Urban metabolism: measuring the Kaunas city sustainable development

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Abstract. Urban metabolism seeks to assess the amount of resources produced, consumer and disposed of in the city. Material and energy flow analysis becomes an important tool to understand the city's environment and propose the more sustainable urban design and planning to improve residents' health, ensure sustainable production and consumption. The purpose of this study is to measure the changes in Kaunas city material and energy use in period from 2010 to 2018. Kaunas city urban metabolism analysis is based on energy production and outflows data analysis with the city's waste management analysis from an urban metabolism perspective. To understand the city social and economic transformation, it is also including social and economic aspects analysis. Research results have revealed better living conditions and a growing economy increase energy production and demand, construction materials, and waste flows along with rising environmental issues. Air pollution analysis has shown that SO_2, CO_2, NO_2 and O_3 emissions in the city remain stable. The paper helps to understand the importance of assessing city's environmental impact and highlights the necessity of Sustainable Development Goals (SDG) implementation.

1. Introduction

Among the challenges of SDG implementation, urban sustainability research requires special attention. Urban policy makers try to balance and ensure a high quality of life along with the preservation of natural resources for future generations. Today's cities are the epicenter of economic, social welfare, technological development, innovations, and industrial progress. The high concentration of population in one place highlights the environmental and ecological problems, pollution of water, soil and air, raises social and economic problems (employment, social inequality, poverty, housing shortages, and etc.) [1]. Therefore, cities are the key players in climate change by adapting and mitigating sustainable solutions. It is estimated that 55,3% of the world's population had lived in the cities in 2018 [2]. A high concentration of population, energy use and industrialization have enormous impacts on the rural, regional and global ecosystems. Considering the rapid growth of population, mobility and concentration in the urban areas, it is crucial to implement the 2030 Agenda for Sustainable development to make more inclusive, sustainable urbanization and reduce the environmental impact of cities [3]. The implementation of the Goal 11 "Sustainable cities and communities" is closely related to other SDG goals such as 9 goal "Industry, innovation and infrastructure" and 12 goal "Responsible consumption and production". Sustainable cities provide an opportunity to develop industry innovations along with growing social and economic welfare [4]. By implementing these goals, it could be reached other SDG related to social and economic growth.

Studies of urban metabolism defines city as the ecosystem or organism having inputs (material and energy) and outputs (waste). Material and energy flow throughout the city provide data for urban planning, efficiency in resource use and predict future needs [1]. Urban metabolism analysis could help better understand the current material and energy situation in the urban areas and could help to identify critical areas for future improvement regarding climate change and growing urbanization. Recent urban metabolism researches focus only on metropolitan areas. Yet most of the European cities are

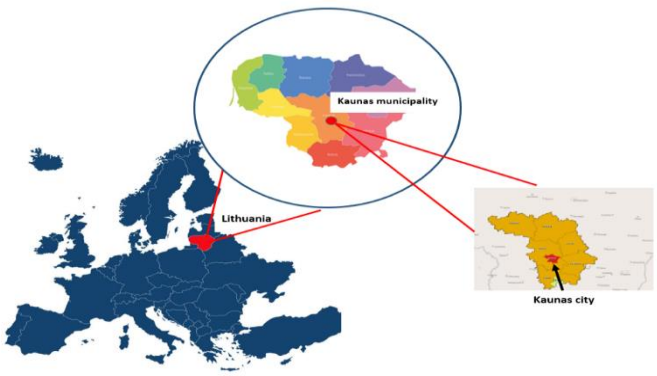
intermediate, medium-sized and small-sized cities. Paris with 10,9 million populations are the first mentioned Europe city is in the 25th position in World City Populations 2019 rakings and this is the only megacity in the European Union (EU) [5]. It is estimated that by 2030, London became the new megacity in the EU [2]. Medium-sized and small-sized cities are lack of scientific attention despite the fact, that large party of Europeans live in medium-sized cities and their impact on sustainable development play significant role in European countries.
Analyzing the material and the energy demand of the medium-sized or small-sized city allows evaluating the inputs and outputs of the city, local environmental impact, and generated waste. Moreover, it shows consequences of their individual activities [6] to global climate system.

