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GHG EMISSIONS INVENTORY FOR LVIVTEPLOENERGO (LTE)

Pacific Northwest National Laboratory

September 2022

PNNL-33536

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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GHG Emissions Inventory for LvivTeploEnergo (LTE)

September 2022

Rachel Hoesly
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Nazar Kholod
Meredydd Evans

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ACRONYMS AND ABBREVIATIONS

CEDS	Community Emissions Data System
CHP	Combined Heat and Power Plant
CH4	Methane
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CNG	Compressed natural gas
DH	District Heating
EBRD	European Bank for Reconstruction and Development
ECLIPSE	Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants
EF	Emission factor
EMEP	European Modeling and Evaluation Programme
Eq	Equivalent
EU	European Union
F	Fluorine
Gcal	Gigacalorie
GHG	Greenhouse gases
GWP	Global warming potential
HFC	hydrofluorocarbon
IFI	International Financial Institution
IIASA	International Institute for Applied Systems Analysis
km	kilometer
LNG	Liquid natural gas
LTE	LvivTeploEnergo
m^3	Cubic meter
N_2O	Nitrous Oxide
NO_X	Nitrogen Oxides
NF_3	nitrogen trifluoride
PFCs	perfluorocarbons
SF_6	Sulphur hexafluoride
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

1. INTRODUCTION

LvivTeploEnergo (LTE) is the leading heat supplier in the city of Lviv, accounting for 75% of the city's district heat (DH) supply (Lviv City 2020). LTE is 100% dependent on natural gas for DH and operates one combined heat and power (CHP) plant, two large heat stations, 154 boiler stations, and 136 central heat stations (LTE 2022). The total installed capacity for LTEs heat supply is 1,562 Gcal/hour (LTE 2022). On average, LTE uses about 300 million m^3 per year for DH (LTE 2021). In the coldest winter months, gas consumption by LTE can reach 30,000 m^3 a month (LTE 2021).

LTE asked USAID and PNNL to prepare a greenhouse gas (GHG) emissions inventory. GHG emissions inventories are essential to garner international funding from financial institutions such as the European Bank for Reconstruction and Development (EBRD). Such funding and lending opportunities are essential to fund the modernization requirements necessary to decarbonize LTE's DH network. LTE has lent from EBRD in the past (EBRD 2017), thus an LTE inventory must follow the standards and protocols set forth by EBRD and similar organizations to guarantee funding opportunities from these sources in the future.

The inventory itself provides an account of total greenhouse gas emissions from (a) heat production, (b) operation of vehicles and equipment, and (c) indirect emissions from purchased electricity. The greenhouse gases analyzed in the inventory include relevant Kyoto Protocol gasses (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)) and select air pollutants (carbon monoxide (CO) and nitrogen oxides (NO_X)). All fuel use and electricity use data gathered for the inventory came directly from LTE.

Emissions of each activity were calculated by using emission factors from several internationally reputable sources, for example, the United National Framework Convention on Climate Change (UNFCCC), the ECLIPSE v6 dataset from the International Institute for Applied Systems Analysis (IIASA), the European Modeling and Evaluation Programme (EMEP), and the World Resources Institute (WRI). This report further explains the methodology and justification for the inclusion and exclusion of varying emissions sources (scopes) and methodology and references for estimating emission factors.

2. INVENTORY COMPONENTS

This inventory includes both relevant Kyoto Protocol gasses and select air pollutants. Kyoto protocol gasses include CO_2, CH_4, and N_2O, as well as the fluorine (F) gasses which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). These gasses are outlined in the Kyoto Protocol and are required by UNFCCC reporting guidelines as well as other reporting standards such the Greenhouse Gas Protocol Corporate Standard (Greenhouse Gas Protocol 2015). F gasses are usually produced by cooling and refrigerants as well as in some high-tech industries and are not relevant to LTE's activities. F gasses are not produced from natural gas combustion or combustion of fuel for vehicles and the IPCC and other relevant methodologies, do not provide guidance for F gasses from those activities (IPCC 2006). Thus, this inventory does not include F gasses. Of the Kyoto Protocol gasses, this inventory only includes CO_2, CH_4, and N_2O, as they are most relevant to LTE's activities.

