Emission projections for waste management cycle: Liguria region case study

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Task force on emission inventories &projections (TFEIP)
Expert Panel on Projections
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Liguria region

a narrow strip of heavily populated land between the sea and the mountains with many highways, three large harbours including the largest Italian port, an airport, two big power stations, a refinery, a steel mill

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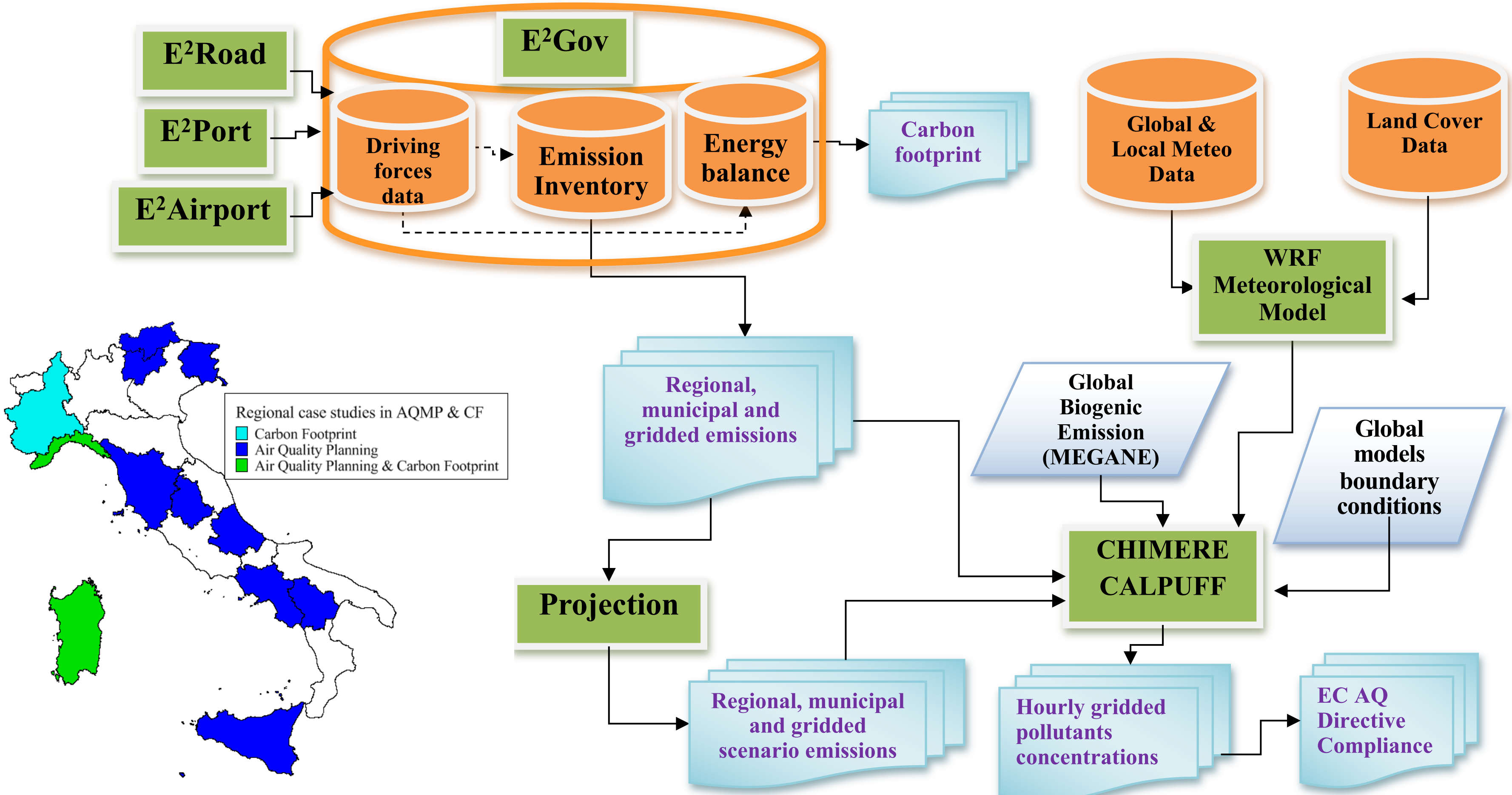
Liguria Region evaluation tools

