

NET ZERO CITIES



EU MISSION PLATFORM

CLIMATE NEUTRAL AND SMART CITIES



NetZeroCities has received funding from the H2020 Research and Innovation Programme under grant agreement n°101036519.



Economic Model Methodology



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Agenda

- **Passenger transport levers**
- Freight transport levers
- Buildings & heating levers
- Electricity levers
- Waste levers
- Appendix: Lever sensitivities
- Appendix: Model Updates & Improvements



Methodology, data, & key assumptions - Madrid example



1.1 Reduced motorised passenger transportation need

Scenarios methodology

Baseline

- Transportation need assumed to increase at same rate as expected population increase (+0.4% per year)
- Passenger cars: ICE improvements (incl. hybrids) for new vehicles according to EU fleet-wide targets¹ (2021: 95 g CO₂/km, 2030: 59 g CO₂/km) resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification
- Buses: Assuming increased efficiency of ICE buses as bus fleet is replaced by Euro VI buses (100% by 2030)

Decarbonisation scenario

- Transportation need (passenger kilometres) for passenger cars and public transport reduced linearly by 5%² by 2030, compared to baseline
- Reduced emissions and other externalities (noise, air pollution, accidents) due to decrease in passenger cars and public transport
- CO₂ abatement potential calculated as difference between Decarbonisation scenario and Baseline scenario

Economic case

Upfront investments

- Upfront investment costs assumed to be near-zero, as this lever is assumed to be driven mainly by digitalisation and primarily involves behavioural change



Methodology, data, & key assumptions - Madrid example



1.1 Reduced motorised passenger transportation need

Net recurring costs/savings

- Cost savings from reduced public transport (bus: 3.3 €/vkm, metro/tram: 2.9 €/vkm)³
- Fuel savings for cars calculated based on national average petrol prices between 2016-2019⁴ (1.2 €/litre)
- Cost savings from reduced car usage (excl. fuel) of 0.06 €/vkm⁵

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM10 (22,300 €/tonne)⁶.
- Value of accidents reduction (cars: 0.014 €/pkm, buses: 0.008 €/pkm)⁶
- Value of noise reduction (cars: 0.006 €/pkm, buses: 0.004 €/pkm, trains: 0.008 €/pkm)⁶

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. 7% by 2050 (IEA ETP 2-degree scenario), assuming 5% can be reached by 2030 in an ambitious scenario. Sudmant et. al. (2016) Low carbon cities: is ambitious action affordable?
3. Swedish Association of Local Authorities and Regions (2017). Kollektivtrafikens kostnadsutveckling – en överblick
4. Bloomberg (2019) – *Gasoline Prices Around the World. Interactive tool available at <https://www.bloomberg.com/graphics/gas-prices/>*
5. Victoria Transport Policy Institute (2017). *Transportation Cost and Benefit Analysis II – Vehicle Costs*
6. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



1.2 Shift to public & non-motorised transport

Scenarios methodology

Baseline scenario

- Transportation need assumed to increase at same rate as expected population increase (+0.4% per year by 2030, compared to 2018)
- Passenger cars: ICE improvements (incl. hybrids) for new vehicles according to EU fleet-wide targets¹ (2021: 95 g CO₂/km, 2030: 59 g CO₂/km) resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification
- Buses: Assuming increased efficiency of ICE buses as bus fleet is replaced by Euro VI buses (100% by 2030)

Decarbonisation scenario

- Number of passenger kilometres driven by cars down by 10% by 2030 (from ~55% of total today to ~50% of total by 2030), out of which 60% goes to Public transport and 40% to walking/cycling
- Reduced emissions due to decrease in passenger cars, increased emissions from public transport
- CO₂ abatement potential calculated as difference between Decarbonisation scenario and Baseline scenario
- Modelling up-front investments and related co-benefits for the period 2020-2030. Co-benefits are not modelled further than 2030 (as in other levers), as if the investments ('running costs') were to stop a specific year, so would the co-benefits.



Methodology, data, & key assumptions - Madrid example



1.2 Shift to public & non-motorised transport

Economic case

Upfront investments & recurring costs/savings

- OPEX + CAPEX of 3.3 €/vkm for bus and 2.0 €/vkm for metro/tram². These costs are assumed to be ~60% CAPEX and ~40% OPEX³.
- Upfront investments for walking/cycling of 0.02 €/pkm (including infrastructure and 'vehicle' costs)^{4,5}
- Fuel savings for cars calculated based on national average petrol prices between 2016-2019⁶ (1.2 €/litre)
- Cost savings from reduced car usage (excl. fuel) of 0.06 €/vkm⁵

Co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM⁷
- Value of accidents reduction (cars: 0.014 €/pkm, buses: 0.008 €/pkm)⁷
- Value of noise reduction (cars: 0.006 €/pkm, buses: 0.004 €/pkm, trains: 0.008 €/pkm)⁷
- Health co-benefits from walking/cycling of 0.3 €/pkm⁸

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. Swedish Association of Local Authorities and Regions (2017). *Kollektivtrafikens kostnadsutveckling – en överblick*
3. Yaping & Xingchen (2016). *Life Cycle Cost Analysis of Urban Rail Transit Vehicle*
4. Gössling et.al. (2018). *The social cost of automobility, cycling and walking in the European Union.*
5. Victoria Transport Policy Institute (2017). *Transportation Cost and Benefit Analysis II – Vehicle Costs*
6. Bloomberg (2019) – *Gasoline Prices Around the World. Interactive tool available at <https://www.bloomberg.com/graphics/gas-prices/>*
7. Essen et. al. (2019). *Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport*
8. Victoria Transport Policy Institute (2019). *Evaluating Active Transport Benefits and Costs.*



Methodology, data, & key assumptions - Madrid example



1.3 Increased car pooling

Scenarios methodology

Baseline scenario

- Transportation need assumed to increase at same rate as expected population increase (+0.4% per year by 2030, compared to 2018)
- Passenger cars: ICE improvements (incl. hybrids) for new vehicles according to EU fleet-wide targets¹ (2021: 95 g CO₂/km, 2030: 59 g CO₂/km) resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification.
- Buses: Assuming increased efficiency of ICE buses as bus fleet is replaced by Euro VI buses (100% by 2030)

Decarbonisation scenario

- Transport efficiency for passenger cars (passengers per vehicle) increased by 11%², from 1.57 to 1.74, reducing the total vehicle kilometres travelled by car
- CO₂ abatement potential calculated as difference between Decarbonisation scenario and Baseline scenario
- Modelling up-front investments 2020-2030 and related co-benefits 2020-2045, based on an assumed lifetime of cars of 15 years.