This inventory also includes select air pollutants, NO_X and CO, which are not required for GHG inventory reporting. However, LTE currently calculates these emissions for their annual environmental report, so they are also calculated here. NO_X and CO emissions are often relevant to or required for local air quality permitting, thus adding importance to why they should be included in this inventory.

2.1 SCOPE 1

Scope 1 emissions include direct emissions or emissions associated with the direct activities of LTE, including emissions from burning fuel, process emissions, or fugitive emissions. Scope 1 emissions accounted for in this inventory include only emissions associated with the direct combustion of fuel for heating and vehicle operation. LTE combusts natural gas for heat production and various fuels for vehicles and equipment. LTE does not burn secondary fuels for heat production, such as backup fuels or heating oil.

While there are likely non-zero methane emissions from fugitive gas leaks, LTE does not monitor this and has no estimate of natural gas leaks within their system. In any system, fugitive gas leaks have the potential to be high, and contribute to a substantial portion of methane emissions in the inventory. However, without site measurements, which LTE does not conduct, there is not enough data or guidance to estimate these emissions, as they vary drastically (from minimal to substantial) across different systems.

2.2 SCOPE 2

Scope 2 emissions consist of indirect emissions from the purchase of electricity and heat, in other words, the emissions associated with electricity and heat purchased by LTE but not directly emitted by LTE. LTE purchases electricity for water pumping, heat production, and other uses. LTE does not buy heat from other producers, therefore purchased electricity is the only aspect included in scope 2 emissions.

2.3 SCOPE 3

Scope 3 emissions include indirect emissions up and down the supply chain of LTE's actions. Scope 3 emissions have an extensive range of indirect emissions from employee commuting to emissions from subsidiaries and leased properties. The most relevant Scope 3 emissions to LTE's activities are upstream emissions from energy, for example, emissions from the production and distribution of natural gas. However, as stated previously, the primary purpose of this inventory is for submission to international funding agencies like EBRD for grant or loan support. As EBRD does not require Scope 3 emissions for their inventory process, Scope 3 emissions are not included in this inventory.

3. METHODOLOGY

For all categories, emissions are calculated from fuel use (or electricity consumption) and corresponding emission factors (EFs) according to Equation 1:

$$Emissions = Fuel\ x\ Emission\ Factor$$

Equation 1

where emission factors are in units of mass of emission species per unit of fuel. All calculations can be found in the accompanying spreadsheet.

CH_4 and N_2O are also reported in 100-year global warming potential (GWP) relative to CO_2, in CO_2 equivalents (CO_2 eq) (Greenhouse Gas Protocol 2014). 100-year GWP values are shown in Table 1.

Table 1 100-year GWP time horizon values for GHGs.

Emission Species	CO_2 eq
CO_2	1
CH_4	28
N_2O	265

3.1 SCOPE 1

Direct Combustion: Heat Production

Emission Factors: Kyoto Protocol Gasses

CO_2, CH_4, and N_2O emission factors for stationary combustion for heat production (sector 1A in the common reporting format) are taken from Ukraine's submission to the UNFCCC, which provide implied emissions factors (UNFCCC 2022). Implied emission factors, in units of carbon per TJ of energy, are multiplied by the heating value of natural gas in Lviv, 34.48 MJ/m^3, (with additional metric unit conversions) to obtain an emission factor in units of emission per volume, used in the inventory. The implied emission factors used in Ukraine's inventory submission are the Tier 1 default emission factors suggested in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). These unit conversions are found in the "Scope 1 EF - Heat" sheet in the companion calculations spreadsheet. Table 2 shows the emission factors used for natural gas combustion for heat production for Kyoto Protocol gasses (CO_2, CH_4, and N_2O) estimated from UNFCCC (the IPCC tier 1 default EF).

