The biomethane potential for public transport decarbonization in Italian cities

Journal of Physics:
Conference Series

PAPER • OPEN ACCESS

The biomethane potential for public transport decarbonization in Italian cities

To cite this article: Michel Noussan *et al* 2024 *J. Phys.: Conf. Ser.* **2893** 012092

Journal of Physics: Conference Series **2893** (2024) 012092
doi:10.1088/1742-6596/2893/1/012092

The biomethane potential for public transport decarbonization in Italian cities

Michel Noussan[1], Matteo Prussi[1] and David Chiaramonti[1]

[1]Department of Energy, Politecnico di Torino, Torino, Italy

E-mail: michel.noussan@polito.it

Abstract. The transport sector remains heavily reliant on oil products, and it is among those that are considered harder to decarbonize, especially in some specific segments. Considering public transport, there is currently a significant interest in electrifying urban buses, especially for some routes that are well suited for the current characteristics of battery electric buses. However, for some applications, including long-distance buses, biomethane could play an important role in contributing to the decarbonisation of the sector, especially considering the important part of the current fleet in Italy that is already operating on fossil natural gas. This analysis presents a comparison of the potential role of biomethane to support public transport decarbonization in Italy, by estimating CO_2 equivalent emissions savings considering the current biogas plants and natural gas buses in Italian cities. An additional evaluation is performed considering the future expected evolution of biomethane production in line with the new Piano Nazionale Integrato per l'Energia e il Clima, that aims to a total production of 5.7 bcm by 2030, as well as the expected 1.5 bcm of biomethane allocated to the transport sector. Within these maximum potential levels, the results of the analysis demonstrate the important savings that can be achieved with biomethane, especially when exploiting specific feedstocks that have a very low impact in terms of well-to-wheels emissions. Biomethane can represent an interesting complement to electric buses, as it can exploit the already existing fleet based on natural gas, and it also shows a number of advantages on routes that are not suitable for electric buses.

1 Introduction

A successful energy transition towards a low-carbon economy requires a combination of technologies across different sectors and applications. Transport is significantly relying on oil products, especially in some specific segments, although electrification is increasingly being seen as a potential alternative. EU and national regulations are supporting the diffusion of private cars with lower emissions, both for local pollutants [1, 2] and CO_2 [3]. Also, in many cities low-emission zones are limiting the access to vehicles with very low or no tailpipe emissions. The policy attention seems to be focused on private cars and trucks, which represent the largest share of vehicle-km driven and resulting emissions.

However, another segment that is seeing a gradual increase of alternative options to diesel is local public transport (PT). While some PT modes are already electrified, such as light rail, subway or trolleybuses, also urban buses are seeing a gradual implementation in many cities worldwide. Some cities have also deployed a large number of buses running on compressed natural gas (CNG), especially to reduce local emissions compared to diesel buses [4, 5], in particular for particulate matter. However, considering fossil gas, their climate emissions are often comparable to those of diesel [6, 7]. However, these buses that are already in operation could be potentially running on biomethane, which could represent an environmental friendly alternative to fossil gas [8, 9].

Biomethane can be produced through different processes, although today the most mature option remains the upgrading of biogas obtained by the anaerobic digestion of different biological feedstock. The produced biomethane is very similar to natural gas, with a high level of methane, and can be directly used in infrastructure and vehicles that currently use fossil gas. Italy has already many vehicles running on CNG, both considering private cars and urban buses, and trucks are gradually seeing a penetration of liquefied natural gas (LNG) as a potential alternative to diesel powertrain.
The emission savings that can be obtained by subsituting fossil gas with biomethane depend on different factors, including the type of feedstock, the specific energy consumption of the different steps of the processes and the forms of storage and distribution. Both EU and National regulations (Decreto Biometano, DM 15/09/2022) have set specific limitations on the feedstock that can be used and on the minimum threshold of emission savings that should be guaranteed compared to the reference alternative based on fossil fuels.
Many studies have evaluated the effect of biomethane in road transport, mostly considering the applications in private cars [10, 11] and heavy-duty vehicles [12, 13], with some applications also focusing on urban buses, evaluating specific case studies for some cities [14, 15, 16].
CNG buses running on biomethane could complement the other main option to decarbonize urban buses, which is direct electrification through the use of battery electric vehicles (BEVs). Instead of competing with BEVs, CNG buses supplied by biomethane could exploit some specific advantages in particular applications: existing CNG buses could be used without modification, the refuelling process is much faster and the range of current vehicles is higher. While BEVs have no tailpipe emissions, the use of biomethane is seen as carbon neutral. On the other hand, both solutions incorporate well-to-tank (WTT) emissions that need to be carefully considered and evaluated. Thus, the comparison of the well-to-wheels (WTW) emissions of the two solutions could vary depending on the feestock and processes used, as well as on the electricity mix of the electricity.
The available literature confirm the interest for biomethane application in transport, also with some studies focusing on urban buses. However, many analyses are not based on real consumption data, nor they are incorporating the effect of upstream emissions, and often biomethane is evaluated against diesel buses only and not compared to electric buses.
This work focuses on the potential contribution of biomethane in decarbonizing urban public transport in Italy. Starting from real data of fuel consumption and mileage from the current bus fleet of the city of Turin, we estimate the potential biomethane demand considering different penetrations of CNG buses fed with biomethane. GHG emission savings are evaluated by considering WTW emission factors for biomethane, electricity, natural gas and diesel, to compare alternative future trends with the current situation.
The analysis also provides a comparison of the expected biomethane demand with the current forecast of biomethane supply deployment at the national level. The results can be of use for both researchers and policy makers to evaluate the potential allocation to public transport of a share of biomethane, also taking into account the other applications that can require it.