Methodology, data, & key assumptions - Madrid example



1.3 Increased car pooling

Economic case

Upfront investments

- Assumed to be near zero, as increased car pooling makes use of existing infrastructure and assets

Recurring costs/savings

- Fuel savings for cars calculated based on national average petrol prices between 2016-2019³ (1.2 €/litre)
- Cost savings from reduced car usage (excl. fuel) of 0.06 €/vkm⁴

Co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM⁵
- Value of accidents reduction (cars: 0.014 €/pkm)⁵
- Value of noise reduction (cars: 0.006 €/pkm)⁵

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. Laine et. al. (2018)¹, studying the potential of car pooling and Mobility as a Service for Nordic countries.
3. Bloomberg (2019) – *Gasoline Prices Around the World. Interactive tool available at <https://www.bloomberg.com/graphics/gas-prices/>*
4. Victoria Transport Policy Institute (2017). *Transportation Cost and Benefit Analysis II – Vehicle Costs*
5. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



1.4.1 Electrification of passenger cars

Scenarios methodology

Baseline

- Transportation need assumed to increase at same rate as expected population increase (+0.4% per year by 2030, compared to 2018)
- Passenger cars: ICE improvements (incl. hybrids) for new vehicles according to EU fleet-wide targets¹ (2021: 95 g CO₂/km, 2030: 59 g CO₂/km) resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification.
- Buses: Assuming increased efficiency of ICE buses as bus fleet is replaced by Euro VI buses (100% by 2030)

Decarbonisation scenario

- CO₂ emissions (100%) and air pollutants (100% NO_x and combustion-related PM) are reduced as EVs are introduced into vehicle stock
- The adaptation of EVs in the city is assumed to follow an aggressive S-curve, starting at near 0% EVs and reaching ~48% of vehicle stock by 2040 (30% by 2030)
- CO₂ abatement potential calculated as difference between Decarbonisation scenario and Baseline scenario.
- Modelling up-front investments 2020-2030 and related co-benefits 2020-2045, based on an assumed lifetime of cars of 15 years.



Methodology, data, & key assumptions - Madrid example



1.4.1 Electrification of passenger cars

Economic case

Upfront investments

- Infrastructure and investment costs based on research from The International Council on Clean Transportation^{2,3}.
 - Cost of charging infrastructure: €850/EV (2020) & €600/EV (2030)
 - Increased investment costs for EVs of 8600€/car (2020), reaching cost parity by 2025
- Infrastructure costs include both home-charging and public/workplace charging, and are assumed to be linear to numbers of EVs introduced. Cost per electric vehicle is reduced over time due to technology improvements and increased utilisation.
- Electricity transmission infrastructure costs are partly included in the cost of increased electricity need.

Net recurring costs/savings

- Fuel savings calculated based on national average petrol prices between 2016-2019⁴ (€1.2/l)
- Increased cost of electricity based on household electricity prices⁵

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NO_x (12,600 €/tonne inside city, 21,300 outside city), PM_{2.5} (252,000 €/tonne inside city, 70,000 outside city) and PM⁶

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. The International Council on Clean Transportation (2019). *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*
3. The International Council on Clean Transportation (2019). *Update on electric vehicle costs in the United States through 2030*
4. Bloomberg (2019) – *Gasoline Prices Around the World*. Interactive tool available at <https://www.bloomber.com/graphics/gas-prices/>
5. Eurostat (2019) - *Electricity prices for household consumers*
6. Essen et. al. (2019). *Handbook on the external costs of transport*. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



1.4.2 Electrification of buses

Scenarios methodology

Baseline

- Transportation need assumed to increase at same rate as expected population increase (+0.4% per year by 2030, compared to 2018)
- Passenger cars: ICE improvements (incl. hybrids) for new vehicles according to EU fleet-wide targets¹ (2021: 95 g CO₂/km, 2030: 59 g CO₂/km) resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification.
- Buses: Assuming increased efficiency of ICE buses as bus fleet is replaced by Euro VI buses (the rate of which the buses are replaced depends on the city's procurement schedule)

Decarbonisation scenario

- CO₂ emissions (100%) and air pollutants (100% NO_x and combustion-related PM) are reduced as electric buses are introduced into bus stock
- All new buses from 2020 and onwards are electric buses. 3% of the total bus stock is replaced during 2020, an additional 10% by 2023, 20% by 2027, and a final 15% by 2030, reaching a total of 48% replacement. (*Madrid 360 strategy*)
- CO₂ abatement potential calculated as difference between Decarbonisation scenario and Baseline scenario



Methodology, data, & key assumptions - Madrid example



1.4.2 Electrification of buses

Economic case

Upfront investments

- Assuming that infrastructure costs and investments are the same as for heavy trucks, since motor characteristics are similar between the two.
 - Charging infrastructure costs: €17,000/bus (2020) to €13,000/bus (2030), based on ECF (2018)²
 - Additional investment cost for electrified buses of €81,600/bus (2020) to €30,600/bus (2030), based on ECF (2018)²
- Electricity transmission infrastructure costs are partly included in the cost of increased electricity need.

Net recurring costs/savings

- Fuel savings calculated based on national average petrol prices between 2016-2019⁴ (€1.2/l)
- Increased cost of electricity based on household electricity prices⁵

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM⁶
- Value of noise reduction (0,004 €/person-kilometre)⁶

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. European Climate Foundation (2018) - *Trucking into a Greener Future: the economic impact of decarbonizing goods vehicles in Europe.*
3. The International Council on Clean Transportation (2019). *Update on electric vehicle costs in the United States through 2030*
4. Bloomberg (2019) – *Gasoline Prices Around the World. Interactive tool available at <https://www.bloomberg.com/graphics/gas-prices/>*
5. Eurostat (2019) - *Electricity prices for household consumers*
6. Essen et. al. (2019). *Handbook on the external costs of transport.* For European Commission Directorate-General for Mobility and Transport





Agenda

- Passenger transport levers
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- Appendix: Lever sensitivities
- Appendix: Model Updates & Improvements



Methodology, data, & key assumptions - Madrid example



2.1 Optimised logistics

Scenarios methodology

Baseline

- Transportation need assumed to increase at same rate as expected population increase (+0.4% per year until 2030)
- ICE improvements for new vehicles
 - Light duty trucks (<3.5 tonnes) according to EU fleet-wide targets¹ (2025: -15% g CO₂/km & 2030: -31% g CO₂/km, compared to 2021)
 - Heavy duty trucks (>3.5 tonnes, assumed to be 12 tonne-trucks when modelling) according to EU fleet-wide targets² (2025: -15% g CO₂/km & 2030: -30% g CO₂/km, compared to 2021)
 - Resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification.

Decarbonisation scenario

- CO₂ emissions and air pollutants (NO_x and combustion-related PM) are reduced as vehicle kilometres in freight transportation decrease.
- Increased load utilisation, from 23% to 45% (average for urban distribution³) for light trucks and from 45% to 60% for heavy trucks (near utilization rate for long-haul heavy trucks³)
- Assuming route optimisation could decrease the vehicle-kilometers needed by 10%⁴
- Modelling up-front investments 2020-2030 and related co-benefits 2020-2040, based on an assumed lifetime of trucks of 10 years.



Methodology, data, & key assumptions - Madrid example



2.1 Optimised logistics

Economic case

Upfront investments

- Assuming near zero upfront investments, however such an initiative requires a lot of coordination, but no big infrastructure investments⁴.

Net recurring costs/savings

- All recurring costs/savings are calculated as difference compared to baseline
- Cost savings based on decreased vehicle kilometres and total cost of ownership (0,43 €/km⁵ for light duty trucks, and 0,67 €/km⁶ for heavy trucks).
- Assuming no decrease in labour, as the initiative and logistics (other than chauffeurs) increase significantly
- Increased fuel consumption per vehicle-kilometre, since increased load factor means heavier trucks.