Table 2 Emission factor comparison for natural gas combustion for heat production (Kyoto Protocol Gasses).

Emission Species	***Emission Factor*** *[kilogram per meter cubed]*
CO_2	*1.93*
CH_4	***3.45 x 10^{-5}***
N_2O	***3.45 x 10^{-6}***

Emission Factors: Air Pollutants

NO_X and CO emission factors are calculated from the ECLIPSE V6 (Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants) emissions, developed by the International Institute for Applied Systems Analysis (IIASA) (Klimont et al. 2017). These estimates are produced with extensive input from country experts, considering common technologies and air pollution controls, to ensure accurate country-level detail.

Emissions and associated energy use used in the ECLIPSE model are available via the Community Emissions Data System (CEDS), an open-source global emissions inventory system (Hoesly et al. 2018). As CEDS and ECLIPSE are updated in future years, updated emission factors may be recalculated using the methods below. Details on locating and downloading these specific files are in the appendix.

Emission factors are derived from the ECLIPSE data using total emissions and total energy use according to Equation 2. Emission factors used are from 2015, the most recent historical (i.e., not modeled, and projected) year in the ECLIPSEv6 data.

$$\boldsymbol{Emissions\ Factor_{Em,Ukr,Sector} = \frac{Emissions_{Em,Ukr,Sector}}{Energy_{Ukr,Sector}}}$$

Equation 2

Where:

- Em = the emission species, NO_X, or CO.
- Ukr = the Ukraine region in ECLIPSEv6 data, “UKRA_PLUS”, as defined in the ECLIPSE v6 data, which includes Ukraine, Moldova, and Belarus.
- Sector = the natural gas energy production sectors, “Power_Gen_NatGas”, as defined in the ECLIPSE v6 data.

These calculations yield emission factors in units of emissions per unit of energy. Emission factors are multiplied by the heating value of gas in Lviv, 34.48 megajoules per cubic meter (with additional metric unit conversions), to obtain emission factors in units of emission per unit volume used in the inventory. These calculations are found in the "Scope 1 EF - Heat" sheet in the companion calculations spreadsheet.

Table 3 compares NO_X and CO emission factors estimated from ECLIPSEv6 and tier 1 default emission factors provided by European Modeling and Evaluation Programme (EMEP) (EEA 2019).While slightly different, estimated ECLIPSEv6 and EMEP emission factors are within the expected magnitude range. ECLIPSEv6 emission factors are used, because they are developed by researchers with input from in country experts with knowledge and experience with technologies in each country. We judge these emission factors to be more accurate than general Tier 1 emission factor guidance.

Table 3 Emission factor comparison for natural gas combustion for heat production (NO_X and CO).

Emission Species	***EMEP****	***ECLIPSEv6**** (2015)**
NO_X	*89 kilograms per terajoule*	*88.6 kilogram per terajoule*
CO	*39 kilograms per terajoule*	*42.9 kilogram per terajoule*
* General guidance emissions factor, not country-specific **Ukraine-specific emission factor		

Direct Combustion: Vehicles

Emission factors:

Vehicle emission factors are derived primarily from IPCC emission factor guidelines (IPCC 2006) for Kyoto Protocol gasses and EMEP guidance (EEA 2019) for other air pollutants. When available, tier 1 emission factors are used, as directed by IPCC guidelines, as detailed vehicle data is not available, and vehicles are not a key category for LTE. When tier 1 emission factors are not available, tier 2 emission factors are used, which are differentiated by vehicle type (light duty, heavy duty, etc.). The breakout of emission factor by vehicle type varies by emission species. CO_2 emission factors are derived from fuel, not vehicle type. For CH_4, N_2O, NO_X, and CO separate emission factors are also used for off road vs on road diesel vehicles and light- and heavy-duty vehicles. For LNG and CNG vehicles, emission factors are given in emission per vehicle kilometer. Fuel economy estimates from industry reports are used to estimate vehicle fuel economy to estimate emissions per unit of fuel use (ICCT 2020) (U.S. DOE 2016). All emission factors and associated assumptions are shown in the accompanying spreadsheet.