2 Methodology

2.1 Public transport demand in Italy

Urban public transport in Italy accounted for 16.4 billion passenger-km (pkm), significantly higher than the 12.5 billion pkm of 2021 but not yet at the pre-COVID level of 2019, that was 19.7 billion pkm [17]. Urban buses represent the majority of the demand, with 62% of the pkm in 2022 (61% in 2019), followed by subways (29%) and trams (9%). However, while the demand has not yet fully recovered, the public transport services in terms of offered pkm are at the same level of 2019: urban buses have offered in 2022 around 57.8 billion pkm, compared to the 57.3 billion pkm of 2019.
Urban buses are the only urban public transport mode that emit tailpipe emissions, as both subways and trams are electrified. For this reason, many cities are considering strategies to decrease emissions of their transit fleet, mostly to reduce local pollution. A significant penetration of CNG buses has appeared in the last decades, thanks to their lower pollutant emissions compared to diesel buses. The introduction of BEVs is more recent, with a significant increase after 2020, as electric buses were before limited to small units operating in short routes in historical city centers or low-emission zones. BEVs represent in 2022 around 4% of the urban bus fleet, compared to 29% for CNG buses and 67% of diesel buses (figures estimated on data from [18, 17]). However, preliminary figures for 2023 show a 54% increase of BEVs compared to 2022, confirming the important electrification trends in Italian urban buses. Moreover, national decarbonization targets also include specific funding supporting cities in decarbonizing public transport, and this trend is expected to continue in the future.

Journal of Physics: Conference Series **2893** (2024) 012092 doi:10.1088/1742-6596/2893/1/012092

2.2 Biomethane supply

In the last two decades the Italian government has supported the electricity generation from biogas with a dedicated incentive scheme. As a result, there are currently almost 2,200 power plants running on biogas produced from anaerobic digestion of different feedstock, for a total installed power of 1.46 GW and an annual gross electricity generation of 7.85 TWh (as of 2022 [19, 20]).

According to the last update of the National Energy and Climate Plan, Italy has fixed an objective to reach a total production of 5 Mtoe of biomethane and biogas by 2030, which is roughly equal to 5.7 billion cubic meters (bcm), of which 1.5 bcm should be allocated to the transport sector. The current biomethane production (annual data for 2022 [21]) reaches around 0.2 bmc, mostly supplied to the national natural gas network.

The current Italian incentive programme, definted in the DM 15/09/2022, called "Biomethane Decree" ("Decreto Biometano" in Italian), provides specific incentives to support the development of biomethane upgrading plants.

The programme has published three rounds of auctions so far, reaching a total of 243 plants, for a total nominal capacity of around 115,000 Sm^3/h, which is equivalent to roughly 1 bcm of biomethane output per year. The auctions require that the plants already decide the expected application of the biomethane produced. So far, 22% of the installed capacity is aiming at producing biomethane for the transport sector, which has specific incentive conditions compared to the other applications.

The maps reported in Figure 1 show the geographical distribution of the plants in Italy (the plants are aggregated per municipality, i.e. if a municipality has more than one plant the installed capacity reported in the map is the total aggregate for that municipality).