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM⁷
- Value of accident reduction: light trucks: 0.046 €/tonne km, heavy trucks: 0.010 €/tonne km⁷
- Value of noise reduction (light trucks: 0.016 €/tonne km, heavy trucks: 0.008 €/tonne km)⁷

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. European commission (2019) - *Reducing CO₂ emissions from heavy duty vehicles*
3. ACEA (2010) – *Commercial vehicles and CO₂*
4. Based on discussion with Södertörn upphandling – a project on route optimisation and utilisation of logistics in southern Stockholm region
5. Macharis et. Al. (2013) - *Electric versus conventional vehicles for logistics: A total cost of ownership*
6. Ernst & Young (2015) - *Own or lease? Are you making the right choice for your truck fleet?*
7. Essen et. al. (2019). *Handbook on the external costs of transport*. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



2.2 Electrification of trucks

Scenarios methodology

Baseline

- Transportation need assumed to increase at same rate as expected population increase (0.4% per year until 2030)
- ICE improvements for new vehicles
 - Light duty trucks (<3.5 tonnes) according to EU fleet-wide targets¹ (2025: -15% g CO₂/km & 2030: -31% g CO₂/km, compared to 2021)
 - Heavy duty trucks (>3.5 tonnes, assumed to be 12 tonne-trucks when modelling) according to EU fleet-wide targets² (2025: -15% g CO₂/km & 2030: -30% g CO₂/km, compared to 2021)
 - Resulting in a reduction in fleet-wide emissions and fuel consumption from ICEs as new ICEs are introduced into the vehicle stock (at national average rate). All new ICEs are assumed to be of Euro VI classification.

Decarbonisation scenario

- CO₂ emissions (100%) and air pollutants (100% NO_x and combustion-related PM) are reduced as electrified trucks are introduced into vehicle stock
- ~56% of light duty truck (<3.5 tonne) and ~25% of heavy duty truck (>3.5 tonne) vehicle kilometres electrified by 2030, based on assumption that they reach 90% and 40% respectively of total fleet by 2040 and that the adaptation to EVs follows an S-curve.
- Modelling up-front investments 2020-2030 and related co-benefits 2020-2040, based on an assumed lifetime of trucks of 10 years.



Methodology, data, & key assumptions - Madrid example



2.2 Electrification of trucks

Economic case

Upfront investments

- Light duty trucks
 - Charging infrastructure costs: assuming 150% of cost for passenger cars - €1,300/truck (2020) to ~€800/ truck (2030)³
 - Additional investment cost for electrified truck of ~€16,000/truck⁴, assuming cost parity reached by 2030, 5 years later than passenger cars⁵
- Heavy duty trucks
 - Charging infrastructure costs: €17,000/heavy truck (2020) to €13,000/heavy truck (2030)⁶
 - Additional investment cost for electrified truck of €82,000/truck (2020) to €29,000/truck (2030)⁶
- Electricity transmission infrastructure costs are partly included in the cost of increased electricity need.

Net recurring costs/savings

- Increased cost of electricity based on household electricity prices⁷, assuming a 20% reduction for commercial actors.

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM⁸
- Value of noise reduction (light trucks: 0.016 €/tonne km, heavy trucks: 0.008 €/tonnekm⁸)

Sources

1. European commission (2019) - *Post-2020 CO₂ emission performance standards for cars and vans*
2. European commission (2019) - *Reducing CO₂ emissions from heavy duty vehicles*
3. The International Council on Clean Transportation (2019). *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*
4. Lebeau et. al (2015). *Electrifying light commercial vehicles for city logistics? A total cost of ownership analysis* Bloomberg (2019) – *Gasoline Prices Around the World. Interactive tool available at <https://www.bloomberg.com/graphics/gas-prices/>*
5. The International Council on Clean Transportation (2019). *Update on electric vehicle costs in the United States through 2030*
6. European Climate Foundation (2018) - *Trucking into a Greener Future: the economic impact of decarbonizing goods vehicles in Europe.*
7. Eurostat (2019) - *Electricity prices for household consumers*
8. Essen et. al. (2019). *Handbook on the external costs of transport.* For European Commission Directorate-General for Mobility and Transport





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Methodology, data, & key assumptions - Madrid example



3.1 Building renovations

Scenarios methodology

Baseline

- The total building stock is assumed to increase at the same rate as the population growth (0.4% per year)
- Renovations: Renovation rate continues its current trend of 1% of building stock being renovated every year
 - 85% of renovations are “Minor heating renovations” (15% reduction in heat use, implementation of 1 or 2 measures. E.g. a new boiler)¹.
 - 15% of renovations are “Extensive heating renovations” (45% reduction in heat use, extensive renovations of e.g. building envelope, including windows, wall insulation, etc.)¹.
- New buildings: Assuming new buildings are built according to Spanish building standards.
- Modelling covers space heating and domestic water heating
- Looks at renovations on the existing stock in 2020, new stock built during 2020-2030 is not included in the renovation rate
- Demolitions: 0.2% of buildings are demolished every year and rebuilt²
- New buildings: Assuming new buildings are built according to minimum building standard
- Emissions of heat and DHW based on weighted average of heating emission factors by heat source

Decarbonisation scenario

- CO₂ emissions (100%) and air pollutants (100% NO_x and combustion-related PM) are reduced as the building stock’s energy consumption reduces
- Increased renovation rate from 1% to 2.5% of building stock each year, in accordance with BPIE’s ambition to renovate all buildings within 40 years.²
- The “depth” of the average renovation is also increased – “extensive renovations” (45% improvements¹) are increased from 15% to 25% of total, with the rest being “minor renovations (15% improvements¹).



Methodology, data, & key assumptions - Madrid example



3.1 Building renovations

Economic case

Upfront investments

- Dependent on how "deep" the renovations are.
 - in 2018 the minor heating renovations cost 57 €/m² and the extensive heating renovations cost 125 €/m²¹
 - The costs of minor renovations are assumed to be constant until 2030 and extensive renovations are assumed to decrease by 1% per year³

Net recurring costs/savings

- Assuming no recurring costs.
- Cost savings from reduced energy consumption (based on cost of heating of 76 EUR/MWh⁴)

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NO_x (12,600 €/tonne inside city, 21,300 outside city), PM_{2.5} (252,000 €/tonne inside city, 70,000 outside city) and PM⁵

Sources

1. European Parliament's Policy Department (2016) – *Boosting Building Renovations: What Potential Value for Europe?*
2. BPIE (2010) – *Europe's Buildings Under the Microscope*
3. Half the rate stated by BPIE (2011) "Europe's buildings under the microscope", based on conversations with Trianon (Swedish construction & property company) and AMAT (Milano)
4. Based on IRENA, "Renewable energy in district heating and cooling - A sector roadmap for remap" (2017)
5. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



3.2 New energy efficient buildings

Scenarios methodology

Baseline

- The total building stock is assumed to increase at the same rate as the population growth (0.4% per year)
- Renovations: Renovation rate continues its current trend of 1% of building stock being renovated every year
 - 85% of renovations are “Minor heating renovations” (15% reduction in heat use, implementation of 1 or 2 measures. E.g. a new boiler)¹.
 - 15% of renovations are “Extensive heating renovations” (45% reduction in heat use, extensive renovations of e.g. building envelope, including windows, wall insulation, etc.)¹.
- Modelling covers space heating and domestic water heating
- Looks at renovations on the existing stock in 2020, new stock built during 2020-2030 is not included in the renovation rate
- Demolitions: 0.2% of buildings are demolished every year and rebuilt²
- New buildings: Assuming new buildings are built according to minimum Spanish building standard
- Emissions of heat and DHW based on weighted average of heating emission factors by heat source

Decarbonisation scenario

- Increased energy performance in 20% of new buildings, to 50% of the energy consumption compared to today’s minimum building standard (19 kWh/m²)
- Assume no rebound effect from improved energy efficiency improvements
- CO₂ emissions (100%) and air pollutants (100% NO_x and combustion-related PM) are reduced as the building stock’s energy consumption reduces.



