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.

NetZeroPlanner Methodology

Detailed Review by Decarbonisation Lever

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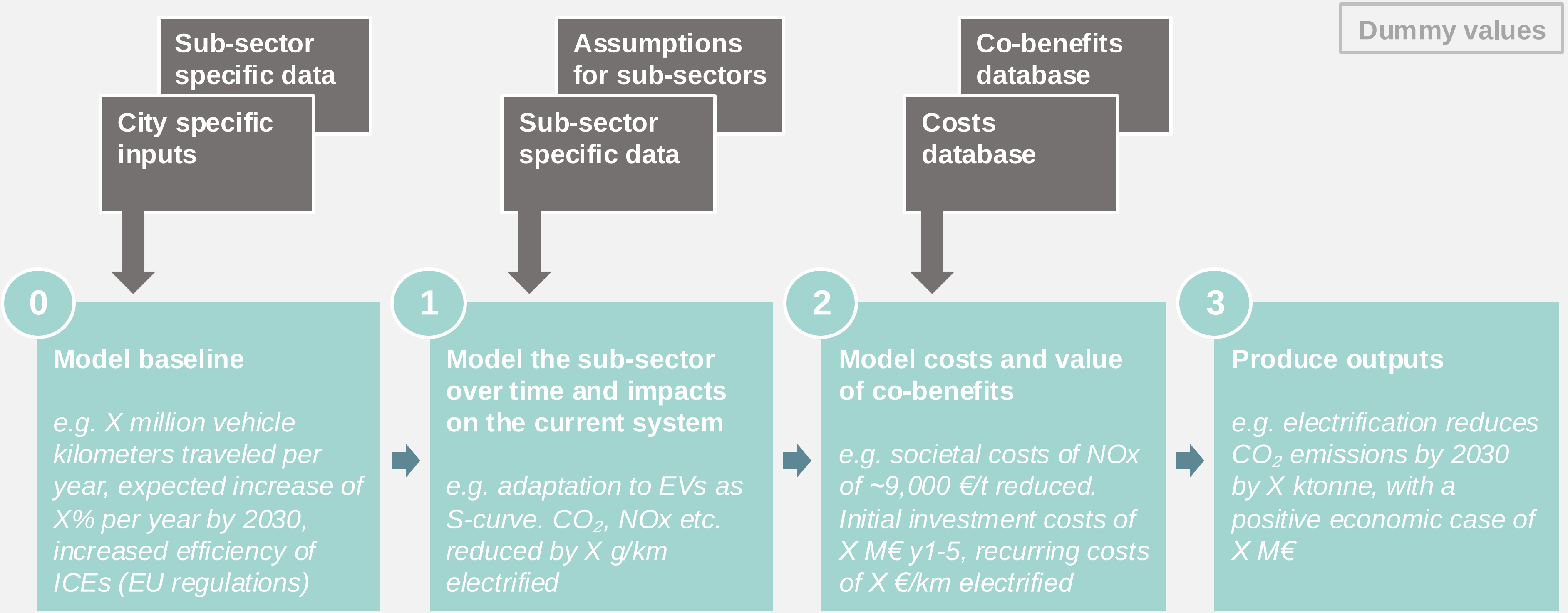
Model methodology - overview

Dummy values



Sub-sector specific data

City specific inputs

0

Model baseline

e.g. X million vehicle kilometers traveled per year, expected increase of X% per year by 2030, increased efficiency of ICEs (EU regulations)

Assumptions for sub-sectors

Sub-sector specific data

1

Model the sub-sector over time and impacts on the current system

e.g. adaptation to EVs as S-curve. CO_2, NOx etc. reduced by X g/km electrified

- Simple and pragmatic modelling as a function over time

Co-benefits database

Costs database

2

Model costs and value of co-benefits

e.g. societal costs of NOx of ~9,000 €/t reduced. Initial investment costs of X M€ y1-5, recurring costs of X €/km electrified

- Use average of 2-3 reliable estimates of co-benefit value. Strive to interview experts for important co-benefits

3

Produce outputs

e.g. electrification reduces CO_2 emissions by 2030 by X ktonne, with a positive economic case of X M€

- NPV
- Investments until 2030
- Co-benefits linked to investments until 2040/2050