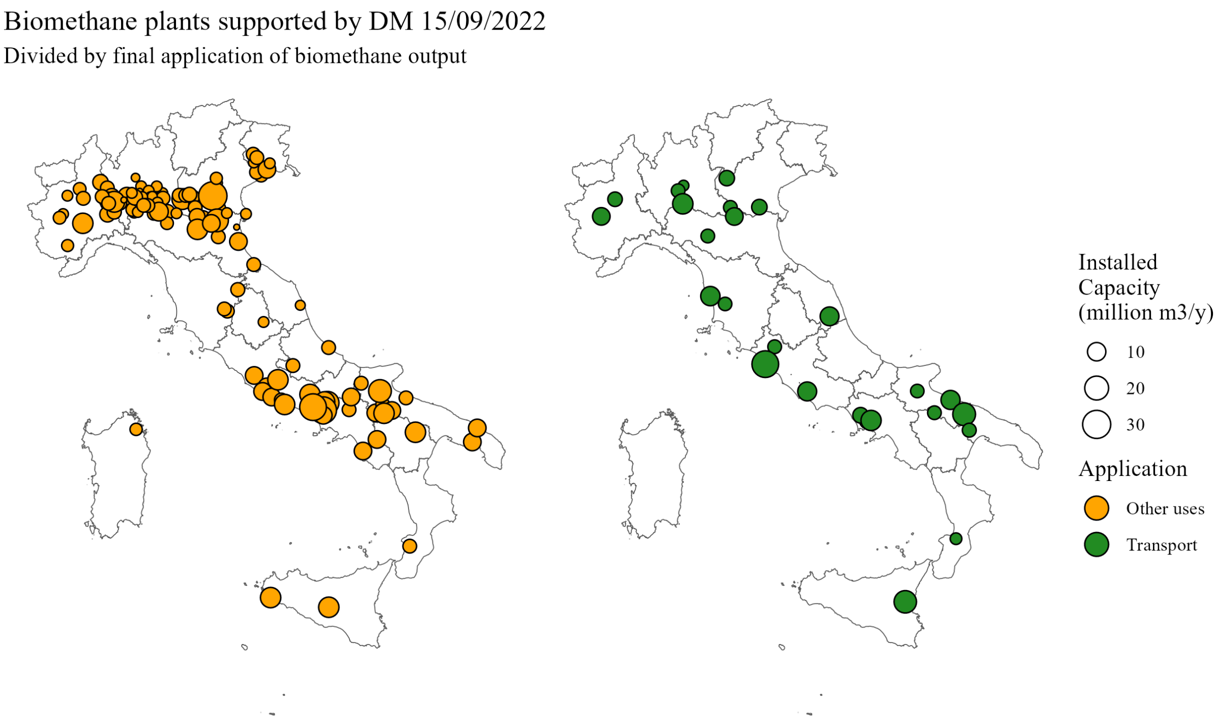

Figure 1: Planned biomethane plants that have applied for the incentives of the DM 15/09/2022. Authors' elaboration on data from [22].

The maps clearly show the high concentration of plants in Northern Italy, which accounts alone for slightly more than 50% of the total number of plants. The top four regions for plants and biomethane output are Lombardy (55 plants, 178 million cubic meters), Campania (39 plants, 176 mcm), Emilia Romagna (29 plants, 116 mcm) and Lazio (24 plants, 121 mcm). While Lombardy and Emilia Romagna are also among the top regions for biogas power plants (together with Veneto and Piedmont), Campania and Lazio have fewer biogas plants. This seems to suggest that this incentive scheme is

helping the development of this resource also in Center and Southern Italy, compared to biogas plants, for which Northern Italy accounts for almost 80% of the total installed capacity.
It is also important to remark that 70% of the total biomethane capacity (158 units) is represented by new installations, while the remaining 30% (85 units) is related to the conversion of former biogas power plants towards biomethane upgrading plants. Most of the installed capacity, over 82%, is related to anaerobic digestion plants that exploit agricultural residues and products, while the remaining 18% is based on the organic fraction of municipal solid waste.
The current information suggests that there is still a shortage of biomethane capacity to reach the 2030 target, and the current incentive program alone may not be enough to trigger the required investments in the next few years.