- air quality monitoring system
- multi-years emission inventory from 1995 at municipal level managed by E²Gov system
- energy balance elaboration and carbon footprint estimate from 2005 at municipal level
- emission projection model implemented with 2011 base year and projections at 5, 10, 15 years
- experiences in air quality models application
- Horizon 2020 ClairCity project partner that has apportioned emissions, concentrations, carbon footprint, health outcomes by citizens' behaviour

E²Plan - Tool for AQP & CF



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Projections planning framework

In April 2022, at the end of the public consultation and evaluation phase, a positive assessment was expressed by the Regional Council regarding the Strategic Environmental Assessment of the 2021-2026 Update of the Regional Plan for waste management and site remediation

The Plan was adopted by Regional Board on December 2021, together with the Environmental Report, including the impact study, comparative emission balance of the solutions to close the waste cycle, monitoring plan and non-technical summary

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Emissions projections in scenarios

- Emissions projection are evaluated for the waste flows forecasted in 2026 in Liguria region
- These flows are estimated to be in a range 160-260 kton/year in input to mechanical-biological treatment plants and 100-161 ktons/year (min/max scenario) leaving the plants
- A study was realized to evaluate the comparison of the greenhouses gases and pollutants emissions, among the different alternative scenarios of final treatment

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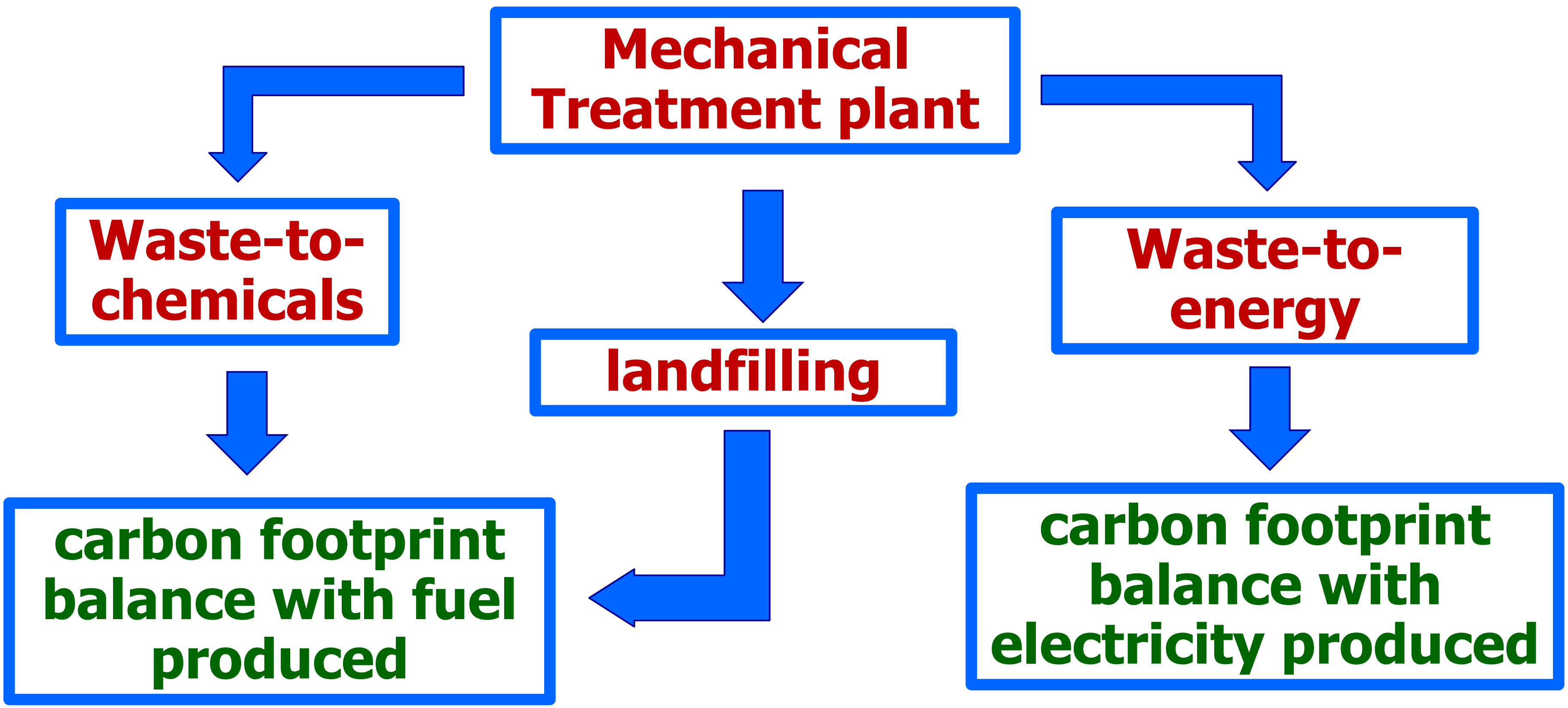
Emissions evaluation 2026 scenarios