2. Methodology

Urban metabolism concept as method analyses cities through the inputs and outputs as a complex system and allow to evaluate the material and energy flows and their transformations [7] by various social, economic and environmental aspects. The specific framework adopted to assess the urban metabolism of Kaunas city was proposed by Kennedy and Hoornweg (2012). This method allows to identify main inputs and outputs of the city [8]. The material and energy flow analysis classifies inputs in 2 basics flows: electricity consumption and energy production. Outputs are classified into generated waste, wastewater, heat, electricity loses and GHG emissions data analysis. This study use material and energy flow analysis to quantify energy and material resources by physical weight or volume, and main social-economic data.
Material and energy flows data analysis was made using several national databases and data sources: Lithuania Official Statistics Portal (OSP), Lithuanian Environmental Agency (EPA) database, National Energy Regulation Council (NERC) database, annual and financial reports from individuals' energy production and waste collection companies. This determines that selected period for analysis is very narrow – 2010, 2015 and 2018 years.
The main limitation of the analysis is a lack of specific material and energy data in national and regional database. OSP presents general annual results on the national level and not on the city level. Other limitation related to electricity production and consumption data diversity, because all produced and imported electricity and natural gas in Lithuania are distributed by the Energy distribution operator and it's creates the difficulty to identify, what type of produced electricity Kaunas city uses.
The achievement of SDG 11 "Sustainable Cities and Communities" was measured by using selected SDG 11 indicators: public transport access, sustainable urbanization rates, urban planning management, protecting cultural heritage, solid waste management, urban air pollution, open spaces in the cities, safe spaces in the cities [3]. Other indicators such as urban population living in slum, public transport access, deaths and injuries from natural disasters, economic loses from natural disasters were rejected, because they were not relevant to current Kaunas city economic, social or geographical situation.

3. Case study

Kaunas county located in the middle of Lithuania with 6 district municipalities and covers 12.4% of the total territory of Lithuania. The population of the county was 287,574 at the beginning of 2018 and population density is 1,827 inhabitants/km^2. Kaunas city is the second biggest city in Lithuania (157 km2 area) [56] (see Figure 1).



Urban areas in the Kaunas county cover 68.6% of the area [9]. The city is moderately urbanized: about 55% of the whole city territory occupy buildings, 2% objects for other purposes, 17% forests or wooded land, 12% agricultural land, 8% water bodies, and 6% roads [10]. Kaunas city and all county are one of the biggest industrial areas of the state, because of grateful geographical location, easily accessible transportation networks (railways, roads, airport and water transport).

Kaunas county is the only one in the Eastern Baltic region where two European transport corridors intersect – the I and IX B road corridors and the I and IX D rail corridors. Kaunas county has well-developed rail transport with designed European gauge railway "Rail Baltica" connecting all 3 Baltic states and running from Polish border through Kaunas and Riga to Tallinn [11]. In comparison from the economic perspective of other Lithuanian cities, Kaunas county creates 8,596.3 million Euro (20.4%) of total Gross Domestic Product (GDP), Vilnius county (capital) creates 40.7%, Klaipeda county – 11.4%, rest of the country creates 38.9% of GDP [12]. Kaunas county has one of the biggest free economic zone strategically located near the airport, railway networks and national roads where located main city's production, electronics, logistics, food industry, and pharmaceuticals companies [13]. Kaunas county attracted 1,562.48 million Euro foreign direct investments (FDI) in 2017, which sharply increased by 81% since 2010 [59]. The largest investments were made into manufacturing (402.38 Million Euro), wholesale and retail (377.58 million Euro) and real estate activities operating companies (238.56 million Euro) [14]. As the result, the employment in Kaunas city increased by 23% [57]. These indicated sectors are the most rapidly growing and demanding employees with high qualification in the county.