3.2 SCOPE 2

Indirect Emissions from Electricity Purchases

Emissions associated with the purchase of electricity are calculated using an estimated emissions factor derived from Ukraine's submission to the UNFCCC (UNFCCC 2022). Average emissions factors for electricity production in Ukraine for each year are calculated according to Equation 3 and shown in the accompanying spreadsheet:

$$Emission\ Factor_{Electricity} = \frac{Total\ Electricity\ Emissions_{All\ fuels}}{Total\ Electricity\ Produced_{All\ fuels}}$$

Equation 3

Only Kyoto Protocol CO_2 emissions are calculated for electricity emissions, as UNFCCC does not collect NO_X nor CO emissions estimates. Additionally, as NO_X and CO are more relevent to local air quality purposes, and indirect electricity emissions do not occur locally, they are less relevant for the purposes of this inventory. Electricity emission factors are shown in Table 4.

Table 4 Electricity Emissions Factors for Kyoto Protocol Gasses (CO_2, CH_4, and N_2O)

	CO_2 Emission Factor (kilograms CO_2/kilo-watt hour)	CH_4 Emissions Factor (kilograms CH_4/kilo-watthour)	N_2O Emission Factor (kilograms N_20/kilo-watt hour)
2018	0.33	4.03E-06	5.40E-06
2019	0.33	4.08E-06	5.35E-06
2020	0.32	4.70E-06	5.23E-06
*2021	0.32	4.70E-06	5.23E-06

4. RESULTS

4.1 SCOPE 1

Annual emissions for all species from heat production are shown in Table 5 and Kyoto Protocol gasses are shown in Figure 1 in CO_2 equivalents. Gas consumption data, and all energy consumption data used in this inventory, was provided by LTE. More results for normalized gas consumption are shown in the Appendix. GHGs are dominated by CO_2 emissions, with small contributions from CH_4 and even smaller contributions from N_2O.

Gas consumption and associated emissions stays relatively flat from 2019 to 2020 but increased in 2021. The increase in natural gas use in 2021 is largely due to cold weather and the increased need for heat, shown in results for normalized gas emissions, in the Appendix. Note that 2022 data only includes data form January to April.

Table 5 Natural gas combustion for heat production emissions

Year	Total Gas Consumption (meters cubed)	Kyoto Protocol Gasses			Air Pollutants	
		CO_2 Emissions (tonnes)	CH_4 Emissions (kilograms)	N_2O Emissions (kilograms)	CO Emissions (kilograms)	NO_X Emissions (kilograms)
2019	170,173,247	328,596	5,868	587	251,727	520,078
2020	170,286,884	328,815	5,871	587	251,896	520,425
2021	186,017,815	359,191	6,414	641	275,165	568,501
2022	86,455,406	166,941	2,981	298	127,889	264,222
*2022 only includes first third of year						