2.3 Fuel consumption and emissions savings

The current statistical data at national level provide information on urban public transport demand and offer and on the bus fleet per powertrain, but no coherent information is available on the energy consumption and emissions with the adequate level of detail.
For this reason, we have estimated the energy consumption by exploiting the results of previous research [23, 16] on the performance of the bus fleet of the city of Turin, based on the real record of fuel consumption for each bus of the fleet. We have used the weighted average consumption of buses based on the offered pkm for diesel buses (4.88 kWh/100pkm), CNG buses (8.22 kWh/100pkm) and electric buses (1.43 kWh/100pkm). These figures were mostly comparable to data provided by manufacturers specifications, although with some minor differences.
Energy consumption is used to estimate well-to-tank (WTT) and tank-to-wheels (TTW) emissions, considering the emission factors reported in Table 1. Figures for diesel and CNG are retrieved from [24], together with WTT emissions for biomethane (considering an average mix estimated for Italy [9]). TTW biomethane emissions are expected to be carbon-neutral, and are thus set to zero, according to the common practice in the literature. WTT emissions for electricity are based on the annual figure calculated for the average Italian electricity mix in a national report [25], including a 10% losses for bus charging.

Emission factors (g/kWh)	**WTT**	**TTW**	**WTW**	**Sources**
diesel	68	265	333	[24]
natural gas	41	207	248	[24]
biomethane	61	0	61	[24, 9]
electricity	135-334	0	135-334	[25]

Table 1: Emission factors for the different energy carriers considered in the analysis (g of CO_2 per kWh).

The combustion of natural gas and biomethane in internal combustion engines can potentially lead to the emission of unburnt methane, which has a significant global warming potential. However, specific research on urban buses [26] and other heavy-duty vehicles for local operations [27] shows that the contribution of methane emissions on total TTW CO_{2e} emissions is in the range 0.1%-0.3% for both buses and dedicated CNG trucks for urban delivery. Given the very limited contribution of these emissions compared to the other WTT and TTW emissions considered in this analysis, we have decided to neglect the contribution of unburnt methane in our assessment.

2.4 Future scenarios

The analysis is based on the current situation, considering the historical evolution of the last five years, 2018-2022, as a basis for the definition of two alternative scenarios towards 2030.
The first scenario is considering the historical evolution of CNG and BEVs in the bus fleet, with an average annual increase of their total number which is equal to 5% and 20% respectively. The hypothesis is that the total number of buses remains roughly constant, which means that the new powertrains are substituting old diesel buses that are approaching the end of their technical life. The result of this assumption on the bus fleet composition is represented in Figure 2, with BEVs representing 25% of the fleet by 2030 and CNG buses representing 45% of the fleet.
The second scenario is proposing an accelerated transition towards the electrification of the fleet, in the hypothesis that priority is given towards a stronger electrification of urban public transport. In this

cases, we assume no growth for CNG buses, and an accelerated growth of 35% year-on-year for the absolute number of BEVs. This results in a fleet composition of 56% of BEVs in 2030, compared to 32% of CNG buses, as reported in Figure 2.