Methodology, data, & key assumptions - Madrid example



3.2 New energy efficient buildings

Economic case

Upfront investments

- The differences in costs between minimum building standard (1074 €/m² in 2018) and the better performing buildings (1222 €/m² in 2018) in the decarbonisation scenario are estimated as the cost for "new built to nZEB standard" today, increased again by the average percentage cost increase for following the "nZEB" standard.³
 - These costs are both projected to decrease by 1% per year until 2030².

Net recurring costs/savings

- Assuming no recurring costs.
- Cost savings from reduced energy consumption (based on cost of heating of 76 EUR/MWh⁴)

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NO_x (12,600 €/tonne inside city, 21,300 outside city), PM_{2.5} (252,000 €/tonne inside city, 70,000 outside city) and PM⁵

Sources

1. European Parliament's Policy Department (2016) – *Boosting Building Renovations: What Potential Value for Europe?*
2. BPIE (2010) – *Europe's Buildings Under the Microscope*
3. ZEBRA2020 (2016) – *Deliverable 5.1: nZEB technology solutions, cost assessment and performance*
4. Based on IRENA, "Renewable energy in district heating and cooling - A sector roadmap for remap" (2017)
5. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



3.3 Efficient lighting & appliances

Scenarios methodology

Baseline

- The total building stock is assumed to increase at the same rate as the population growth (0.4% per year)
- Renovations: Renovation rate continues its current trend of 1% of building stock being renovated every year
 - 85% of renovations are “Minor heating renovations” (15% reduction in heat use, implementation of 1 or 2 measures. E.g. a new boiler)¹.
 - 15% of renovations are “Extensive heating renovations” (45% reduction in heat use, extensive renovations of e.g. building envelope, including windows, wall insulation, etc.)¹.
- New buildings: Assuming new buildings are built according to minimum Spanish standards.
- Lighting & appliances: Minor efficiency improvements (13%^{2,3}) for all new and renovated buildings, corresponding to efficient lighting and 1 highly efficient appliance
- Modelling covers space heating and domestic water heating
- Looks at renovations on the existing stock in 2020, new stock built during 2020-2030 is not included in the renovation rate
- Demolitions: 0.2% of buildings are demolished every year and rebuilt⁴
- New buildings: Assuming new buildings are built according to minimum building standard
- Emissions of heat and DHW based on weighted average of heating emission factors by heat source

Decarbonisation scenario

- Aggressive efficiency improvements for lighting and appliances (38%^{2,3}) in new and renovated buildings, corresponding to efficient lighting and 4 highly efficient appliances
- Assume no rebound effect from improved energy efficiency improvements
- CO₂ emissions (100%) and air pollutants (100% NO_x and combustion-related PM) are reduced as the building stock’s energy consumption reduces.



Methodology, data, & key assumptions - Madrid example



3.3 Efficient lighting & appliances

Economic case

Upfront investments

- Cost of lighting upgrade: 0.6 EUR/m², cost of appliance upgrade: 5.9 EUR/m² & appliance⁵.
- These costs are assumed to decrease at same rate as minor heating renovations (1% per year) until 2030⁴.

Net recurring costs/savings

- Cost savings from reduced electricity consumption (based on cost of electricity of 0.17 EUR/kWh⁶)

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NO_x (12,600 €/tonne inside city, 21,300 outside city), PM_{2.5} (252,000 €/tonne inside city, 70,000 outside city) and PM⁷

Sources

1. European Parliament's Policy Department (2016) – *Boosting Building Renovations: What Potential Value for Europe?*
2. Cantzler et. al.(2018). A policy spotlight on energy efficiency in appliances & lights could see big climate gains
3. Odysee-Mure (2019). Energy consumption of appliances and lighting per dwelling.
4. BPIE (2010) – *Europe's Buildings Under the Microscope*
5. Dinh et. al. (2013). *Energy Efficiency Potential of the European Building Stock*.
6. Eurostat (2019) - *Electricity prices for household consumers*
7. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport



Methodology, data, & key assumptions - Madrid example



3.4 Decarbonising heating

Scenarios methodology

Baseline

- Total heat demand until 2030 assumed to increase at same rate as expected population increase (0.4% per year until 2030)
- Modelling covers space heating and domestic water heating
- Assuming same ratio of fossil and renewable heating sources as today, i.e. same heat energy mix by 2030 as in 2018 (currently: Local heating, fired with 92% fossil fuels, 7% electricity (heat pumps) & 1% biobased¹)

Decarbonisation scenario

- District heating expanded to cover 10% of total heating demand, based only on newly built areas (no conversion of existing local heating)
- Fuels in 2030 local heating: Fossil 40% (92% today), electric 50% (7% today) & bio 10% (1% today)¹
- Fuels in 2030 district heating: Fossil 10% (60% today), Electric 20% (20% today), biobased 40% (20% today) and waste incineration 30% (0% today)
- Reduced CO₂ emissions from shift from fossil fuels, and improved air quality with shift towards electricity-based production (net improvements)



Methodology, data, & key assumptions - Madrid example



3.4 Decarbonising heating

Economic case

Upfront investments

- District heating: Fossil – 446 EUR/MWh, Biomass 370 EUR/MWh, Electric heat pumps / geothermal – 347 EUR/MWh, Waste – 460 EUR/MWh², network/infrastructure – 1,431 EUR/MWh.²
- Local heating: Fossil – 238 EUR/MWh, Biomass – 219 EUR/MWh, Electric heat pumps / geothermal – 320 EUR/MWh. Based on average levelized cost of heat production in Europe³, assuming lifetime of 20⁴ years (50 for network⁵) and 4% WACC

Net recurring costs/savings (OPEX)

- District heating: Fossil – 66 EUR/MWh, Biomass – 82 EUR/MWh, Electric heat pumps / geothermal – 41 EUR/MWh, Waste – (-17) EUR/MWh (savings)²
- Local heating: Fossil – 74 EUR/MWh, Biomass/waste – 47 EUR/MWh, Electric heat pumps / geothermal – 61 EUR/MWh²

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NO_x (12,600 €/tonne inside city, 21,300 outside city), PM_{2.5} (252,000 €/tonne inside city, 70,000 outside city) and PM⁵.