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Emissions: mechanical/biological treatment plants

input to mechanical/biological treatment plants 160-260 kton wastes

GHG/pollutant	EF (g/Mg)	Emissions min (Mg)	Emissions max (Mg)
CH_4	2.000	320	520
CO_{2eq}	42.000	6.720	10.920
NH_3	227,1	36	59

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste (https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.htm)

EMEP/EEA air pollutant emission inventory guidebook 2019, 5.B.2 Biological treatment of waste - anaerobic Digestion Biogas (2019) (https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/5-waste/5-b-2-biological-treatment/view)

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Emissions scenarios: landfill disposal

Disposal of municipal, industrial and other solid waste produces significant amounts of methane. In addition landfilling also produces biogenic carbon dioxide and non-methane volatile organic compounds as well as PM and other pollutants.

Methane emissions continue several decades (or even centuries) after waste disposal. Likewise, methane emissions released from a landfill in any given year include emissions from waste disposed that year, as well as from waste disposed in prior years.

There are two commonly acceptable methods for estimating methane emissions from solid waste disposal: first order of decay (IPCC waste model Tier 2) and methane commitment (IPCC Tier 1)°

°2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste
https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.htm

Greenhouse Gas Protocol, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), An Accounting and Reporting Standard for Cities https://ghgprotocol.org/sites/default/files/ghgp/standards/GHGP_GPC_0.pdf

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methane commitment estimate

CH_4 emissions =
$MSW_x \times L_0 \times (1-f_{rec}) \times (1-OX)$

Description			Value
CH_4 emissions	=	Total CH_4 emissions in metric tonnes	Computed
MSW_x	=	Mass of solid waste sent to landfill in inventory year, measured in metric tonnes	User input
L_0	=	Methane generation potential	
f_{rec}	=	Fraction of methane recovered at the landfill (flared or energy recovery)	User input
OX	=	Oxidation factor	0.1 for well-managed landfills; 0 for unmanaged landfills

takes a lifecycle and mass-balance approach and calculates emissions based on the amount of waste disposed in a given year, regardless of when the emissions actually occur (a portion of emissions are released every year after the waste is disposed)

L_0 =
$MCF \times DOC \times DOC_F \times F \times 16/12$

Description			Value
L_0	=	Methane generation potential	Computed
MCF	=	Methane correction factor based on type of landfill site for the year of deposition (managed, unmanaged, etc., fraction)	Managed = 1.0 Unmanaged (≥5 m deep) = 0.8 Unmanaged (<5 m deep) = 0.4 Uncategorized = 0.6
DOC	=	Degradable organic carbon in year of deposition, fraction (tonnes C/tonnes waste)	
DOC_F	=	Fraction of DOC that is ultimately degraded (reflects the fact that some organic carbon does not degrade)	Assumed equal to 0.6
F	=	Fraction of methane in landfill gas	Default range 0.4-0.6 (usually taken to be 0.5)
16/12	=	Stoichiometric ratio between methane and carbon	

DOC =
$(0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) + (0.15 \times F)$

A	=	Fraction of solid waste that is food
B	=	Fraction of solid waste that is garden waste and other plant debris
C	=	Fraction of solid waste that is paper
D	=	Fraction of solid waste that is wood
E	=	Fraction of solid waste that is textiles
F	=	Fraction of solid waste that is industrial waste

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Emissions: landfilling

GHG/pollutant	Emissions min (Mg)	Emissions max (Mg)
CH_4	2.926	1.229
CO_{2eq}	61.447	25.808
NMVOC	27	11
NH_3	21	9

