- Urban settlements	4,807	17,441	47,715	18,033.2	167.3
3	- Rural area	3,407	8,762	17,590	1,171.6	164.1
4	Oblast centers	885	4,175	12,707	9,355.3	163.0
5	Enterprises of communal property	3,698	14,645	36,583	6,924.5	161.5
6	Enterprises of the Ministry of Fuel and Energy of Ukraine	116	763	2,810	4,531.5	169.7
7	Boiler plants of the other enterprises	4,400	10,795	25,912	7,748.8	169.7[8]

Note: Oblast centers are also included in urban settlements.

The first three lines of Table 10 include the indicators of district-heating for Ukraine, the urban settlements (including the oblast centers and the capital of AR Crimea), and the rural settlements. The fourth line presents the information on the oblast centers. The fifth and the sixth lines include the indicators of the boiler houses for the Communal Enterprises and the Enterprises of the Ministry of Fuel and Energy. Line seven provides the indicators for the boiler plants of other enterprises obtained by subtracting fifth and six lines from the first line.

This information indicates that the most appropriate object for the detailed GHG inventory in the district-heating sector of Ukraine are the enterprises of communal property as 45% of enterprises produce heat and more than 55% of total number of the boiler plants and boilers belong to the enterprises of communal property.

The form 1-tep provides only general information on energy consumption in t.c.e. To estimate GHG emissions, data on amounts of specific fuels consumption: coal, mazut and natural gas is required. Therefore to estimate GHG emissions in the 27 largest Ukrainian cities[9] an additional survey was conducted. The requests were prepared with participation of the specialists from the State Committee on Construction, Architecture and Housing Policy of Ukraine, as well as those from the State Committee of Ukraine of Energy Conservation.

The following equation was used to estimate fuel combustion in the district-heating sector in Ukraine's largest cities, using survey results and data from form 1-tep. Heat produced in the communal boiler plants of the city is consumed primarily in the municipal infrastructure with the remainder used by the industrial sector.

(3) $E_i = E_i^m + E_i^e + E_i^o$,

where: i – city index;

[8] When calculating this indicator the data on the heat production in the boilers plants of the other enterprises, obtained from Annex D-2, was used.

[9] The capital of Autonomous Republic of Crimea, Simferopol, and three cities with population over 250,000 (Gorlivka, Kryviy Rig and Sevastopol) were considered to be among Ukraine's largest cities.

$E_i^m; E_i^e; E_i^o$ – quantity of energy consumption in boiler plants of communal enterprises, enterprises of the Ministry of Fuel and Energy, and other enterprises in the cities, respectively.

It is technically difficult and practically not feasible to perform a survey on energy consumption in all 27 of Ukraine's largest cities. It is sufficient to estimate only the amounts of coal, mazut and natural gas combustion in the boiler plants owned by the largest owner – the municipality. In this situation energy consumption in the boiler plants, owned by the Ministry of Fuel and Energy and other enterprises could be determined based on the energy balance.

Unfortunately 1-tep form does not provide data on distribution of energy consumption between the three categories of owners at a level of oblast centers, only at a level of oblast as a whole. Therefore to estimate energy consumption in the boiler plants owned by the Ministry of Fuel and Energy and other enterprises we made the following assumption:

(4) $E_i^e / E_i^o = E_{vi}^e / E_{vi}^o$,

where v – index of the oblast where the city is located;

E_i^e and E_i^o - volumes of fuel combusted in the boiler plants subordinated to the Ministry of Fuel and Energy and industrial enterprises in the oblast center;

E_{vi}^e and E_{vi}^o - volumes of fuel combusted in the boiler plants subordinated to the Ministry of Fuel and Energy and industrial enterprises in the oblasts of Ukraine.