Sources

1. Based on Data Request and interview with Carlos Gonzales
2. IRENA, "Renewable energy in district heating and cooling - A sector roadmap for remap" (2017).
3. Popovski, E., et al., "Technical and economic feasibility of sustainable heating and cooling supply options in southern European municipalities-A case study for Matosinhos, Portugal" (2018).
4. Euroheat (2012) - Energy Distribution: District Heating and Cooling - DHC.
5. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport





Agenda

- Passenger transport levers
- Freight transport levers
- Buildings & heating levers
- **Electricity levers**
- Waste levers
- Appendix: Lever sensitivities
- Appendix: Model Updates & Improvements



Methodology, data, & key assumptions - Madrid example



4.1 Decarbonising electricity

Scenarios methodology

Baseline

- Total electricity demand until 2030 assumed to increase at same rate as expected population increase (0.4%/year)
- Assuming same ratio of fossil and renewable sources by 2030 as in 2018 (i.e. constant emission factors)

Decarbonisation scenario

- 74% of current fossil production replaced by renewables by 2030
- Renewable energy supplied by 10% local solar PV and 90% centralised solar PV/wind¹



Methodology, data, & key assumptions - Madrid example



4.1 Decarbonising electricity

Economic case

Upfront investments

- District heating: Fossil – 446 EUR/MWh, Biomass 370 EUR/MWh, Electric heat pumps / geothermal – 347 EUR/MWh, Waste – 460 EUR/MWh², network/infrastructure – 1,431 EUR/MWh.²
- Local heating: Fossil – 238 EUR/MWh, Biomass – 219 EUR/MWh, Electric heat pumps / geothermal – 320 EUR/MWh. Based on average levelized cost of heat production in Europe³, assuming lifetime of 20⁴ years (50 for network⁵) and 4% WACC

Net recurring costs/savings (OPEX)

- District heating: Fossil – 66 EUR/MWh, Biomass – 82 EUR/MWh, Electric heat pumps / geothermal – 41 EUR/MWh, Waste – (-17) EUR/MWh (savings)²
- Local heating: Fossil – 74 EUR/MWh, Biomass/waste – 47 EUR/MWh, Electric heat pumps / geothermal – 61 EUR/MWh²

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NO_x (12,600 €/tonne inside city, 21,300 outside city), PM_{2.5} (252,000 €/tonne inside city, 70,000 outside city) and PM₅.

Sources

1. Based on Data Request and interview with Carlos Gonzales
2. IRENA, "Renewable energy in district heating and cooling - A sector roadmap for remap" (2017).
3. Popovski, E., et al., "Technical and economic feasibility of sustainable heating and cooling supply options in southern European municipalities-A case study for Matosinhos, Portugal" (2018).
4. Euroheat (2012) - Energy Distribution: District Heating and Cooling - DHC.
5. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport





Agenda

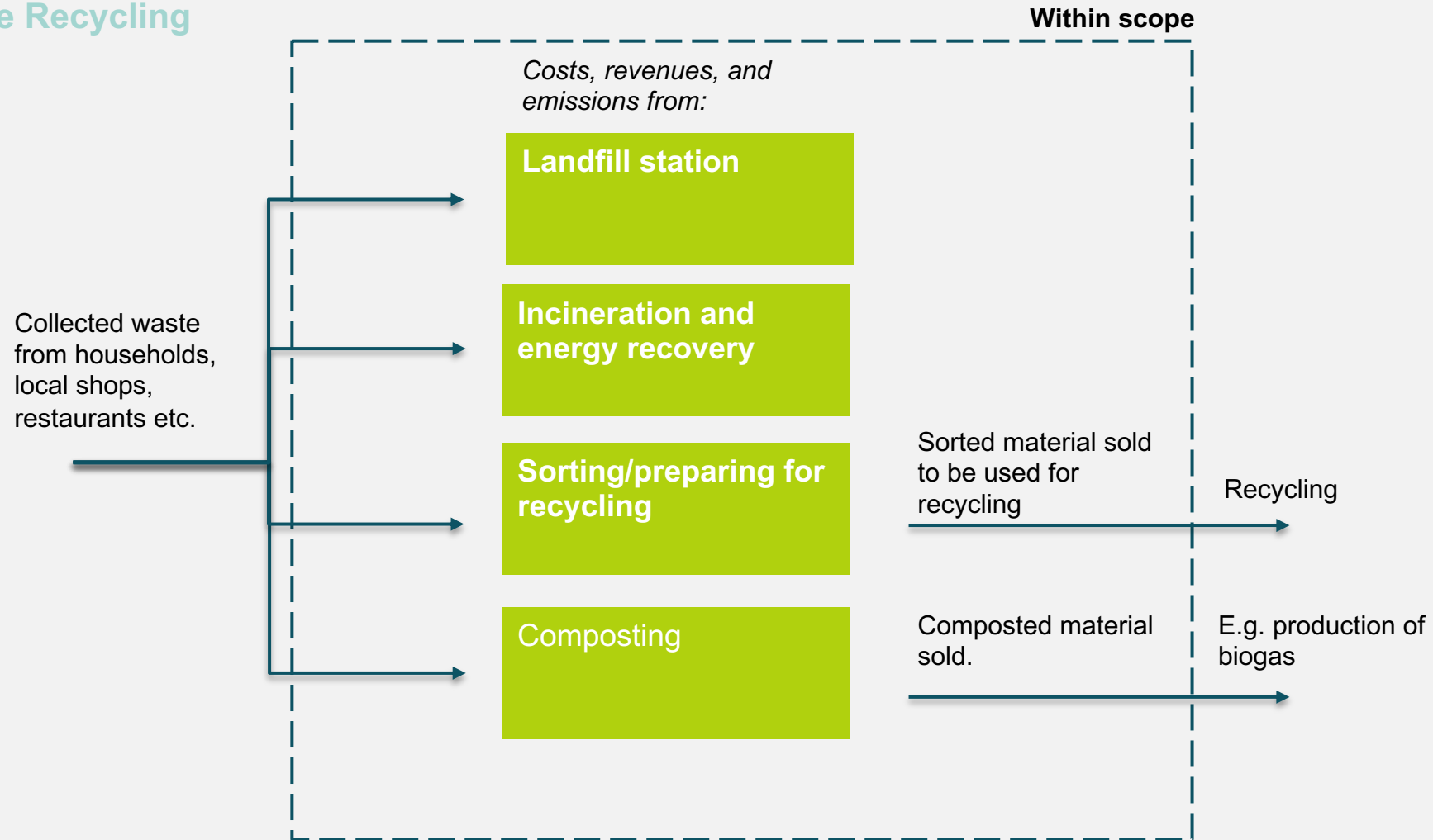
- Passenger transport levers
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- Appendix: Lever sensitivities
- Appendix: Model Updates & Improvements



Scope of waste lever



5.1 Waste Recycling



Methodology, data, & key assumptions - Madrid example



5.1 Waste recycling

Scenarios methodology

Baseline

- The total amount of waste collected is assumed to increase at same rate as expected population increase (+0.4%/year)
- Packaging materials is assumed to reach at a minimum EU's recycling targets for packaging waste by 2030 (paper – 85%, plastics – 55%, metal – 80%, glass – 75%) .¹
- Organic waste and “other materials” reaches EU's recycling targets (65%) for municipal waste by 2030. ²
 - “Other materials” represent all the materials that are not explicitly mentioned but still are included in municipal solid waste – e.g. wood, textiles and rubble.
 - Landfill rates are decreasing to at most 10% for paper, plastic, metal, and organic waste – in accordance with EU legislation.²

Decarbonisation scenario

- CO₂ emissions and air pollutants (NO_x and combustion-related PM) are reduced as the landfill and incineration rates decrease.
- Glass, and organic waste are assumed to reach the same recycling rate as paper (85%), while plastic is assumed to reach 68% - in accordance with the report “*The Circular Economy – A Powerful source of Climate Mitigation*”.³
- Metals are assumed to reach 100% recycling rates (from 97% today)
- Landfill rates for paper and organic waste are reduced to 0%. Landfill rates for plastics are assumed to decrease to 10% - the same as in the baseline scenario.
- Treatment rates of “Other materials” remains the same as in the baseline scenario

Emissions

- Methane emissions from landfill mainly generates from paper and organic waste, but some emissions come from “other materials” as well.
- Emissions from incineration mainly generates from plastics, but some emissions come from “other materials” as well.