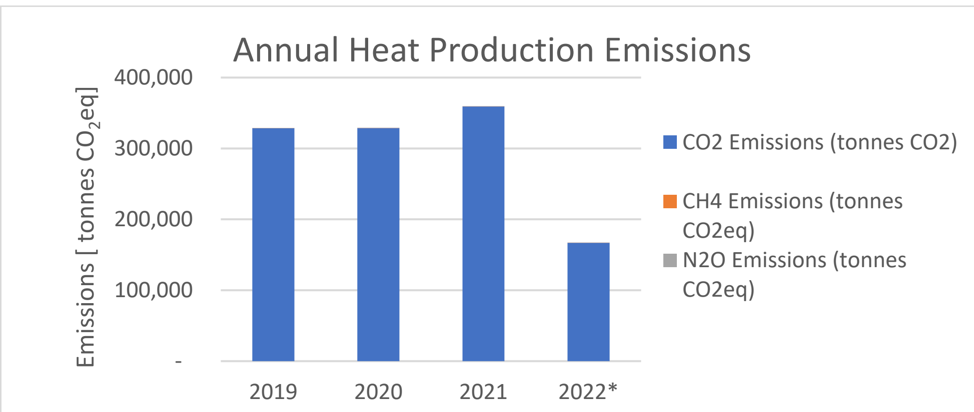

Figure 1 CO_2, CH_4 and N_2O Emissions from heat production, shown annually in CO_2 equivalents. 2022 only includes data from January through April.

CO_2 emissions from vehicle fuel combustion by fuel type are shown in Figure 2. Diesel vehicles contribute to about 40% of CO_2 emissions, while gasoline, CNG and LNG each contribute roughly 20%.

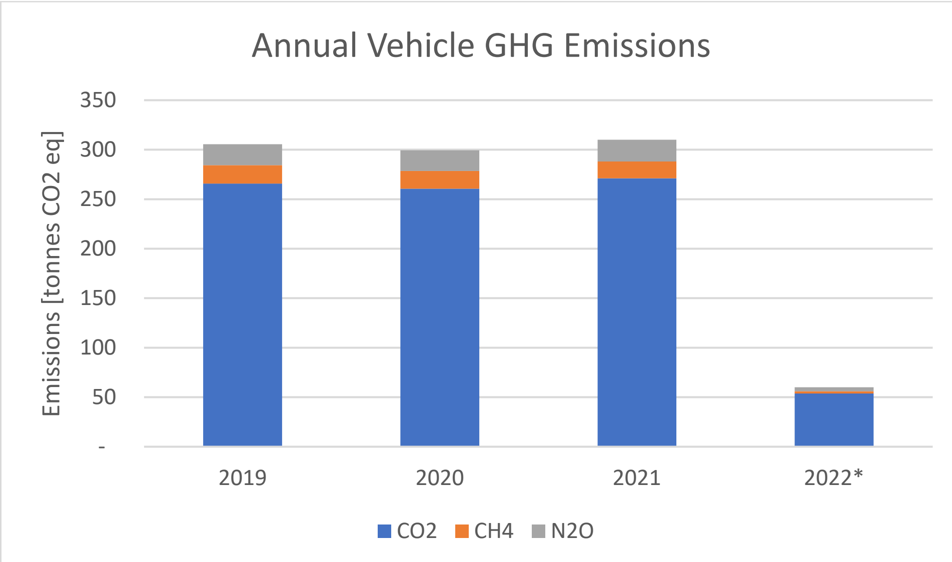

Figure 2 Annual vehicle CO_2 emissions. 2022 only includes data from January through April.

CO_2, CH_4, and N_2O vehicle emissions are shown in Figure 3 in units of CO_2 equivalents. Vehicle GHGs emissions are dominated by CO_2 emissions, with CH_4 and N_2O contributing to just over 10% of total GHG emissions.