The assumption (4) is taken because the cities share in oblast energy consumption exceeds 50%. Then the volumes of fuel combusted in the boiler plants subordinated to the Ministry of Fuel and Energy, and industrial enterprises are calculated using the following formulas:

(5) $E_i^e = \left(E_i - E_i^m\right) E_{vi}^e / \left(E_{vi}^e + E_{vi}^o\right)$;

(6) $E_i^o = \left(E_i - E_i^m\right) E_{vi}^o / \left(E_{vi}^e + E_{vi}^o\right)$

We can use the following formulas to convert the volumes of coal, mazut, and natural gas from physical units into t.c.e.:

(7) $E_{is}^e = E_i^e k_s^e / k_s$;

(8) $E_{is}^o = E_i^o k_s^o / k_s$,

where: s – fuel index;

k_s^e and k_s^o – share of the volumes of s-fuel combustion in the total volume of fuel combustion in the boiler plants of the enterprises subordinated to the Ministry of Fuel and Energy, and industrial enterprises;

k_s –factors for converting the physical units of fuel into t.c.e.

The factors for converting physical units of fuels combusted in the boiler plants of the enterprises subordinated to the Ministry of Fuel and Energy, and industrial enterprises into t.c.e. are 0.664 for coal; 1.37 for mazut and 1.15 for natural gas.

The share of the volumes of fuel s combusted in the total volume of fuel combustion in the boiler plants of the enterprises subordinated to the Ministry of Fuel and Energy, and industrial enterprises were determined based on 4-mtp form of statistical reports.

Table 11 provides a summary of data on fuel combustion in the district-heating sector of the largest cities of Ukraine

Table 11. Indicators of the operating boiler plants in Ukraine, 2001 (based on survey data)

#	Object of inventory	Coal, thousand t	Mazut, thousand t	Natural gas, mln m^3	Total energy consumption, thousand t.c.e.
1	Communal boiler plants in 27 largest cities	11.63	7.64	3,857.08	4,453.4
2	District-heating boiler plants in 27 largest cities	30.83	28.10	6,368.85	7,324.17
3	Total for Kyiv boiler plants	0.00	237.71	1,982.3	2,605.3
4	Total for district-heating sector in 28 largest cities	30.83	265.81	8,351.15	9,929.47

Notes: District heating boiler plants (line 2) contains communal boiler plants (line 1) as well as the boiler plants of the Ministry of Fuels and Energy and of other enterprises.
The survey was not administered in Kyiv because all heat supply enterprises of Kyiv are managed by the energy supply company «Kyivenergo», which is subordinated to the Ministry of Fuel and Energy
Data on fuel combustion in Kyiv boiler plants were taken from [4].

The first line of Table 11 contains the survey results, and the second was calculated from the design data and formulas (3)-(8) that used data from the 1-tep form. The last line of the Table 11, which presents general data on fuel combustion, is the sum of the second and third lines.

Table 12 presents the estimated GHG emissions for communal boiler plants in Ukraine's 28 largest cities based on the survey results related to the quantity of combusted fuel. Table 13 contains the estimated GHG emissions from the district-heating sector in these cities, based on the results of the survey and formulas (3)-(8) for the quantities of combusted fuel.

Based on the analysis of Tables 12-13 the following conclusions are made:

- CO_2 emissions from the district-heating of Ukraine's 28 largest Ukrainian cities make over 16 million t of CO_2 equivalent, which is approximately 99% of the total district-heating sector GHG emissions in these cities;
- CO_2 emissions from fuel combustion in the communal boiler plants of the largest Ukrainian cities (11,517.47 Gg – Table 12) are 71% of total emissions from the district-heating sector in these cities (16,186.75 Gg – Table 13)
- fuel combustion in the district-heating sector of Kyiv accounts for 4,377.88 Gg of CO_2 emissions, Kharkiv - 1371.58 Gg, Dniprpetrovsk - 1076.19 Gg, Zaporizhzhya - 1166.08 Gg, and Donetsk - 939.92 Gg – the total equals approximately 9 million t or over 55% of total emissions from the district-heating sector in Ukraine's 28 largest cities;
- the estimated GHG emissions for the district-heating sector in Ukraine's 28 largest cities correlate very well with the following factors that can be assumed to influence fuel consumption and GHG emissions:

- city population;
- climatic conditions – the farther to north a city is located, the larger its heat requirements.