1 t CO_2	1 t CO_{2eq}
1 t CH_4	21 t CO_{2eq}
1 t N_2O	310 t CO_{2eq}

An estimate of the biogas recovered was subtracted from the calculated quantity. **For the assessment of recovery, reference was made to the average percentage of recovery (42%) from landfills assessed at national level. However, it should be emphasized that the quantity of recoverable methane has decreased in recent years due to the variation in the composition of the waste itself, therefore the estimate is conservative and consequently the emissions could be underestimated.**

Finally a sensitivity study was realized for the composition of waste; the variation is very limited: in the order of -4% if we take street collection as a reference and in the order of + 3% if we take door-to-door collection as a reference

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Emissions factors: waste to energy

Tier 1 default emission factors					
	Code	Name			
NFR source category	5.C.1.a	Municipal waste incineration			
Fuel	NA				
Not applicable					
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO_x	1071	g/Mg	749	1532	Nielsen et al. (2010)
CO	41	g/Mg	7	253	Nielsen et al. (2010)
NMVOC	5.9	g/Mg	2.7	12.9	Nielsen et al. (2010)
SO_2	87	g/Mg	16	466	Nielsen et al. (2010)
NH_3	3.0	g/Mg	0.5	18.3	Nielsen et al. (2010)
TSP	3.0	g/Mg	1.1	8.3	Nielsen et al. (2010)
PM_{10}	3.0	g/Mg	1.1	8.3	CEPMEIP
$PM_{2.5}$	3.0	g/Mg	1.1	8.3	CEPMEIP
BC[1]	3.5	% of $PM_{2.5}$	1.8	7	Olmez et al. (1988)
Pb	58.0	mg/Mg	12.0	280.3	Nielsen et al. (2010)
Cd	4.6	mg/Mg	1.1	19.3	Nielsen et al. (2010)
Hg	18.8	mg/Mg	7.3	48.3	Nielsen et al. (2010)
As	6.2	mg/Mg	1.3	29.6	Nielsen et al. (2010)
Cr	16.4	mg/Mg	3.0	88.7	Nielsen et al. (2010)
Cu	13.7	mg/Mg	3.9	47.3	Nielsen et al. (2010)
Ni	21.6	mg/Mg	4.2	111.6	Nielsen et al. (2010)
Se	11.7	mg/Mg	2.2	62.0	Nielsen et al. (2010)
Zn	24.5	mg/Mg	2.7	219.6	Nielsen et al. (2010)
PCBs	3.4	ng/Mg	1.2	9.2	Nielsen et al. (2010)
PCDD/F	52.5	ng/Mg	16.6	166.3	Nielsen et al. (2010)
Benzo(a)pyrene	8.4	µg/Mg	2.8	33.6	Nielsen et al. (2010)
Benzo(b)fluoranthene	17.9	µg/Mg	6.0	71.4	Nielsen et al. (2010)
Benzo(k)fluoranthene	9.5	µg/Mg	3.2	37.8	Nielsen et al. (2010)
Indeno(1,2,3-cd)pyrene	11.6	µg/Mg	3.9	46.2	Nielsen et al. (2010)
HCB	45.2	µg/Mg	8.0	254.1	Nielsen et al. (2010)

Pollutants emission factors from EMEP/EEA GB waste chapter. Efs assume that desulphurization, NOx abatement (SNCR), particle abatement (ESP and/or FB) and activated carbon are in place. It can be assumed that these emission factors are representative for modern waste incineration plants

As far as carbon dioxide is concerned, the emissions are estimated as 50% of the quantity actually emitted taking into account the organic fraction of the waste itself considered as neutral

TABLE 2.3 (CONTINUED)
DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN MANUFACTURING INDUSTRIES AND CONSTRUCTION
(kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel	CO_2			CH_4			N_2O		
	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Municipal Wastes (non-biomass fraction)	n 91 700	73 300	121 000	30	10	100	4	1.5	15

<u>2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy, Chapter 2: Stationary Combustion</u>

<u>EMEP/EEA air pollutant emission inventory guidebook 2019, 5.C.1.a Municipal waste incineration (2019)</u>