In last few years, Kaunas city industrial sector value added at the production cost raised from 2,528 million Euro in 2013 to 3,928 million Euro in 2017 (20.2% of the total country), the number of business and industrial companies also is growing and was around 21 thousand in 2018 [15]. It is rapidly growing city and requires important changes in urban architecture, city planning, public transport, waste management with special attention to the environment.

Still, Lithuania has no urban metabolism studies of the cities. Lithuania had made the first steps to address circular economy issues and SDGs' implementation in national regulations and urban planning processes. Kaunas is the only city of Lithuania participating in the European Union "Urban Agenda for EU" guidelines creation for the development of a sustainable society in future cities [16].

Urban metabolism analysis will help to evaluate the current situation of SDG's implementation. Stable economic growth in the city implies that, SDG goal 8 "Decent Work and Economic Growth" is successfully implemented. Energy production and consumption requires a lot of natural resources, despite the fact, that Kaunas city because of this favourable geographical location has the largest hydroelectric power plant, but all produced energy in Lithuania is distributed by Energy distribution operator (EDO). Material and energy flow, socioeconomic factor analysis will help to evaluate how Kaunas city meets SDG goal 11 "Sustainable Cities and Communities".

4. Results

Tables 1 summarizes the results of urban metabolism in Kaunas city in 2010, 2015 and 2018. It presents the gross and per capita volume of materials and energy produced and consumed in the city.

Kaunas city is located between two main rivers of the country and one of the main energy producers in the city is a hydroelectric power plant (KHPP) which is the largest power plant in Lithuania that uses renewable energy sources [17]. Kaunas city also has 4 cogeneration power plants and 189 solar power plants (most of them are for individual use – 129) with the power from 0.0029 to 0.6998 MW [18]. Despite the fact, that Kaunas city mostly produces sustainable energy and number of population is decreasing in past years, the demand for electricity and energy consumption is rising. Data results show that energy use and electricity consumption is rapidly growing by 17% and 22% in the last 3 years. Growing FDI in Kaunas county attract new production companies in the Kaunas city such as Continental, Hollister, Hella Lithuania, and others. This is also having an impact to higher electricity consumption. The electricity consumption increased in all sectors (residential 6%, industrial 11%, commercial 9%, public services 13%).

Growing production and construction sector demand more energy and materials. Although, KHPP produce 30% of total electric energy in Lithuania, Lithuania cannot fulfil higher electric energy demand