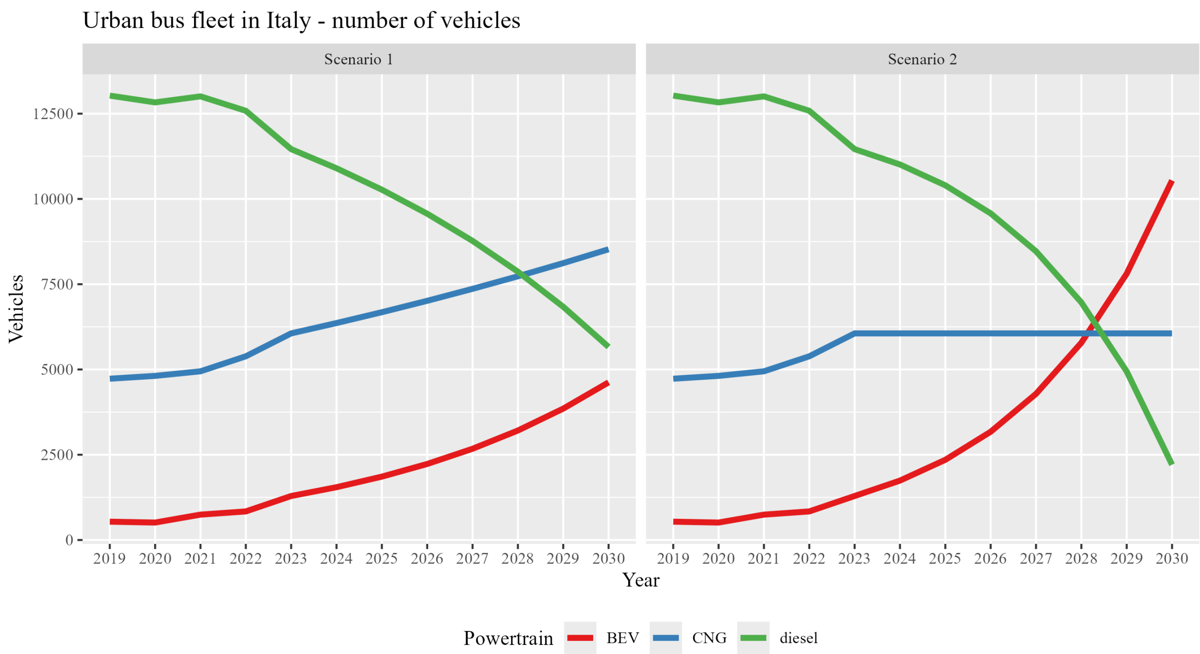

Figure 2: Estimated urban bus fleet per type of powertrain - Scenario 2, accelerated electrification trend.

An additional assumption considered in this work is the gradual increase in the share of biomethane allocated on urban public transport. From a current share of 100% fossil natural gas in the supply of CNG buses, we assume a gradual increase towards 100% biomethane by 2030 (with a 20% share in 2025 and 50% share in 2028). This trend is assumed for both scenarios, to estimate the potential biomethane demand that the sector would require, and compare it with the expected maximum biomethane supply and its share devoted to the transport sector.

3 Results

Urban buses in Italy are currently consuming around 3.2 TWh of fuel (2022 data), causing 0.98 Mt of CO_2 emissions, of which 0.78 Mt are TTW emissions and the remaining 0.20 Mt are WTT emissions. Around two thirds of these emissions are related to diesel buses, and a third is due to CNG buses, while BEVs are responsible for a marginal part of WTT emissions.

The future expected evolution of these figures can be evaluated by comparing the two scenarios presented in this study, depending on the different evolution of the powertrains and the penetration of biomethane in the sector.

The WTW emissions related to the first scenario, considering the historical trend of penetration of CNG buses and BEVs, are reported in Figure 3. Total WTW emissions reach 0.44 Mt by 2030, showing a 55% reduction compared to 2022. These emissions are almost equally split between WTT and TTW emissions, due to the fact that both electricity and biomethane, that represent 74% of the total energy consumption in 2030, have no TTW emissions. In fact, WTT emissions show a 11% increase in 2030 compared to 2022, also taking into account the strong expected decrease in the carbon intensity of the electricity due to the power decarbonisation targets. Around two thirds of the total WTW emissions remain related to diesel buses. Shifting away from this powertrain will be a necessary step to reach very low emissions in the future, but given the fact that new diesel buses have been put in operation in the last years, their technical lifetime will span well beyond 2030.

The second scenario considered in this study evaluates a stronger penetration of BEVs, with a fixed number of CNG buses in the vehicle fleet, where however biomethane is gradually substituting fossil gas. The evolution of WTW emissions of this scenario are depicted in Figure 4. By 2030, total WTW

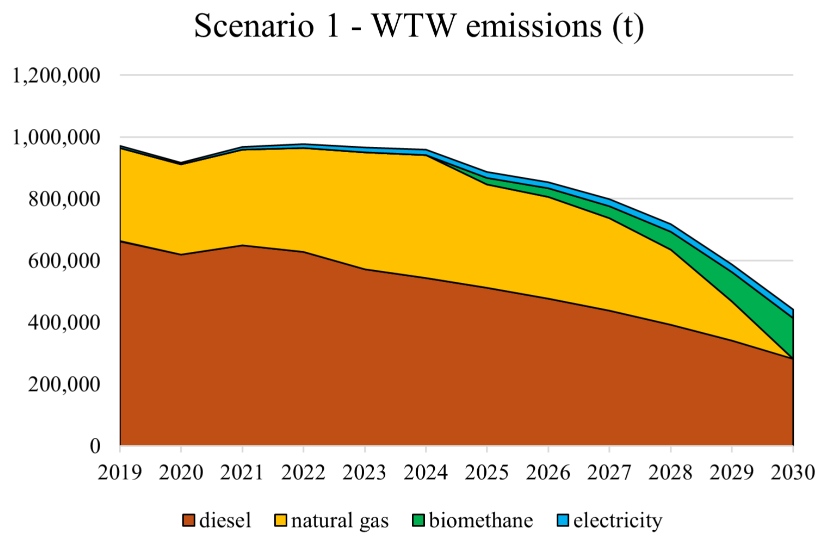

Figure 3: Estimated WTW CO_2 emissions per type of powertrain - Scenario 1, historical development trend.