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Emissions: waste to energy

GHG/pollutant		E min	E max
CO_{2eq}	Mg	53.608	86.309
CO_2	Mg	52.300	84.203
N_2O	Mg	4	7
CH_4	Mg	0	0
CO	Mg	4,1	6,6
NMVOC	Mg	0,6	0,9
NO_x	Mg	107,1	172,4
PM_{10}	Mg	0,3	0,5
$PM_{2,5}$	Mg	0,3	0,5
TSP	Mg	0,3	0,5
SO_x	Mg	8,7	14,0
NH_3	Mg	0,3	0,5
Black Carbon	kg	10,5	16,9

GHG/pollutant		E min	E max
As	kg	0,6	1,0
Cd	kg	0,5	0,7
Cr	kg	1,6	2,6
Cu	kg	1,4	2,2
Hg	kg	1,9	3,0
Ni	kg	2,2	3,5
Pb	kg	5,8	9,3
Se	kg	1,2	1,9
Zn	kg	2,5	3,9
Benzo(a)pyrene	kg	0,8	1,4
Benzo(b)fluoranthene	kg	1,8	2,9
Benzo(b)fluoranthene	kg	1,0	1,5
Indenopyrene	kg	1,2	1,9
HCB	g	4,5	7,3
PCB	mg	0,3	0,5
PCDD-F	mg	5,3	8,5

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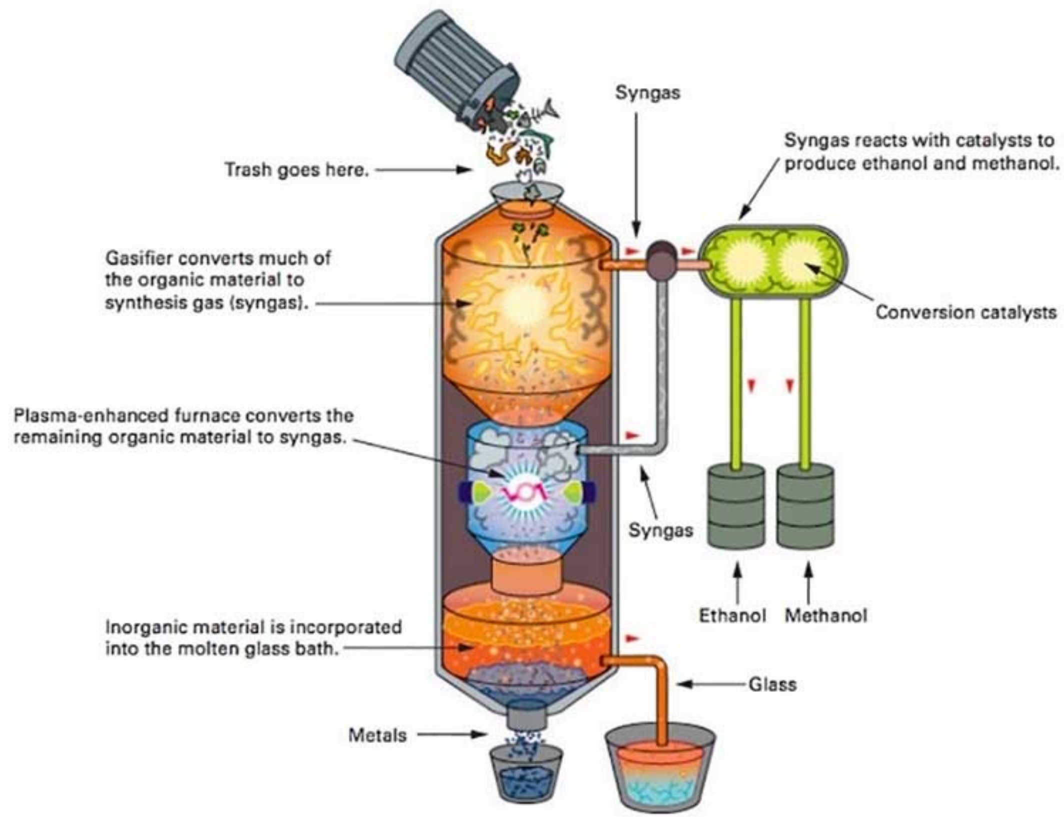
waste to chemical

A Plant was planned for the production of hydrogen and methanol structured in a series of macro-stages: first of all the waste gasification phase, followed by the purification of the generated syngas and, finally, the treatment of the latter in a catalytic reactor, a section in which chemical transformations take place, for the synthesis of ethanol, methanol and then hydrogen.