Table12.GHG emission from fuel combustion in municipal boiler plants of the 28 largest cities of Ukraine, 2001

Ukraine's cities (in Ukrainian alphabetic order)	CO_2 emission (Gg) during combustion				CH_4 emission (Mg) during combustion				CH_4 emission (Mg, CO_2^e)	N_2O emission (Mg) during combustion				N_2O emission (Mg, CO_2^e)
	coal	Mazut	natural gas	total	coal	mazut	natural gas	total		coal	mazut	natural gas	total	
Vinnutsya	0.00	0.00	144.55	144.55	0.00	0.00	13.242	13.24	278.04	0.00	0.00	0.265	0.26	80.6
Gorlivka*	0.00	0.00	374.54	374.54	0.00	0.00	34.312	34.31	720.51	0.00	0.00	0.686	0.69	213.9
Dnipropetrovsk	0.00	0.00	584.58	584.58	0.00	0.00	53.554	53.55	1,124.55	0.00	0.00	1.071	1.07	331.7
Donetsk	10.25	0.00	71.97	82.22	1.064	0.00	6.593	7.66	160.86	0.149	0.00	0.132	0.28	86.8
Zhytomyr	0.00	0.00	147.11	147.11	0.00	0.00	13.477	13.48	283.08	0.00	0.00	0.269	0.27	83.7
Zaporizhzhya	0.60	3.63	652.09	656.32	0.062	0.474	59.738	60.27	1,265.67	0.009	0.028	1.195	1.23	381.3
Ivano-Frankivsk	0.00	0.00	197.90	197.90	0.00	0.00	18.130	18.13	380.73	0.00	0.00	0.363	0.36	111.6
Kyiv	0.00	731.23	3,646.65	4,377.88	0.00	95.448	334.071	429.52	9,019.92	0.00	5.727	6.681	12.41	3,847.1
Kirovograd	0.00	0.00	95.05	95.05	0.00	0.00	8.707	8.71	182.91	0.00	0.00	0.174	0.17	52.7
Kryvyi Rig*	0.00	0.00	422.10	422.10	0.00	0.00	38.669	38.67	812.07	0.00	0.00	0.773	0.77	238.7
Lugansk	1.58	0.00	312.07	313.65	0.164	0.00	28.589	28.75	603.75	0.023	0.00	0.572	0.59	182.9
Lutsk	0.00	0.00	203.44	203.44	0.00	0.00	18.637	18.64	391.44	0.00	0.00	0.373	0.37	114.7
Lviv	0.00	0.00	321.41	321.41	0.00	0.00	29.444	29.44	618.24	0.00	0.00	0.589	0.59	182.9
Mykolayiv	1.72	0.00	204.81	206.53	0.178	0.00	18.763	18.94	397.74	0.025	0.00	0.375	0.40	124
Odessa	0.00	0.00	504.11	504.11	0.00	0.00	46.182	46.18	969.78	0.00	0.00	0.924	0.92	285.2
Poltava	0.00	0.00	223.60	223.60	0.00	0.00	20.484	20.48	430.08	0.00	0.00	0.410	0.41	127.1
Rivne	0.00	0.00	192.74	192.74	0.00	0.00	17.657	17.66	370.86	0.00	0.00	0.353	0.35	108.5
Sevastopol*	5.03	0.00	164.65	169.68	0.522	0.00	15.084	15.61	327.81	0.073	0.00	0.302	0.37	114.7
Simferopol	0.00	6.83	208.78	215.61	0.00	0.891	19.127	20.02	420.42	0.00	0.053	0.383	0.44	136.4
Sumy	0.44	12.00	33.41	45.85	0.046	1.566	3.061	4.67	98.07	0.006	0.094	0.061	0.16	49.6
Ternopil	0.00	0.00	186.70	186.70	0.00	0.00	17.103	17.10	359.1	0.00	0.00	0.342	0.34	105.4
Uzhgorod	0.00	0.00	89.40	89.40	0.00	0.00	8.190	8.19	171.99	0.00	0.00	0.164	0.16	49.6
Kharkiv	0.94	0.00	1,164.57	1,165.51	0.097	0.00	106.686	106.78	2,242.38	0.014	0.00	2.134	2.15	666.5
Kherson	0.04	0.00	50.56	50.59	0.004	0.00	4.632	4.64	97.44	0.001	0.00	0.093	0.09	27.9
Khmelnytskyi	0.00	0.00	190.68	190.68	0.00	0.00	17.468	17.47	366.87	0.00	0.00	0.349	0.35	108.5
Cherkassy	0.00	1.05	126.67	127.71	0.00	0.137	11.604	11.74	246.54	0.00	0.008	0.232	0.24	74.4
Chernivtsi	0.00	0.00	120.79	120.79	0.00	0.00	11.066	11.07	232.47	0.00	0.00	0.221	0.22	68.2
Chernigiv	0.00	0.00	107.22	107.22	0.00	0.00	9.822	9.82	206.22	0.00	0.00	0.196	0.20	62
TOTAL	20.58	754.73	10,742.16	11,517.47	2.137	98.516	984.091	1,084.74	22,779.54	0.299	5.911	19.682	25.89	8,025.9