and about 70% of necessary electric energy Lithuania imports from EU and third countries [19]. Lithuania exports only 6% of the produced electric energy [20].
Wind energy production accounts for a small proportion of all energy production in Lithuania and it highly depends on meteorological conditions. Kaunas city located in the center of Lithuania and its geographical location is not favourable for wind energy production.
Kaunas city has 3 biofuel cogeneration plants for heating energy production: "SSPC Taika" with 5MW power, "Danpower" with 5 MW and "Foksita" with 4,99 MW power [17]. To increase cheaper and more sustainable energy production by using biomass, Kaunas city is developing 3 more new biofuel boiler house construction projects. The first biomass biofuel boiler with 17,5 MW power construction work was finished in 2017. It produces 7% of the city total annual energy demand [22]. City has new high-efficiency waste-fired cogeneration plant with an electric capacity of about 24 MW and heat production capacity of about 70 MW. These capacities allow to use about 200 000 t of municipal waste generated in the region [32]. This will help to reduce energy costs and ensures more effective waste management in the city. Energy production results analysis shows that the city gives significant effort to implement SDG goal 7 "Affordable and Green Energy" by using more efficient and sustainable resources for energy production.
The city adopted new types of sustainable energy production from biomass (614%) and solar panels (19%) to improve more effective and sustainable energy production. A growing number of private cars (9%) to 157.569 in 2018 affects the consumption of transport fuel (26%), despite the fact, that the city invested 33 million euros in new and more sustainable public transport [23].
Effective sustainability and sustainable cities are closely related to effective waste collection, recycling and use as a renewable energy source. Still, waste potential is not fully exploited [24]. The number of population has been gradually decreasing for 8 years along with food intake (-4%) in Kaunas city. However, the amount of waste increased by 22% just in 3 years. The major growth of waste consumption is in the commercial and industrial sectors 283%. Moreover, the data of the same period shows the correlation between growing FDI in business (1,989 million euro in 2018) and a growing number of commercial, industrial and C&DW waste. SDG goal 12 "Responsible consumption and production" seek to improve resources and energy efficiency and reduce waste [25]. Data analysis showed that waste recycling rate increased in past years. About 43.03% of total collected waste recycled in 2018 and only 18.12% of waste recycled in 2015 [20].
The growth of waste recycling determined by new Law on Packaging and Packaging waste accepted by Lithuania government in 2016. New law increased the deposit amount from 0.7 to 0.1 Euro for purchased eligible drink containers along with PET and metal packages types expansion in deposit system [29]. Data results show the growth of recyclable waste by 264% as well as other types of recyclable packages such as glass (455%), metal (152%) and plastic (253%) [30], [31], [63]. For more effective waste collection and recycling, Kaunas county installed the containers for different types of recyclable waste such as paper, cardboard, glass, metals, plastic and textile and their accessibility have led to positive changes in waste utilization and disposal [28].
Kaunas city is also known for having the biggest fuel, oil and air filters recycling line, called MeWa, in Baltic states, which helps to recover 100% of recycled raw material: oil regenerate into base oil, the metal melted, and a mixture of plastic, rubber and paper used for energy generation [32].
Another essential output is drinking water consumption and wastewater. Water consumption raised 5% in 3 years and the consumption in industrial and commercial sector raised dramatically by 78%, while drinking water consumption by residents decreased by -17%. Comparing 2010, 2015 and 2018 years, it can be stated that the total amount of wastewater was unstable and fluctuating. Kaunas city implements networks of drinking water and wastewater reconstruction and development from 2017.

Table 1. Urban metabolism of Kaunas – gross value.

Material Category	Unit	2010	2015	2018	2015/2018 %	Source
Inputs						
Food intake	ton/yr	320,644	322,753	310,579	-4	OSP [37]
Electricity consumption (total)		*17,459,400*[b]	*29,622,718*	*36,157,614*	*22*	
Residential	MW/h	3,495,000[a]	3,704,710	3,928,950	6	OSP [38]