emissions reach 0.27 Mt, a 73% decrease against 2022 levels, and in this case the WTT emissions represent the lion's share, with 0.18 Mt of CO_2. WTW emissions in 2030 are 40% lower than those estimated for Scenario 1, thanks to a stronger penetration of BEVs that reduces overall the number of diesel buses compared to the other scenario (see Figure 2).
In addition to GHG emissions, whose reduction is the main goal of public transport decarbonization, this analysis also provides an estimate of the energy consumption that will be required by urban buses. Considering electricity, BEVs will require in 2030 a total of 204 GWh in the first scenario and 465 GWh in the second scenario, a 5-times to 12-times increase compared to the 2022 estimate of 37 GWh. Such an increase will require proper charging infrastructure for the vehicles, and will also be associated with important levels of charging peak power, that will need to be properly accounted for through optimized charging cycles and schedules.
Another important evaluation is the estimated demand of biomethane. A full coverage of the fuel consumption of CNG buses in 2030 with biomethane would require 2.2 TWh for Scenario 1 and 1.5 TWh for Scenario 2 (where the number of CNG buses remains constant compared to 2022). These levels correspond to roughly 0.22 and 0.16 bcm of biomethane respectively, well below the 1.5 bcm allocated to the transport sector by the same year, and in line with the current planned biomethane plants for transport applications included in the DM 15/9/2022 funding mechanism. However, it is important to remember that other transport segments may also consume a significant amount of biomethane, such as trucks and maritime, although in these cases bio-LNG may be a more efficient solution, requiring a proper infrastructure for its transportation and distribution.

4 Conclusions

This paper presents a comparison of two alternative future scenarios to gradually decarbonize the urban public transport sector in Italy, increasing the contribution of electricity and biomethane in its electricity mix. The results show that a synergy between these two solutions can significantly reduce the total WTW emissions compared to the current situation, with emission savings in 2030 reaching 55% to 73% against 2022.
Reaching these challenging targets will require an important shift towards alternative powertrains, non only in terms of vehicles, but also considering the required infrastructure to recharge BEVs and to produce and distribute compressed biomethane. The total amount of biomethane required would be 0.22 bcm in the worse case, representing a fraction of the 1.5 bmc expected for transport applications in 2030.
This work focuses on the public transport sector, but it is important to remember that there are also many private companies that operate on extra-urban routes, accounting for a significant number of

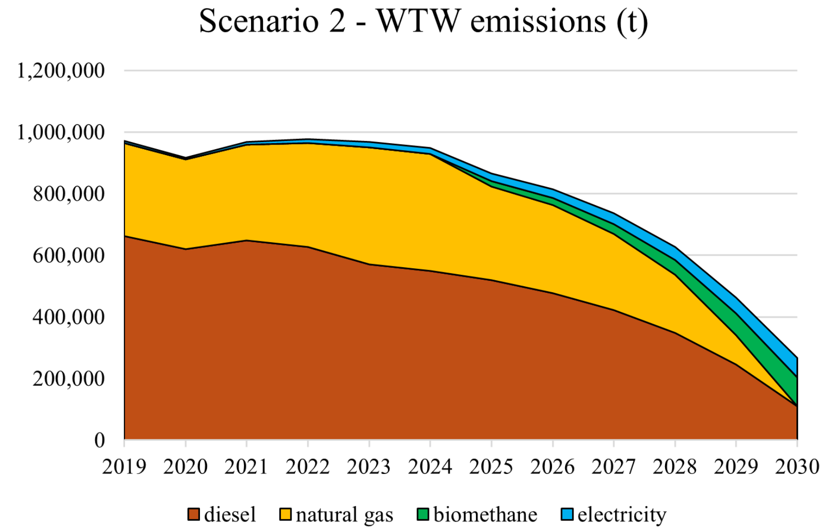

Figure 4: Estimated WTW CO_2 emissions per type of powertrain - Scenario 2, accelerated electrification trend.

buses. However, it is not easy to estimate the actual number of annual trips and vkm, since available data remain limited compared to the public transport sector information.
Moreover, as already explained above, extraurban buses may see a penetration of LNG powertrains, but today this technology remains limited compared to the use of CNG buses in the urban public transport. Thus, a future work will evaluate specifically the potential contribution of LNG powertrains combined with biomethane, that can represent a promising solution to decarbonize long-distance collective transport.