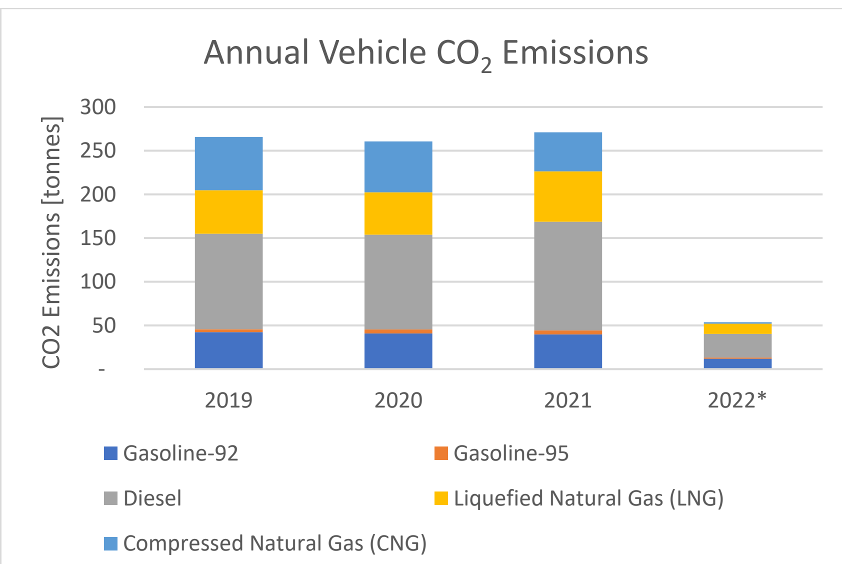

Figure 3 Annual Vehicle GHG Emissions

Air pollutant emissions from vehicles are shown in Table 6. However, LTE's total NO_X and CO emissions are dominated by heat pollutant emissions. NO_X and CO emissions from vehicles contribute to less than one percent of LTE's air pollutant emissions.

CH_4, N_2O, NO_X, and CO emissions are much more uncertain than CO_2 emissions in vehicles, especially when using tier 1 emission factors, as have been used here. However, these emissions make up a very small part of LTE's inventory.

Table 6 Air Pollutant emissions from vehicle fuel combustion

	NO_X				CO			
	2019	**2020**	**2021**	**2022***	**2019**	**2020**	**2021**	**2022***
Gasoline	189	183	179	63	189	188	184	55
Diesel (heavy)	422	55	56	17	96	95	109	24
Diesel (light)	50	49	57	12	25	25	28	6
Diesel (off road)	786	779	892	194	260	257	295	64
CNG	241	230	177	7	106	101	77	3
LNG	83	81	96	20	140	137	162	33
Total	1,771	1,377	1,457	312	815	803	856	185

4.2 SCOPE 2

Scope 2 emissions, or the emissions associated with electricity purchases are shown in Table 7. GHG emissions, dominated by CO_2 emissions, stay relatively stable from 2018 to 2021, within 10% of the max in 2021.

Table 7 Annual GHG Emissions from Electricity Purchases

	CO_2 Emissions (tonnes)	**CH_4 Emissions (tonnes CO_2 eq)**	**N_2O Emissions (tonnes CO_2 eq)**
2018	9,606	3	41
2019	9,747	3	42
2020	9,177	4	39
2021	9,980	4	43

4. CONCLUSION

LTE is the main producer and supplier of heat with a 100% dependence on the use of natural gas as its fuel source. This GHG emissions inventory keeps track of Kyoto Protocol Gases CO_2, CH_4, and N_2O, and select air pollutants NO_x, and CO emissions. Activities include natural gas combustion for LTEs heat production, emissions from LTEs purchased electricity, and emissions from LTEs vehicle fuel consumption (e.g., road vehicles).

For LTE to maintain the inventory for heat production, each year LTE will need to enter their monthly natural gas consumption (in cubic meters). Next, the emissions for all gases will automatically be calculated using the EFs for various gases from heat production already provided in the current inventory. Similarly, for LTE to maintain the inventory for purchased electricity, LTE will need to gather annual electricity consumption data, which will then automatically be multiplied by the electricity EF for CO_2 emissions from electricity provided in the current inventory to give the resulting annual CO_2 emissions from purchased electricity. Finally, for LTE to maintain the inventory for vehicles, LTE will need to gather data for vehicle fuel use by fuel type, as well as a proportion of fuel use for on-road/off-road and light-duty/heavy-duty vehicles. As with all of LTEs other activities, annual emissions from vehicle use will automatically be calculated using the EF for vehicle use CO_2 emissions provided in the inventory.