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

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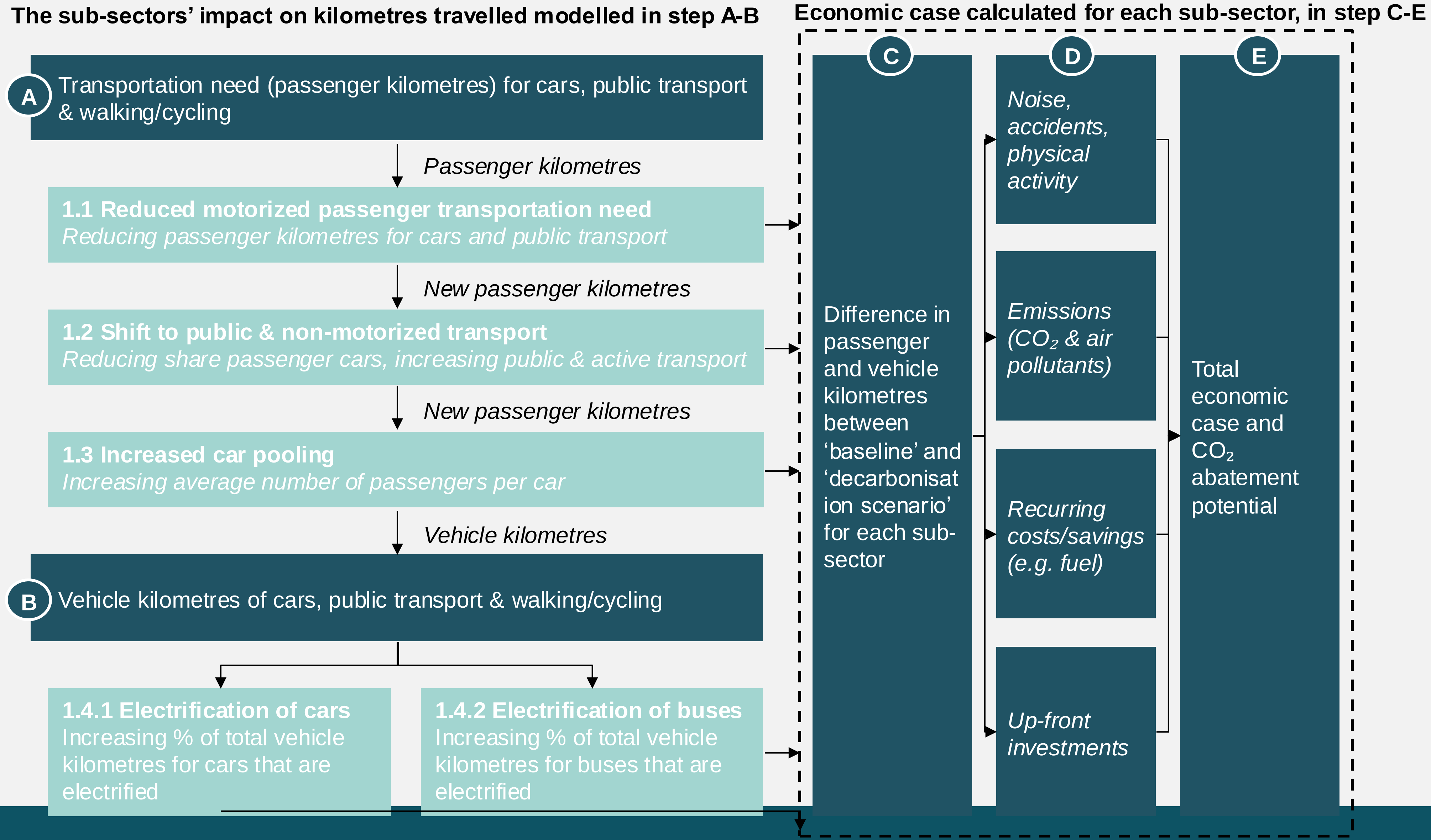
PASSENGER TRANSPORT

Overview of modelling methodology

■ Main modelling steps
■ Sub-sectors



The sub-sectors' impact on kilometres travelled modelled in step A-B

Economic case calculated for each sub-sector, in step C-E

A Transportation need (passenger kilometres) for cars, public transport & walking/cycling

Passenger kilometres

1.1 Reduced motorized passenger transportation need
Reducing passenger kilometres for cars and public transport

New passenger kilometres

1.2 Shift to public & non-motorized transport
Reducing share passenger cars, increasing public & active transport

New passenger kilometres

1.3 Increased car pooling
Increasing average number of passengers per car

Vehicle kilometres

B Vehicle kilometres of cars, public transport & walking/cycling

1.4.1 Electrification of cars
Increasing % of total vehicle kilometres for cars that are electrified

1.4.2 Electrification of buses
Increasing % of total vehicle kilometres for buses that are electrified

C Difference in passenger and vehicle kilometres between 'baseline' and 'decarbonisation scenario' for each sub-sector

D

Noise, accidents, physical activity

Emissions (CO_2 & air pollutants)

Recurring costs/savings (e.g. fuel)

Up-front investments

E Total economic case and CO_2 abatement potential

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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 targets[1] (2021: 95 g CO_2/km, 2030: 59 g CO_2/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
- CO_2 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

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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 2016-2019[4] (1.2 €/litre)
- Cost savings from reduced car usage (excl. fuel) of 0.06 €/vkm[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 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 CO_2 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

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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 targets[1] (2021: 95 g CO_2/km, 2030: 59 g CO_2/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
- CO_2 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') where to stop a specific year, so would the co-benefits.