Commercial	MW/h	-	10 096,379	11,102,035	9	
Publix services	MW/h	7,037,400[a]	6,238,046	7,077,089	13	OSP [39]
Other	MW/h	-	2,923,378	3,055,660	4	
Electricity import	*MW/h*	*12,221,580[b]*	*20,735,902*	*21,254,653*	*2*	IGNITIS [17]
Energy production (total)	MW/h	453,100	342,757	442,235	29	
Renewable energy	*MW/h*	*446,800*	*330,554*	*354,573*	*7*	
Solar	MW/h	-	3,854	4,573	19	VERT [40], LEI [41], OSP [38]
Hydroenergy	MW/h	446,800	326,700	350,000	7	
Biomass	MW/h	*6,300*	*12,203*	*74,932*		
Food	MW/h	6,300	12,203	12,730	4	KRATC [42]
Wood	MW/h	-	-	62202.00	-	Ekopartneris [22]
Energy consumption (total)	units	-	2,386,015.84	2,812,207.68	17	
Renewable energy	*MW/h*	-	*65,724*	*74,573*		
Solar	MW/h	-	3,854	4,573	19	REGULA [43]
Hydroenergy	MW/h	-	65,340	70,000	7	
Biomass	*MW/h*	-	*12,203*	*74,932*	*614*	
Food	MW/h	-	12,203	12,730	4	KRATC [42]
Wood	MW/h	-	-	62,202	-	Ekopartneris [22]
Nonrenewable energy	*units*	-	*4,080.52*	*4,553.68*	*16*	
Natural gas	TJ	-	2,283.4	2,482.4	8	OSP[44]
Fossil fuels (oil)	t/yr	-	1,797.12	2,071.28	15	
Transport fuel	*t/yr*	-	*918,820,00*	*1 159,660.00*	*26*	REGITRA [45], OSP [46]
Gasoline	t/yr	-	69,598,00	74,720,00	7	
Diesel	t/yr	-	849,222,00	1 084.940,00	27	
Heating	MW/h	-	1,384,612	1,497,810	8	Danpower [47] Kauno energija [48]
Coal and lignite	TJ	-	576.32	679	17	OSP [49]
Drinking water consumption	*10^3 ton/yr*		*16,797.6[c]*	*17,716.29*	*5*	
Industrial and commercial	10^3 ton/yr		4,031,00	7,195.32	78	Kauno vandenys [33], [34]
Residentials	10^3 ton/yr		12,727,00	10,521	-17	
Outputs	ton/yr					
Solid waste	*ton/yr*	-	*122,702.23*	*149,330.55*	*22*	*EPA [21]*
Construction and demolition waste (C&DW)	ton/yr	-	7,067.66	8,528.00	21	
Commercial and industrial waste (C&IW)	ton/yr	-	6,659.00	25,506.00	283	
Domestic – municipal solid waste (MSW)	ton/yr	-	108,975.50	115,296.85	6	
Paper and cardboard	ton/yr	-	2,125.76	2,816.35	32	
Textile	ton/yr	-	323,570	379,145	17	
Electronics	ton/yr	-	1,051.91	1,128.89	7	
Recyclable waste	*ton/yr*	-	*1955,951[c]*	*7625,591*	*264*	
Glass	ton/yr	-	717,532[c]	3985,159	455	CSA[30], [31], Kauno svara [63]
Metals	ton/yr	-	337,009[c]	852,408	152	
Plastic	ton/yr	-	901,411[c]	3188,024	253	
Biodegradable waste	ton/yr	-	5,101.49	8,076.53	58	EPA [21]
Healthcare waste	ton/yr	-	424,38	387,18	-9	EPA [50]
Toxic waste	ton/yr	-	1275,524	1710,184	34	
Tree waste	ton/yr	-	5101,490	8653,748	69	EPA [21]
Wastewater	10^3m^3	25,895.5	27,866.72	24,821.9	-11	
Heat losses	MW/h	-	21,556.92	14,978.10	-31	REGULA [51]
Electricity losses	MW/h	-	65,970	184,620	179	REGULA[51]-[55]
GHG emissions						EPA [26]
CO_2	Cmax8 h/mg/m3	2,7	2,23	2,5	13	
SO_2	Cavg/μg/m3	1,3	2,4	3,2	33	
O_3	$C_{max8\ h}$/μg/m3	134,5	123,5	117,5	-5	
NO_2	Cavg/μg/m3	16,3	16	18,7	17	
C_6H_6	Cavg/μg/m3	0,25	0,38	-	-	
PM_{10}	Cavg/μg/m3	30	24,6	26	5	
$PM_{2,5}$	Cavg/μg/m3	17,5	12	12,2	2	

[b]There were no data for commercial and other sectors energy consumption.
[c]Data from 2016.
[d]Data from 2014.

As all urbanized territories, Kaunas is also having some problems according with GHG emissions, which origins are very different. Due to the peculiar geographical location and the lack of bridges and bypasses, very intensive traffic flows cross the central part of the city, therefore, the air in the central suburbs of Kaunas city (Center, Old Town) is heavily polluted. In 10 year period, most of the emissions to air came from vehicles: 98% – car emissions and only 2%. - pollutants from other means of transport (trains, airplanes, ships and off-road vehicles) [10], [35], [36]. The highest levels of nitrogen oxide and nitrogen dioxide pollution in Kaunas city coincide with the east and west peaks of transport flows. Rising cost of district heating in recent years might have caused an increasing proportion of the population living in the city centre, who has expressed a desire to disconnect from the district heating system, increasing air pollution in the city centre [10]. According to the Kaunas Air Quality Survey, the highest number of PM_{10} exceedances were observed in 2010 and 2014, during cold season [10]. This could be influenced by increased emissions to ambient air, production of thermal energy in power plants and individual home heating systems. The highest values of $PM_{2.5}$ were also recorded during the cold season during the most intense housing heating season. The highest concentration of benzene was in 2011- reached 2.5 μg / m3, but did not exceed the limit value for benzene for the calendar year average of 5 μg / m3. From 2015 to 2018 the problems remained the same. The most common sources of fine particulate matter pollution are transport, and boiler plants, which use fossil fuels (ash and soot), industrial plants (metal, fabric dust), soil erosion and photochemical processes [36].
Kaunas city sustainable development was evaluated on selected SDG goal 11 indicators (table 2).