A preliminary evaluation of the quantity of methanol and hydrogen produced would amount to 88,800 t / year and 1,440 t / year respectively.



From MIT energy initiative (https://energy.mit.edu/news/turning-waste-into-clean-fuels/)

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Emissions: waste to chemical

some preliminary calculations estimate the primary energy consumption for the natural gas turbine connected to the reactor of 154 - 248 GWh in the min/max hypothesis. The following emissions are obtained with GB EFs for gas turbines

GHG/pollutant	Units	Emissions min	Emissions max
CO_{2eq}	Mg	31.320	50.450
NO_x	Mg	26,6	42,8
COVNM	Mg	0,9	1,4
CO	Mg	2,7	4,3
Black Carbon	Kg	2,8	4,5

EMEP/EEA air pollutant emission inventory guidebook 2019, 1.A.1Energy industries (2019)

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Direct emissions balance

GHG pollutant		Emissions min				Emissions max			
		MBT	land-filling	waste to energy	waste to chemical	MBT	land-filling	waste to energy	Waste to chemicals
CO_{2eq}	Mg	6.720	52.705	53.608	31.318	10.920	84.856	86.309	50.452
CO_2	Mg			52.300	31.100			84.203	50.100
N_2O	Mg			4,2	0,6			7	0,9
CH_4	Mg	320	2.510		2,2	520	4.041		3,6
NO_x	Mg			107,1	26,6			172,4	42,8
COVNM	Mg		23	4,1	0,9		37	0,9	1,4
SO_x	Mg			8,7	0,2			14,0	0,3
NH_3	Mg	36	18	0,3	0,0	59	29	0,5	0,0
HMs	kg			17,6	0,1			28,3	0,2
PAHs	kg			4,7	0,0			7,6	0,0
BC	kg			10,5	2,8			16,9	4,5
HCB	g			4,5	0,0			7,3	0,0
PCB	mg			0,3	0,0			0,5	0,0
PCDD-F	mg			5,3	0,0			8,5	0,0

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Carbon footprint projections

Considering the general goals of the project we evaluated avoided emissions from electricity and fuels produced by selected technologies in term of:

- **Fuel (methanole-hydrogen) produced from waste-to chemical process**
- **Electricity produced by incineration with energy recover**
- **Biogas recovered from landfilling**

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Carbon footprint waste-to-chemical

Assuming the substitution of methanol produced with this process with methanol produced from fossil sources, it is possible to evaluate the reduction of CO_2 emissions for the production of methanol, using an IPCC* emission factor of 0.67 Mg per Mg of methanol produced from natural gas

CO_2	Units	Emissions min	Emissions max
Emissions from electricity generation	Mg	31.100	50.100
Savings for substitution of methanol by natural gas	Mg	-29.700	-47.900
Final emissions	Mg	1.400	2.200

*2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3. Industrial Processes and Product Use.
Conventional Steam Reforming, without primary reformer (Default Process and Natural Gas Default Feedstock)

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Carbon footprint waste-to-energy

Assuming a national average producibility * of electricity from waste (760 kWh/Mg) and a national emission factor # for CO_2 emissions from electricity consumed (258,3 g CO_2/kWh) we obtain a reduction of emission of 19.631-31.606 Mg

°ISPRA, Rapporto rifiuti urbani, 2021

*ISPRA, Indicatori di efficienza e decarbonizzazione del sistema energetico nazionale e del settore elettrico, 2021

Carbon footprint landfill

The recovered biogas produce, in substitution of natural gas a reduction of 170-230 Mg of CO_2

2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy, Chapter 2: Stationary Combustion

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Final carbon footprint emissions balance

GHG pollutant		Emissions min				Emissions max			
		MBT	land-filling	waste to energy	waste to chemical	MBT	land-filling	waste to energy	Waste to chemicals
CO_{2eq}	Mg	6.720	52.536	33.971	1.618	10.920	84.582	54.694	2.552
CO_2	Mg			32.669	1.400			52.597	2.200
N_2O	Mg			4,2	0,6			7	0,9
CH_4	Mg	320	2.510		2,2	520	4.041		3,6

From a summary comparison of the emissions in the different plant solutions considered, the waste to chemicals solution appears significantly to have the least impact both in terms of Carbon footprint and air pollutants.

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The project team

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