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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/tram[2]. These costs are assumed to be ~60% CAPEX and ~40% OPEX[3].
- 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 2016-2019[6] (1.2 €/litre)
- Cost savings from reduced car usage (excl. fuel) of 0.06 €/vkm[5]

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 PM[7]
- 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 €/pkm[8]

Sources
1. European commission (2019) - *Post-2020 CO_2 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.

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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 targets[1] (2021: 95 g CO_2/km, 2030: 59 g CO_2/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
- CO_2 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.

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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 2016-2019[3] (1.2 €/litre)
- Cost savings from reduced car usage (excl. fuel) of 0.06 €/vkm[4]

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 PM[5]
- 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 CO_2 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

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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 targets[1] (2021: 95 g CO_2/km, 2030: 59 g CO_2/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

- CO_2 emissions (100%) and air pollutants (100% NOx 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)
- CO_2 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.

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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 2016-2019[4] (€1.2/l)
- Increased cost of electricity based on household electricity prices[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 PM[6]

Sources

1. European commission (2019) - *Post-2020 CO_2 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.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

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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 targets[1] (2021: 95 g CO_2/km, 2030: 59 g CO_2/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

- CO_2 emissions (100%) and air pollutants (100% NOx 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*)
- CO_2 abatement potential calculated as difference between Decarbonisation scenario and Baseline scenario

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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 2016-2019[4] (€1.2/l)
- Increased cost of electricity based on household electricity prices[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 PM[6]
- Value of noise reduction (0,004 €/person-kilometre)[6]

Sources

1. European commission (2019) - *Post-2020 CO_2 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

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

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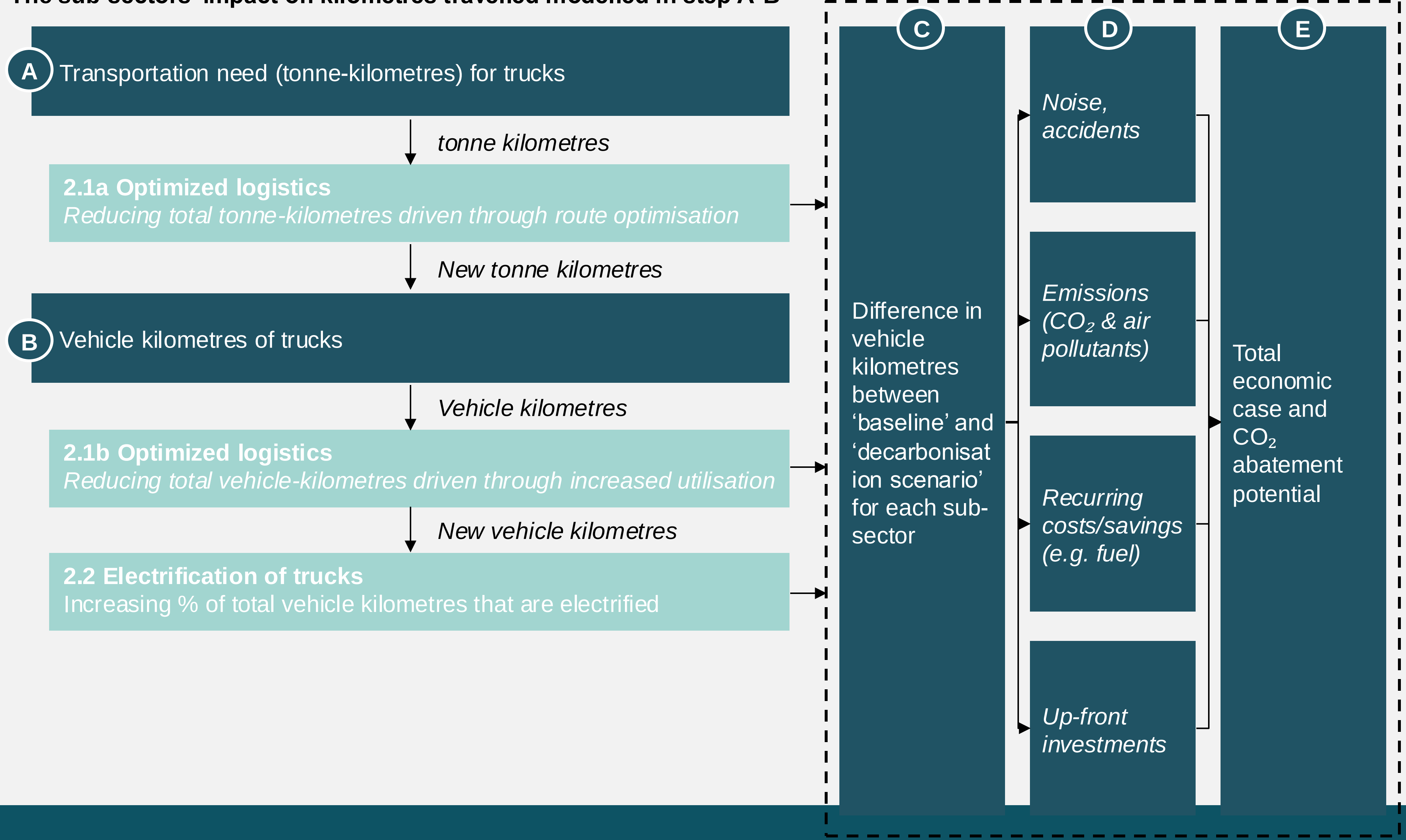
FREIGHT TRANSPORT