References

[1] M. Crippa et al. "EU effect: Exporting emission standards for vehicles through the global market economy". In: *Journal of Environmental Management* 183 (2016), pp. 959–971. ISSN: 0301-4797. DOI: `10.1016/j.jenvman.2016.09.068`. URL: `https://www.sciencedirect.com/science/article/pii/S0301479716307319`.

[2] Junhong Park et al. "Estimating the effectiveness of vehicle emission regulations for reducing NOx from light-duty vehicles in Korea using on-road measurements". In: *Science of The Total Environment* 767 (2021), p. 144250. ISSN: 0048-9697. DOI: `10.1016/j.scitotenv.2020.144250`. URL: `https://www.sciencedirect.com/science/article/pii/S0048969720377810`.

[3] Christian Thiel et al. "The impact of the EU car CO2 regulation on the energy system and the role of electro-mobility to achieve transport decarbonisation". In: *Energy Policy* 96 (2016), pp. 153–166. ISSN: 0301-4215. DOI: `10.1016/j.enpol.2016.05.043`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421516302737`.

[4] Samuel Rodman Oprešnik et al. "Real-World Fuel Consumption, Fuel Cost and Exhaust Emissions of Different Bus Powertrain Technologies". In: *Energies* 11.8 (2018). ISSN: 1996-1073. DOI: `10.3390/en11082160`. URL: `https://www.mdpi.com/1996-1073/11/8/2160`.

[5] John O. Olawepo and L.-W. Antony Chen. "Health Benefits from Upgrading Public Buses for Cleaner Air: A Case Study of Clark County, Nevada and the United States". In: *International Journal of Environmental Research and Public Health* 16.5 (2019). ISSN: 1660-4601. DOI: `10.3390/ijerph16050720`. URL: `https://www.mdpi.com/1660-4601/16/5/720`.

[6] Jiadong Guo et al. “On-road measurement of regulated pollutants from diesel and CNG buses with urea selective catalytic reduction systems”. In: *Atmospheric Environment* 99 (2014), pp. 1–9. ISSN: 1352-2310. DOI: https://doi.org/10.1016/j.atmosenv.2014.07.032. URL: https://www.sciencedirect.com/science/article/pii/S1352231014005548.

[7] Fredy Rosero et al. “Effects of passenger load, road grade, and congestion level on real-world fuel consumption and emissions from compressed natural gas and diesel urban buses”. In: *Applied Energy* 282 (2021), p. 116195. ISSN: 0306-2619. DOI: https://doi.org/10.1016/j.apenergy.2020.116195. URL: https://www.sciencedirect.com/science/article/pii/S0306261920315956.

[8] M. Prussi et al. “Review of technologies for biomethane production and assessment of Eu transport share in 2030”. In: *Journal of Cleaner Production* 222 (2019), pp. 565–572. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2019.02.271. URL: https://www.sciencedirect.com/science/article/pii/S0959652619306808.

[9] Michel Noussan et al. “The potential role of biomethane for the decarbonization of transport: An analysis of 2030 scenarios in Italy”. In: *Applied Energy* 355 (2024), p. 122322. ISSN: 0306-2619. DOI: 10.1016/j.apenergy.2023.122322. URL: https://www.sciencedirect.com/science/article/pii/S0306261923016860.

[10] Olivier Bordelanne et al. “Biomethane CNG hybrid: A reduction by more than 80% of the greenhouse gases emissions compared to gasoline”. In: *Journal of Natural Gas Science and Engineering* 3.5 (2011). International Gas Research Conference 2011, pp. 617–624. ISSN: 1875-5100. DOI: 10.1016/j.jngse.2011.07.007. URL: https://www.sciencedirect.com/science/article/pii/S1875510011000771.

[11] D. Goulding and N. Power. “Which is the preferable biogas utilisation technology for anaerobic digestion of agricultural crops in Ireland: Biogas to CHP or biomethane as a transport fuel?” In: *Renewable Energy* 53 (2013), pp. 121–131. ISSN: 0960-1481. DOI: 10.1016/j.renene.2012.11.001. URL: https://www.sciencedirect.com/science/article/pii/S096014811200691X.