Methodology, data, & key assumptions - Madrid example



5.1 Waste recycling

Economic case

Upfront investments

- CAPEX is differing between the treatment methods, with sorting/recycling being the costliest and landfill being the cheapest alternative.⁴
 - CAPEX: Landfill - 18 €/tonne. Incineration – 36 €/tonne. Composting – 21 €/tonne. Sorting – 77 €/tonne. Sorting plastics – 108 €/tonne.
 - Plastic is much more expensive to sort and recycle, and therefore it has separate values for the cost calculations.

Net recurring costs/savings

- Recurring costs are similar to upfront investments, with sorting/recycling being the expensive alternative, and landfill the cheap alternative.⁴
 - Plastic is the most expensive material regarding OPEX for sorting (164 €/tonne) while the other materials have an average cost of 116 €/tonne.
 - OPEX: Landfill – 11 €/tonne. Incineration - 39 €/tonne. Composting – 32 €/tonne. Sorting – 116 €/tonne. Sorting plastics – 164 €/tonne.
 - Assuming collection cost being the same, independent of where the waste is sent after being collected (landfill, incineration, or to a sorting station).
- Sorting is assumed to have the same split between CAPEX and OPEX as composting has.
- Revenues/cost savings come from selling sorted material or using the incineration process to recover energy. Landfill gives no revenues.⁵
 - Revenues from incineration: 23 €/tonne. Based on energy generated (0,6 MWh / tonne waste) and energy price (40 EUR/MWh).
 - Revenues from selling sorted material:
 - Paper – 158 €/tonne. Metal – 193 €/tonne. Plastics – 315 €/tonne. Glass – 52 €/tonne. Organic waste – 10 €/tonne.⁵

Value of co-benefits

- All emission reduction and co-benefits are calculated as net improvements compared to baseline
- Value of NOx (12,600 €/tonne inside city, 21,300 outside city), PM2.5 (252,000 €/tonne inside city, 70,000 outside city) and PM⁶

Sources

1. European commission (2019) – *Implementation of the circular economy action plan*
2. European commission (2019) – *Review of Waste Policy and Legislation*
3. Material Economics (2018) – *The Circular Economy, A Powerful Source of Climate Mitigation.*
4. Eunomia Research & Consulting – *Costs for Municipal Waste Management in the EU.*
5. Eurostat (2019) – *Secondary material price indicator*
6. Essen et. al. (2019). Handbook on the external costs of transport. For European Commission Directorate-General for Mobility and Transport.





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- Passenger transport levers
- Freight transport levers
- Buildings & heating levers
- Electricity levers
- Waste levers
- **Appendix: Lever sensitivities**
- Appendix: Model Updates & Improvements



Some assumptions in the analysis are sensitive to changes and can potentially greatly impact results



Assumptions with potentially high sensitivity per lever

Reduced private transportation need	<ul style="list-style-type: none">• Estimated reduction in passenger kms until 2030	Electrification of trucks	<ul style="list-style-type: none">• Share of vehicle kms electrified by 2030• Cost reduction of trucks until 2030
Shift to public & non-motorised transport	<ul style="list-style-type: none">• Reduction in car passenger kms until 2030• Share of kms going to public transport vs walking/cycling• Health benefits of walking/cycling	Building renovations	<ul style="list-style-type: none">• Potential increased annual renovation rate• Cost per m² of different levels of renovations• Efficiency improvement potential for different levels of renovation
Increased car pooling	<ul style="list-style-type: none">• Average passengers per car journey in 2030	New energy efficient buildings	<ul style="list-style-type: none">• Cost per m² of different construction standards• Efficiency improvement potential for different construction standards
Electrification of passenger cars	<ul style="list-style-type: none">• Share of vehicle kms electrified by 2030• Up-front cost reduction of EVs vs ICE vehicles over time	Decarbonising heating	<ul style="list-style-type: none">• Share of heating from district vs local heating until 2030• Share of fossil waste in waste incinerated until 2030• Cost of increased sorting & price of sorted plastics
Electrification of buses	<ul style="list-style-type: none">• Share of vehicle kms electrified by 2030• Cost reduction of buses until 2030	Decarbonising electricity	<ul style="list-style-type: none">• Share of fossil production replaced by renewables until 2030• Share of new renewable that is rooftop PV vs centralised utility scale wind/solar• Cost decreases of wind and solar until 2030
Optimised logistics	<ul style="list-style-type: none">• Average load factor improvement until 2030• Total vehicle km reduction potential from improved routing by 2030		





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Analysis: Validation of model emissions calculations by sector versus city emissions inventory



Model Updates & Improvements

Sector emissions as calculated by the model are compared with city emissions inventories to validate model data inputs in advance of cost / benefit analysis. Since city emissions inventories vary in methodology and accuracy, this analysis validates emissions inventories by sector as the foundation for the accurate calculation of the costs and benefits of decarbonization.

	2020 kton Emissions - model calculations	% of Total	2020 kton Emissions - emissions inventory	% of Total
Transportation	2,315	24%	2,591	26%
Buildings & Heating	2,191	22%	2,183	22%
Electricity	2,867	30%	2,867	28%
Waste	519	5%	735	7%
Other (Not Analyzed)	1,699	18%	1,699	17%
Total	9,531	100%	10,075	100%





Climate City Contract Alignment: Model results are displayed in the form of Annex I and Annex II tables

Model Updates & Improvements

Model results are presented in the exact format of the tables required by the Climate City Contract allowing for analysis and iteration on decarbonization plans and costs / benefits.

ANNEX I

- A-1.2: Emission factors applied (from economic model data inputs)
- A-1.3: Activity by source sector (from economic model data inputs)
- A-1.4b: GHG emissions by source sector – 2019 (from economic model inputs)
- A-1.4b: GHG emissions by source sector – Business as Usual / BAU 2030 (from economic case)
- A-2.3: Emissions gap (kt CO₂e)
- B-1.1: Impact pathways [only numerical inputs; additional text inputs required]
- C-3.1: Summary of interventions with related costs [additional text inputs required]





Key Analytical Outputs: Table A-1.4b (Annex I) displays source of carbon by sector

Model Updates & Improvements

Analysis of emissions by sector in the Business as Usual (BAU) case allows cities to focus their decarbonization efforts in the areas emitting the most carbon.

A-1.4b: GHG emissions by source sector (from economic case)					
Base year	BAU 2030 (Business as Usual 2030)				
Unit	t CO ₂ equivalent/year				
	Scope 1	Scope 2	Scope 3	Total	% of Total
Transport	1701787			1701787	19%
Buildings & Heating	2166648			2166648	24%
Electricity		3105603		3105603	35%
Waste*			283178	283178	3%
Other	1698728			1698728	19%
Total	5567163	3105603	283178	8955944	100%

** Includes Scope 1 Waste emissions (produced and processed in the city) and Scope 3 (produced by the city but processed outside the city border)*



Key Analytical Outputs: Table A-2.3 (Annex I) highlights the emissions reduction and remaining gap



Model Updates & Improvements

The NetZeroCities goal is to reduce carbon by at least 80% by 2030 with the remainder to be offset. Table A-2.3 breaks down the carbon reduction, the offset, and the remaining gap that needs to be reduced in order to reach 80%.