* Oblast centers are not included

Tables 13.GHG emissions from fuel combustion in the district-heating sector for the 28 largest Ukrainian cities, 2001

Ukraine's cities (in Ukrainian alphabetic order)	CO_2 emission (Gg) during combustion				CH_4 emission (Mg) during combustion				CH_4 emission (Mg, CO_2^e)	N_2O emission (Mg) during combustion				N_2O emission (Mg, CO_2^e)
	coal	mazut	natural gas	total	coal	mazut	natural gas	total		coal	mazut	natural gas	total	
Vinnutsya	1.41	2.62	336.73	340.77	0.147	0.342	30.85	31.34	658.14	0.021	0.021	0.617	0.66	204.6
Gorlivka*	0.00	0.00	374.54	374.54	0.00	0.00	34.31	34.31	720.51	0.00	0.00	0.686	0.69	213.9
Dnipropetrovsk	3.54	6.56	1,066.09	1,076.19	0.368	0.856	97.66	98.89	2,076.69	0.051	0.051	1.953	2.06	638.6
Donetsk	16.42	11.44	912.05	939.92	1.705	1.494	83.55	86.75	1,821.75	0.239	0.099	1.671	2.00	620.0
Zhytomyr	0.37	0.69	197.80	198.87	0.039	0.090	18.12	18.25	383.25	0.005	0.005	0.362	0.37	114.7
Zaporizhzhya	4.27	10.43	1,151.38	1,166.08	0.444	1.362	105.48	107.28	2,252.88	0.062	0.082	2.110	2.25	697.5
Ivano-Frankivsk	0.10	0.18	211.29	211.57	0.010	0.024	19.36	19.39	407.19	0.001	0.001	0.387	0.39	120.9
Kyiv	0.00	731.23	3,646.65	4,377.88	0.00	95.448	334.07	429.52	9,019.92	0.00	5.727	6.681	12.41	3,847.1
Kirovograd	0.23	0.43	126.88	127.55	0.024	0.057	11.62	11.70	245.7	0.003	0.003	0.232	0.24	74.4
Kryvyi Rig*	0.00	0.00	422.10	422.10	0.00	0.00	38.67	38.67	812.07	0.00	0.00	0.773	0.77	238.7
Lugansk	1.81	0.44	344.65	346.91	0.188	0.058	31.57	31.820	668.22	0.026	0.003	0.631	0.66	204.6
Lutsk	0.26	0.48	238.34	239.07	0.027	0.062	21.83	21.92	460.32	0.004	0.004	0.437	0.44	136.4
Lviv	2.38	4.40	644.74	651.52	0.247	0.575	59.06	59.89	1,257.69	0.035	0.035	1.181	1.25	387.5
Mykolayiv	2.33	1.14	288.35	291.81	0.242	0.149	26.41	26.81	563.01	0.034	0.009	0.528	0.57	176.7
Odessa	0.48	0.89	569.36	570.73	0.050	0.116	52.16	52.32	1,098.72	0.007	0.007	1.043	1.06	328.6
Poltava	0.36	0.66	272.06	273.07	0.037	0.086	24.92	25.05	526.05	0.005	0.005	0.498	0.51	158.1
Rivne	1.33	2.47	373.84	377.64	0.138	0.322	34.25	34.71	728.91	0.019	0.019	0.685	0.72	223.2
Sevastopol*	5.03	0.00	164.65	169.68	0.522	0.00	15.08	15.61	327.81	0.073	0.00	0.302	0.37	114.7
Simferopol	1.41	9.44	400.65	411.51	0.146	1.233	36.70	38.08	799.68	0.021	0.074	0.734	0.83	257.3
Sumy	3.09	16.90	393.23	413.22	0.321	2.206	36.02	38.55	809.55	0.045	0.132	0.720	0.90	279.0
Ternopil	0.75	1.39	288.89	291.04	0.078	0.182	26.47	26.73	561.33	0.011	0.011	0.529	0.55	170.5
Uzhgorod	0.08	0.14	99.67	99.89	0.008	0.018	9.13	9.16	192.36	0.001	0.001	0.183	0.18	55.8
Kharkiv	2.42	2.75	1,366.41	1,371.58	0.252	0.359	125.18	125.79	2,641.59	0.035	0.021	2.503	2.56	793.6
Kherson	1.39	2.51	234.45	238.35	0.144	0.327	21.48	21.95	460.95	0.020	0.020	0.430	0.47	145.7
Khmelnytskyi	0.26	0.48	226.17	226.91	0.027	0.063	20.72	20.81	437.01	0.004	0.004	0.414	0.42	130.2
Cherkassy	2.72	6.08	496.49	505.29	0.282	0.794	45.48	46.56	977.76	0.039	0.048	0.910	1.00	310.0
Chernivtsi	0.28	0.51	158.32	159.10	0.029	0.067	14.50	14.60	306.6	0.004	0.004	0.290	0.30	93.0
Chernigiv	1.84	3.40	357.04	362.28	0.191	0.444	32.71	33.34	700.14	0.027	0.027	0.654	0.71	220.1
TOTAL	54.21	817.04	15,315.50	16,186.75	5.630	106.734	1407.390	1519.8	31,915.8	0.792	6.413	28.058	35.26	10,930.6