Table 2. Selected indicators for SDG Goal 11 "Sustainable cities and communities" evaluation

Indicator	Description
Sustainable urbanization rate	Kaunas city density was 1836.7 person/sq. km in 2018. Kaunas city some districts are highly urbanized. Urbanized areas cover about 68.6% of the Kaunas county, 17% forests or wooded land, 6% roads [10].
Urban planning management	Kaunas city isn't expanding, but urban changes are taking place through the redevelopment of inner city areas.
Protecting cultural heritage	Kaunas city have 65 cultural heritage objects. Each year Kaunas municipality prepare each cultural heritage monitoring reports [61].
Solid waste management	Kaunas municipality installed containers for different types of recyclable waste such as paper, cardboard, glass, metals, plastic and textile collection in past 2 years. It's allow to collect and recycle more waste from households [28].
Urban air pollution	Kaunas city effectively reduce CO_2, O_3 emissions, except NO_2 emissions where is stable growth. Average annual urban air pollution data don't exceed maximum air pollution threshold value.
Open spaces in the cities	Green areas cover 17% of the Kaunas city territory. Kaunas city already renovated 8 parks. Kaunas city has new bike lines, bicycle lines in the streets, adapted sidewalks and new bike racks [27].
Safe spaces in the cities	Kaunas city has new 240 video surveillance camera system in the public spaces to improve safety [62]

The public transport access wasn't evaluated, because Kaunas city has highly development public transport network and easy access to habitants is ensured.
In general, selected SDG goal 11 indicators evaluation show that Kaunas city invested and implemented a lot of good initiatives to reduce negative impact to the environment, ensure more effective waste management and improve citizens' quality of life in the city. Transport sectors (increasing number of cars, traffic) and more effective waste recycling remain the areas to improve.

5. Conclusion

Urban metabolism data analysis provided an overview of Kaunas city main material and energy flows in the period of 2015 and 2018. Case analysis results showed the correlation in quality of social and economic factors due to higher use of resources and pollution. Although Kaunas city sustainable energy production by using hydroelectric, cogeneration power plants and solar panels have positive impact for sustainable city development. The growth of business and production sector, individual houses construction and streets reconstruction has the major impact to energy demand, waste production and air pollution. Therefore, local governmental actions such as increased number of recycling containers and national regulations for packaging waste resulted positive changes for waste recycling data. Regarding to biological treatment technology wastewater transformed into biogas and used in more

efficient way. Even if, GHG emissions only a few times in a year cross the allowable limits, the main problems for its generation remain the same in comparative period.

Social indicators analysis showed economic growth in the city. However, economic growth is strongly related to negative impact to environment which is necessary to maintain more effectively. Selected SDG goal 11 indicator analysis results show that city made a lot of decisions and improvement to reduce negative impact to environment and improve the quality of life in the city. However, waste management and transport sector requires improvements in the future.

Kaunas city urban metabolism analysis is the first step to becoming more efficient and sustainable city in the future. This study helped to identify the critical points for future urban planning, design and decision-making. Kaunas city have to be aware of its contribution to sustainable development and seek to prevent environmental problems. In future studies, there should be more detailed analysis of material and energy flow within the city.

Although medium or small cities are lacking scientists' attention from the urban planning and sustainable development perspective, Kaunas urban metabolism study results highlights common problems in similar cities with rapid urban development and economic growth.

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