If LTE is interested in expanding the inventory to other gases, appropriate emission factors must be added to the spreadsheet. However, the way the inventory spreadsheet is setup, any LTE staff members will easily be able to use consumption data from the activity and multiply by the newly gathered EF for the specific added gas to obtain emissions results. Similarly, if LTE wishes to add any activities from its work, the structure of multiplying activity consumption by the newly gathered emission factor for a specific gas for that activity to calculate the resulting emissions remains the same and can easily be replicated.

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APPENDIX A

Downloading ECLIPSE files from CEDS for calculating CO_2, NOx, and CO heat production emission factors.

CEDS is an open-source data system for creating global emissions inventory, using existing emission inventories, activity/energy data, and emission factors. CO_2, NO_X and CO emission factors for Ukraine natural gas heat and electricity production can be derived from the ECLIPSE model files, available through CEDS. The CEDS github community site is available here: https://github.com/JGCRI/CEDS. Individual files can be downloaded by clicking through the file structure until the appropriate file is found.

As described in the methodology, $NO_{X,}$ and CO emission factors natural gas consumption for heat production are derived from ECLIPSE energy data, NO_X emissions, and CO emissions.

File location:

NO_X emissions: CEDS/input/emissions-inventories/GAINS/Global by region-detail_emf30_NOx_wSE.csv

CO emissions: CEDS/input/emissions-inventories/GAINS/Global by region-detail_emf30_CO_wSE.csv

Energy data: CEDS/input/emissions-inventories/GAINS/Global by region-detail_emf30_activity_wSE.csv

APPENDIX B

Normalizing Gas Use using Heating Degree Days

To understand gas use trends beyond regular seasonal variation, temperature can be used to smooth the variation in annual weather (temperature) fluctuations. For example, if LTE uses more natural gas one heating season compared to the next, it may be due to a harsher winter in the first heating season compared to the second rather than a fundamental difference in their heating system. Normalized gas consumption is calculated using heat degree days (HDD), the difference between the mean ambient air temperature and room temperature, to measure the heating required each day based on daily temperatures (Energy Data GmbH 2022). While normalized gas consumption and emissions can be useful to look at trends, actual emissions (rather than normalized emissions) must be reported for inventories.

Methodology

Natural gas use for heat production is normalized over the years to smooth the variation in annual weather fluctuations. For example, if LTE uses more natural gas in one year than in another, it does not mean that the DH system was less efficient in the first year – the reason may be that the winter in the first year was colder. Heating degree days (HDD), the difference between the mean ambient air temperature and room temperature, are used to measure the heating required each day based on the daily temperature (Energy Data GmbH 2022). Monthly HDD sums, and a 10-year monthly average HDD for Lviv, are used to smooth over the variable in monthly temperature over the year, according to Equation 4.

$$Natural\ Gas\ Use_{Normalized,month,year} = Natural\ Gas\ Use_{Actual,month,year} \times \frac{HDD_{10-year-average}}{HDD_{actual,month,year}}$$

Equation 4

HDD data was unavailable from January 2019 through March 2019 because of limitations on the accessibility of historical data. As such, normalized HDD estimates are not available for all months where LTE energy use data is provided.

Normalized vs. actual monthly gas consumption is shown in Figure 1. Normalized gas consumption, which removed the temperature variability from month to month, is more uniform across the seasons than actual gas consumption. While actual gas consumption/emissions are essential for inventory purposes, normalized gas consumption/emissions can be helpful for cross-year analysis and evaluating any emission-related goals in future years. Emissions from both actual natural gas consumption and normalized natural gas consumption are provided in the inventory.