* Oblast centers are not included

Conclusions and results

1. Consumption of heat in Ukraine's district-heating sector is accounted for by the residential sector at 55% of heat produced, the public sector at about 24%, the industrial sector at about 20%.
2. The source of GHG emissions in the district-heating sector is fuel combustion in the boilers of the enterprises of communal property, Ministry of Fuel and Energy and other enterprises.
3. The main fuel types consumed in the Ukrainian district-heating sector are natural gas (90%), coal (7%) and mazut. (2%).
4. GHG emissions from the three main fuel types exceed 99% of total GHG emissions. Therefore, this report contains results of the inventory of GHG emissions from combustion of natural gas, black coal and mazut.
5. The primary data for estimating GHG emissions in the district-heating sector for Ukraine and the oblasts can be prepared from data submitted onforms 1-tep and 4-mtp.
6. GHG inventories of smaller objects (geographical areas) depend on their size and the resources available for the collection and preparation of primary data. It is possible to use information from government institutions, interested ministries and departments, or to use more detailed information obtained from an instrumental examination (audit) and/or a survey.
7. The report provides a suggested tabular format for the survey of heat producers in order to obtain the primary data required for preparing a detailed GHG inventory at the level of the boiler plants, enterprises and administrative regions.
8. Table 14 presents inventory results in Ukraine's district-heating sector and the 28 largest cities.

Table 14. District-heating sector GHG emissions for Ukraine and the 28 largest cities, 2001

Geographic level	Carbon Dioxide, thousand t	Methane (CH4), t	Nitrous Oxides, t
Total Ukraine	32, 948.75	3,128.85	126.78
Ukraine's 28 largest cities	16,186.75	1,519.8	35.26

This shows that CO_2 emissions from fuel combustion in the communal boiler plants of the 28 largest Ukrainian cities account for about 50% of total emissions from the district-heating sector of Ukraine.

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Annex 1. Tables for survey questionnaire on the preparation of primary data for greenhouse gases inventory at the boiler plants of enterprises

Table A.1.1. Technical performance of the boilers operation

Name (address) of the boiler plant	Boiler type	Fuel	Nominal capacity, Gcal/year; t/year	Annual fuel consumption, thousand nm^3; thousand t	Annual production of: heat, Gcal/year; steam, t/year	Operation hours during one year

Table A.1.2. Quality indicators of solid and liquid fuel, which is consumed by the boiler plant

Fuel type	Rank of coal or mazut	Annual consumption of fuel of this rank, thousand t

Table A.1.3. Heat delivered by the boiler plant

Annual delivery of heat Gcal/year; steam, t/year	including		
	population	communal and household needs	production needs

Annex 2. Design factors for heat supply system