[12] Anil K. Madhusudhanan et al. “Modelling and evaluation of a biomethane truck for transport performance and cost”. In: *Transportation Research Part D: Transport and Environment* 87 (2020), p. 102530. ISSN: 1361-9209. DOI: 10.1016/j.trd.2020.102530. URL: https://www.sciencedirect.com/science/article/pii/S1361920920307173.

[13] Marcus Gustafsson and Niclas Svensson. “Cleaner heavy transports – Environmental and economic analysis of liquefied natural gas and biomethane”. In: *Journal of Cleaner Production* 278 (2021), p. 123535. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2020.123535. URL: https://www.sciencedirect.com/science/article/pii/S0959652620335800.

[14] Enrique Chan Gutiérrez et al. “An economic and carbon analysis of biomethane production from food waste to be used as a transport fuel in Mexico”. In: *Journal of Cleaner Production* 196 (2018), pp. 852–862. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2018.06.051. URL: https://www.sciencedirect.com/science/article/pii/S0959652618317013.

[15] Willian Cézar Nadaleti et al. “A pioneering study of biomethane and hydrogen production from the wine industry in Brazil: Pollutant emissions, electricity generation and urban bus fleet supply”. In: *International Journal of Hydrogen Energy* 46.36 (2021), pp. 19180–19201. ISSN: 0360-3199. DOI: https://doi.org/10.1016/j.ijhydene.2021.03.044. URL: https://www.sciencedirect.com/science/article/pii/S0360319921008909.

[16] Michel Noussan. “The Use of Biomethane in Internal Combustion Engines for Public Transport Decarbonization: A Case Study”. In: *Energies* 16.24 (2023). ISSN: 1996-1073. DOI: 10.3390/en16247995. URL: https://www.mdpi.com/1996-1073/16/24/7995.

[17] Ministero delle Infrastrutture e dei Trasporti. *Conto Nazionale delle Infrastrutture e dei Trasporti - Anni 2021-2022*. https://www.mit.gov.it/node/18826. Accessed: 2024-05-30. 2023.

[18] Automobile Club d’Italia. *Open Parco Veicoli*. https://opv.aci.it/WEBDMCircolante/. Accessed: 2024-05-30. 2024.

[19] TERNA - Italian TSO. *Statistiche - Impianti di generazione 2022*. Tech. rep. 2023.

[20] TERNA - Italian TSO. *Statistiche - Produzione 2022*. Tech. rep. 2023.

[21] Gestore Servizi Energetici. *Contatore Biometano*. `https://www.gse.it/contatore-biometano`. Accessed: 2024-05-30. 2024.

[22] Gestore Servizi Energetici. *Produzione di Biometano - DM 15/9/2022, Graduatorie*. `https://www.gse.it/servizi-per-te/attuazione-misure-pnrr/produzione-di-biometano/graduatorie`. Accessed: 2024-05-30. 2024.

[23] Andrea Dutto. “Tesi di Laurea Magistrale -Analisi dei dati di consumo ai fini della diagnosi energetica del sito virtuale di GTT”. MA thesis. Politecnico di Torino, 2019.

[24] M Prussi et al. *JEC Well-to-Tank report v5*. Scientific analysis or review, Policy assessment, Technical guidance KJ-NA-30269-EN-N (online). Luxembourg (Luxembourg), 2020. DOI: `10.2760/959137(online)`.

[25] Istituto superiore per la protezione e la ricerca ambientale. *Fattori di emissione per la produzione e consumo di energia elettrica*. `https://emissioni.sina.isprambiente.it/wp-content/uploads/2023/04/Fattori-emissione-produzione-e-consumo-elettricita_2022-Completo-V0.xlsx`. Accessed: 2024-05-30. 2024.

[26] Pedro Muñoz et al. “Comparative analysis of cost, emissions and fuel consumption of diesel, natural gas, electric and hydrogen urban buses”. In: *Energy Conversion and Management* 257 (2022), p. 115412. ISSN: 0196-8904. DOI: `10.1016/j.enconman.2022.115412`. URL: `https://www.sciencedirect.com/science/article/pii/S0196890422002084`.

[27] UK Department of Transport. *Emissions Testing of Gas-Powered Commercial Vehicles*. `https://assets.publishing.service.gov.uk/media/5a803c7f40f0b62305b89fa9/emissions-testing-of-gas-powered-commercial-vehicles.pdf`. Accessed: 2024-06-13. 2017.