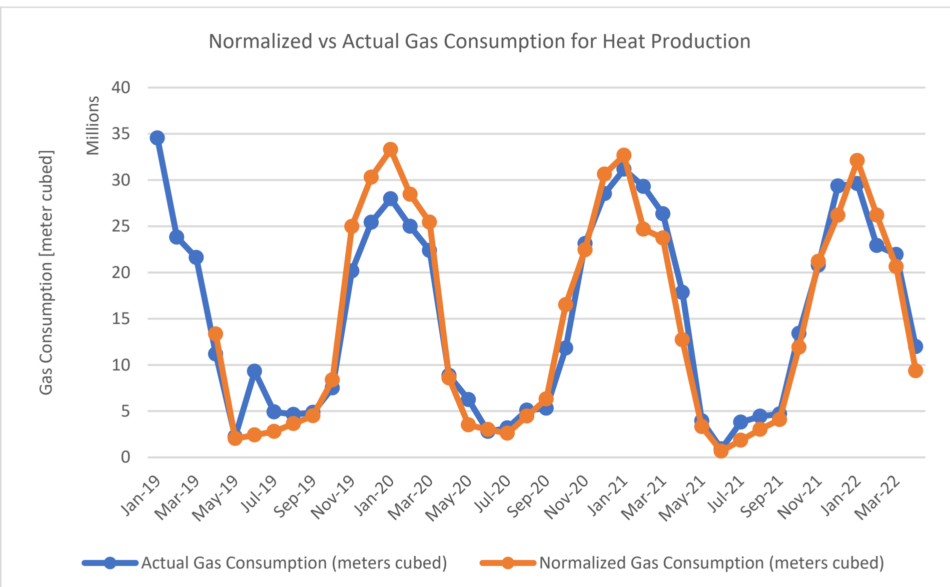

Figure 4 Normal vs actual monthly gas consumption (January 2019 to April 2022)

Results

Table 8 Natural gas combustion emissions Kyoto Protocol Gases (CO_2, CH_4, N_2O), actual and normalized by year.

Year	Total Gas Consumption [cubic meter]	CO_2 Emissions [tons]		CH_4 Emissions [kilogram]		N_2O Emissions [kilogram]	
		Actual	Normalized	Actual	Normalized	Actual	Normalized
2019	170,173,247	328,596	*	5,868	*	587	*
2020	170,286,884	328,815	357,722	5,871	566,176	587	274,040
2021	186,017,815	359,191	320,533	6,414	507,316	641	245,551
2022**	86,455,406	166,941	170,495	2,981	269,847	298	130,611

*Normalized emissions for Jan-March 2019 are not available, as such, the total annual values are not show. Normalized monthly values for April-December 2019 are available in the accompanying spreadsheet.
**2022 only includes January through April (last available data).

Gas consumption and actual and normalized CO_2 emissions by heating season are shown in Table 8. Actual gas consumption increased in the 2020-2021 heating season from the 2019-2020 by 22% and in the 2021-2022 heating season from the 2019-2020 heating season by 9.2%. These variations are largely due to temperature differences over heating seasons as the normalized CO_2 emissions are more stable, increasing 2.5% in the 2020-2021 season and decreasing by 7% when comparing the 2019-2020 heating season to the 2021-2022 season.

Table 9 Gas Consumption, CO2 emissions and normalized CO2 emissions by heating season.

Heating Season (Oct-April)	Total Gas Consumption (meters cubed)	Total CO_2 Emissions (kilograms)	Total Normalized CO_2 Emissions (kilograms)
Oct '19- April '20	137,282,881	265,086,015	307,836,187
Oct '20- April '21	168,123,676	324,637,966	315,497,735
Oct '21- April '22	150,015,999	289,672,995	284,961,086

Table 10 Natural gas combustion Air Pollutants (CO, NO_x), actual and normalized by year.

Year	Total Gas Consumption [cubic meter]	CO Emissions [kilogram]		NO_x Emissions [kilogram]	
		Actual	Normalized	Actual	Normalized
2019	170,173,247	251,727	*	520,078	
2020	170,286,884	251,896	274,040	520,425	566,176
2021	186,017,815	275,165	245,551	568,501	507,316
2022**	86,455,406	127,889	130,611	264,222	269,847

*Normalized emissions for Jan-March 2019 are not available, as such, the total annual values are not show. Normalized monthly values for April-December 2019 are available in the accompanying spreadsheet.
**2022 only includes January through April (last available data).