A-2.3: Emissions gap (kt CO ₂ e)							
	Baseline emissions (BAU 2030)	Residual emissions offsetting ¹		Emissions reduction target		Emissions gap (amount necessary to achieve net-zero)	
	(Absolute value)	(Absolute value)	(% of BAU 2030)	(Absolute value)	(% of BAU 2030)	(Absolute value)	(% of BAU 2030)
Transport	1702	496	29%	800	47%	407	24%
Buildings & Heating	2167	433	20%	1332	61%	401	19%
Electricity	3106	466	15%	2640	85%	0	0%
Waste	283	57	20%	90	32%	137	48%
Other²	1699	340	20%	1138	67%	221	13%
Total	8956	1,791	20%	5999	67%	1166	13%

¹ Residual emissions consist of those emissions which can't be reduced through climate action and are being offset. Residual emission may amount to a maximum of 20 % as stated by the Mission Info Kit.

² Emissions reduction target percentage for "Other" sector is assumed to be the same as for the other 4 main sectors unless updated by city. Activities and commitments to reduce these emissions are documented in the Climate Neutrality Action Plan.



Key Analytical Outputs: Table C-3.1 (Annex I) aligns decarbonization levers with impacts



Model Updates & Improvements

Decarbonization levers are aligned with GHG reductions and costs and benefits (including co-benefits).

C-3.1: Summary of interventions with related costs									
Actions	Actions & Results		Responsible entity and person	Start / end date	Sector	Impact			Total investment cost (CAPEX)(MEUR NPV 2020-2030)
						GHG reduction (k CO2e)	Operational cost/savings (OPEX) (MEUR NPV 2020-2050)	Co-benefits (MEUR - NPV 2020-2050)	
<i>(list the actions of your portfolio of transformative projects from modules B-2, C-1 and C-2)</i>	2030 Assumptions		<i>(indicate the entity and person responsible)</i>	<i>(indicate the start and end date of the activity)</i>	<i>(indicate the sector to which the action belongs)</i>	<i>(indicate the impact of the action. Eg GHG reduction/co-benefits)</i>			<i>(Indicate the estimated total cost for the performance in €)</i>
Reduced motorized passenger transportation need	15%	reduction		2020-2030	Transport	215	€ 3,822	€ 1,010	€ -
Shift to public & non-motorized transport	7%	reduction in car passenger kms		2020-2030	Transport	54	€ 179	€ 457	€ (236)
Increased car pooling	11%	increase in average passengers per car		2020-2030	Transport	97	€ 1,446	€ 518	€ -
Electrification of cars + motorcycles	32%	electric cars + motorcycles by 2040		2020-2040	Transport	178	€ (118)	€ 72	€ (258)
Electrification of buses	49%	electric buses		2020-2030	Transport	64	€ 141	€ 98	€ (61)



Key Analytical Outputs: Tables B-1.1a and B-1.1b (Annex I) show costs and benefits for the city and for all stakeholders



Model Updates & Improvements

Sum of CAPEX and OPEX is aligned with CO2e reduction by subsector to highlight which subsectors generate the biggest carbon benefit for the least money.

B-1.1b: Sector costs in TOTAL (city, citizens, businesses)					
Sector	Subsector	Investment (CAPEX) (MEUR cash basis 2020-2030)	Operational cost/savings (OPEX) (MEUR cash basis 2020-2030)	Total CAPEX + OPEX (MEUR - cash basis 2020-2030)	CO2e reduction (kton)
Transport	Reduced motorized passenger transportation need	€ -	€ 2,251	€ 2,251	215
	Shift to public & non-motorized transport	€ (291)	€ 219	€ (73)	54
	Increased car pooling	-	€ 805	€ 805	97
	Electrification of cars + motorcycles	€ (300)	€ 35	€ (264)	178
	Electrification of buses	€ (71)	€ 123	€ 53	64
	Optimized logistics	€ -	€ 379	€ 379	133
	Electrification of trucks	€ (403)	€ 25	€ (379)	59





Climate City Contract Alignment: Model results are displayed in the form of Annex I and Annex II tables

Model Updates & Improvements

ANNEX II

- B1.1a: Sector costs (CITY ONLY)
- B1.1b: Sector costs in TOTAL (city, citizens, businesses)
- B3.1: Economic indicators by sector
- B-3.2: Financial indicators by sector
- C-3.2: Asset Owners – CAPEX / Upfront Investment (MEUR cash)



Key Analytical Outputs: Table B-3.1 (Annex II) shows Key Performance Indicators by sector



Model Updates & Improvements

The baseline year and the goal for 2030 is shown to highlight level of ambition for each KPI and allow for management of performance against plan in the MEL framework.

B-3.1: Economic indicators by sector				
Sector	Indicator	Indicator Unit	Indicator baseline	Indicator target 2030
Transport	Reduced motorized passenger transportation need	% reduction by 2030		15%
	Reduced passenger kilometers by car through shift to public & non-motorized transportation	% reduction in car passenger kilometers by 2030		7%
	Car pooling	average passengers per car	1.6	1.7
	Electrification of cars + motorcycles by 2040	% of fleet electrified	0%	32%
	Electrification of buses	% of fleet electrified	2%	49%
	Optimization of trucking logistics - light duty trucks (< 3.5 t)	average utilization of maximum load weight for light duty trucks (< 3.5t)	23%	45%
	Optimization of trucking logistics - heavy duty trucks (> 3.5 t)	average utilization of maximum load weight for heavy duty trucks (> 3.5t)	45%	60%
	Electrification of light duty trucks <3.5t by 2040	% of fleet electrified	0%	90%
	Electrification of heavy duty trucks >3.5t by 2040	% of fleet electrified	0%	40%





Key Analytical Outputs: Table B-3.2 (Annex II) shows Key Financial Indicators by sector

Model Updates & Improvements

Net Present Value is calculated for CAPEX, OPEX and Co-benefits to allow for the analysis of Return on Investment (ROI) by sector. Investment per kton CO2e reduction allows for analysis of what subsectors reduce the most carbon for the least cost.

B-3-2: Financial indicators by sector							
Sector	Subsector	NPV total investment - CAPEX (MEUR)	NPV OPEX (MEUR)	NPV co-benefits (MEUR)	NPV Return on Investment (ROI) (MEUR)	CO2e reduction (kton)	NPV MEUR total investment per kton CO2e reduction
Transport	Reduced motorized passenger transportation need	€ -	€ 3,822	€ 1,010	€ 4,832	215	€ -
	Shift to public & non-motorized transport	€ (236)	€ 79	€ 457	€ 400	54	€ 4.39
	Increased car pooling	€ -	€ 1,446	€ 518	€ 1,964	97	€ -
	Electrification of cars + motorcycles	€ (258)	€ (118)	€ 72	€ (304)	178	€ 1.45
	Electrification of buses	€ (61)	€ 141	€ 98	€ 179	64	€ 0.95
	Optimized logistics	€ -	€ 663	€ 197	€ 860	133	€ -
	Electrification of trucks	€ (325)	€ 22	€ 35	€ (267)	59	€ 5.55



Key Analytical Outputs: Table C-3.2 (Annex II) shows investment required of each stakeholder group



Model Updates & Improvements

90+% of all investment required to decarbonize will be borne, not by the city, but by citizens and businesses. This table shows how much each group has to pay to reduce carbon in each subsector.

C-3.2: Asset Owners - CAPEX / Upfront Investment (MEUR cash)							
Sector	Subsector	Citizens	Businesses	City	Transport Operators	Utilities	Total
Transport	Reduced motorized passenger transportation need	€ -	€ -	€ -	€ -	€ -	€ -
	Shift to public & non-motorized transport	€ (26)	€ -	€ (16)	€ (249)	€ -	€ (291)
	Increased car pooling	€ -	€ -	€ -	€ -	€ -	€ -
	Electrification of cars + motorcycles	€ (216)	€ (76)	€ (8)	€ -	€ -	€ (300)
	Electrification of buses	€ -	€ -	€ -	€ (71)	€ -	€ (71)
	Optimized logistics	€ -	€ -	€ -	€ -	€ -	€ -
	Electrification of trucks	€ -	€ (66)	€ (9)	€ (328)	€ -	€ (403)
Buildings & Heating	Building renovations (envelope)	€ (1,540)	€ (557)	€ (111)	€ -	€ -	€ (2,228)
	New energy-efficient buildings	€ (146)	€ (293)	€ (49)	€ -	€ -	€ (488)
	Efficient lighting & appliances	€ (1,185)	€ (423)	€ (85)	€ -	€ -	€ (1,693)
	Decarbonizing heating generation	€ (416)	€ (149)	€ (360)	€ -	€ (1,323)	€ (2,248)
Electricity	Decarbonizing electricity generation	€ (161)	€ (57)	€ (11)	€ -	€ (1,457)	€ (1,687)
Waste	Increased waste recycling	€ -	€ -	€ (7)	€ -	€ -	€ (7)
TOTAL		€ (3,711)	€ (1,621)	€ (658)	€ (648)	€ (2,780)	€ (9,417)
% of Total		39%	17%	7%	7%	30%	100%



Key Analytical Outputs: Analysis of CAPEX and OPEX by year allows for comparison to city budgets



Model Updates & Improvements

Comparison of annual decarbonization expenses (in cash, not NPV) to city budget highlights any gaps in funding by subsector. Once gaps are isolated, cities can seek out additional funding or adjust their Climate Neutrality Action Plan to reduce cost.

Cities - CAPEX (in millions of Euros)												
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Main decarbonization levers modeled:												
Transportation												
Reduced passenger transportation need												€ -
Shift to public & non-motorized transport	€ (0)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (2)	€ (2)	€ (2)	€ (2)	€ (2)	€ (16)
Increase car pooling												€ -
Electrification of passenger cars	€ (0)	€ (0)	€ (0)	€ (0)	€ (0)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (8)
Electrification of buses	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Optimized logistics (trucks)												€ -
Electrification of trucks	€ (0)	€ (0)	€ (0)	€ (0)	€ (0)	€ (1)	€ (1)	€ (1)	€ (2)	€ (2)	€ (2)	€ (9)
Buildings & Heating												
Building renovations	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (10)	€ (111)
New energy efficient buildings	€ (2)	€ (5)	€ (5)	€ (5)	€ (5)	€ (5)	€ (5)	€ (5)	€ (5)	€ (5)	€ (5)	€ (49)
Efficient lighting & appliances	€ (5)	€ (8)	€ (8)	€ (8)	€ (8)	€ (8)	€ (8)	€ (8)	€ (8)	€ (8)	€ (8)	€ (85)
Decarbonizing heating generation	€ (34)	€ (33)	€ (33)	€ (33)	€ (33)	€ (33)	€ (33)	€ (32)	€ (32)	€ (32)	€ (32)	€ (360)
Electricity												
Decarbonizing electricity generation	€ (0)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (2)	€ (11)
Waste												
Increased waste recycling	€ (0)	€ (0)	€ (0)	€ (0)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (1)	€ (7)
Total	€ (52)	€ (59)	€ (59)	€ (60)	€ (60)	€ (60)	€ (61)	€ (61)	€ (62)	€ (62)	€ (62)	€ (658)





Key Analytical Outputs: Analysis of KPIs per capita allows for comparison across cities

Model Updates & Improvements

Comparison of KPIs across cities further validates model accuracy and highlights best practices to be shared.

	Density - '30 Population / Sq Kms	'20 car kms / capita / yr	'30 % reduced motorized transport	'30 % shift in car kms to public transport	maximum electrificatio n of cars	'20 kWh heating demand / capita / yr	'30 share of heating as local (vs district)	'30 % point reduction in fossil local heating	'30 % point reduction in fossil district heating	Building envelope renovation rate / yr	'20 kWh electricity demand / capita / yr	'20 % of electricity production using fossil fuels	'30 % of electricity production using fossil fuels
City A	5,390	3,497	15%	7%	32%	3.0	90%	41%	50%	2.0%	3.8	41%	6%
City B	16,533	2,284	15%	25%	32%	2.4	95%	30%	-4%	6.0%	3.8	41%	6%
City C	5,937	2,985	35%	30%	35%	1.9	95%	45%	60%	2.5%	2.6	41%	6%
City D	1,521	3,797	30%	20%	35%	4.7	55%	64%	1%	2.0%	4.4	41%	6%
City E	693	2,843	35%	30%	32%	6.3	80%	76%	50%	4.0%	2.3	41%	6%
City F	921	2,909	33%	18%	35%	4.4	70%	60%	60%	4.0%	5.0	41%	6%
City G	16,792	2,403	21%	40%	36%	4.2	100%	44%	0%	3.5%	3.1	62%	14%
City H	649	3,878	30%	35%	36%	3.6	100%	12%	0%	2.0%	4.8	49%	10%
City I	4,011	4,836	35%	30%	35%	2.5	89%	35%	0%	4.4%	5.1	44%	7%
City J	3,691	4,557	22%	40%	80%	5.6	99%	59%	0%	5.0%	4.9	52%	10%
City K	5,781	3,235	25%	30%	100%	3.3	100%	35%	0%	2.5%	5.9	71%	7%
City L	2,806	5,686	21%	26%	30%	3.0	100%	45%	0%	3.5%	4.4	100%	33%
City M	849	4,959	35%	10%	35%	6.5	45%	73%	0%	5.0%	2.9	29%	4%
City N	1,463	5,184	23%	22%	34%	9.2	37%	54%	75%	3.0%	4.5	44%	9%



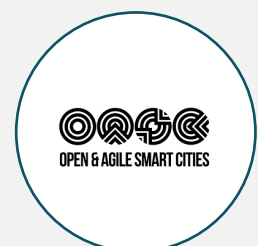
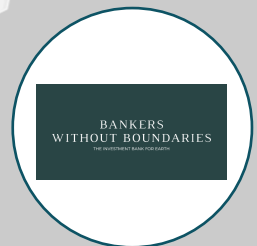
Other Model Updates and Improvements



Model Updates & Improvements

- Addition of 2030 assumptions input for carbon reduction percentage in the “Other” sector (represents emissions outside of four main sectors of Transport, Buildings, Electricity, and Waste). Original model assumed “Other” sector would have no carbon reductions through 2030.
- Addition of data point for City Area in order to calculate city density for analysis purposes.
- Original model included Forestation (carbon sinks) and Reduced Building Materials (Scope 3) in some decarbonization outputs and not others. These subsectors have been removed from all outputs for consistency.
- Original model included the subsector of “Efficient Lighting and Appliances” under Buildings & Heating in some areas and under Electricity in other areas. This has been corrected to put “Efficient Lighting and Appliances” under Buildings & Heating in all cases for consistency.
- Original model excluded Waste from some calculations. Waste is one of the four main sectors in the model, so this omission has been corrected.





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