Overview of modelling methodology

🟦 Main modelling steps 🟩 Sub-sectors

The sub-sectors' impact on kilometres travelled modelled in step A-B

Economic case calculated for each sub-sector, in step C-E



A Transportation need (tonne-kilometres) for trucks

tonne kilometres

2.1a Optimized logistics
Reducing total tonne-kilometres driven through route optimisation

New tonne kilometres

B Vehicle kilometres of trucks

Vehicle kilometres

2.1b Optimized logistics
Reducing total vehicle-kilometres driven through increased utilisation

New vehicle kilometres

2.2 Electrification of trucks
Increasing % of total vehicle kilometres that are electrified

C Difference in vehicle kilometres between 'baseline' and 'decarbonisation scenario' for each sub-sector

D

Noise, accidents

Emissions (CO_2 & air pollutants)

Recurring costs/savings (e.g. fuel)

Up-front investments

E Total economic case and CO_2 abatement potential

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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 targets[1] (2025: -15% g CO_2/km & 2030: -31% g CO_2/km, compared to 2021)
  - Heavy duty trucks (>3.5 tonnes, assumed to be 12 tonne-trucks when modelling) according to EU fleet-wide targets[2] (2025: -15% g CO_2/km & 2030: -30% g CO_2/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

- CO_2 emissions and air pollutants (NOx and combustion-related PM) are reduced as vehicle kilometres in freight transportation decrease.
- Increased load utilisation, from 23% to 45% (average for urban distribution[3]) for light trucks and from 45% to 60% for heavy trucks (near utilization rate for long-haul heavy trucks[3])
- 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.

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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 investments[4].

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 €/km[5] for light duty trucks, and 0,67 €/km[6] 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 PM[7]
- Value of accident reduction: light trucks: 0.046 €/tonne km, heavy trucks: 0.010 €/tonne km[7]
- Value of noise reduction (light trucks: 0.016 €/tonne km, heavy trucks: 0.008 €/tonne km)[7]

Sources

1. European commission (2019) - *Post-2020 CO_2 emission performance standards for cars and vans*
2. European commission (2019) - *Reducing CO_2 emissions from heavy duty vehicles*
3. ACEA (2010) – *Commercial vehicles and CO_2*
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 choise 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

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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 targets[1] (2025: -15% g CO_2/km & 2030: -31% g CO_2/km, compared to 2021)
  - Heavy duty trucks (>3.5 tonnes, assumed to be 12 tonne-trucks when modelling) according to EU fleet-wide targets[2] (2025: -15% g CO_2/km & 2030: -30% g CO_2/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

- CO_2 emissions (100%) and air pollutants (100% NOx 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.

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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/truck[4], assuming cost parity reached by 2030, 5 years later than passenger cars[5]
- 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 prices[7], 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 PM[8]
- Value of noise reduction (light trucks: 0.016 €/tonne km, heavy trucks: 0.008 €/tonnekm[8]

Sources

1. European commission (2019) - *Post-2020 CO_2 emission performance standards for cars and vans*
2. European commission (2019) - *Reducing CO_2 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 analysisBloomberg (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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- Passenger transport levers
- Freight transport levers
- **Buildings & heating levers**
- Electricity levers
- Waste levers
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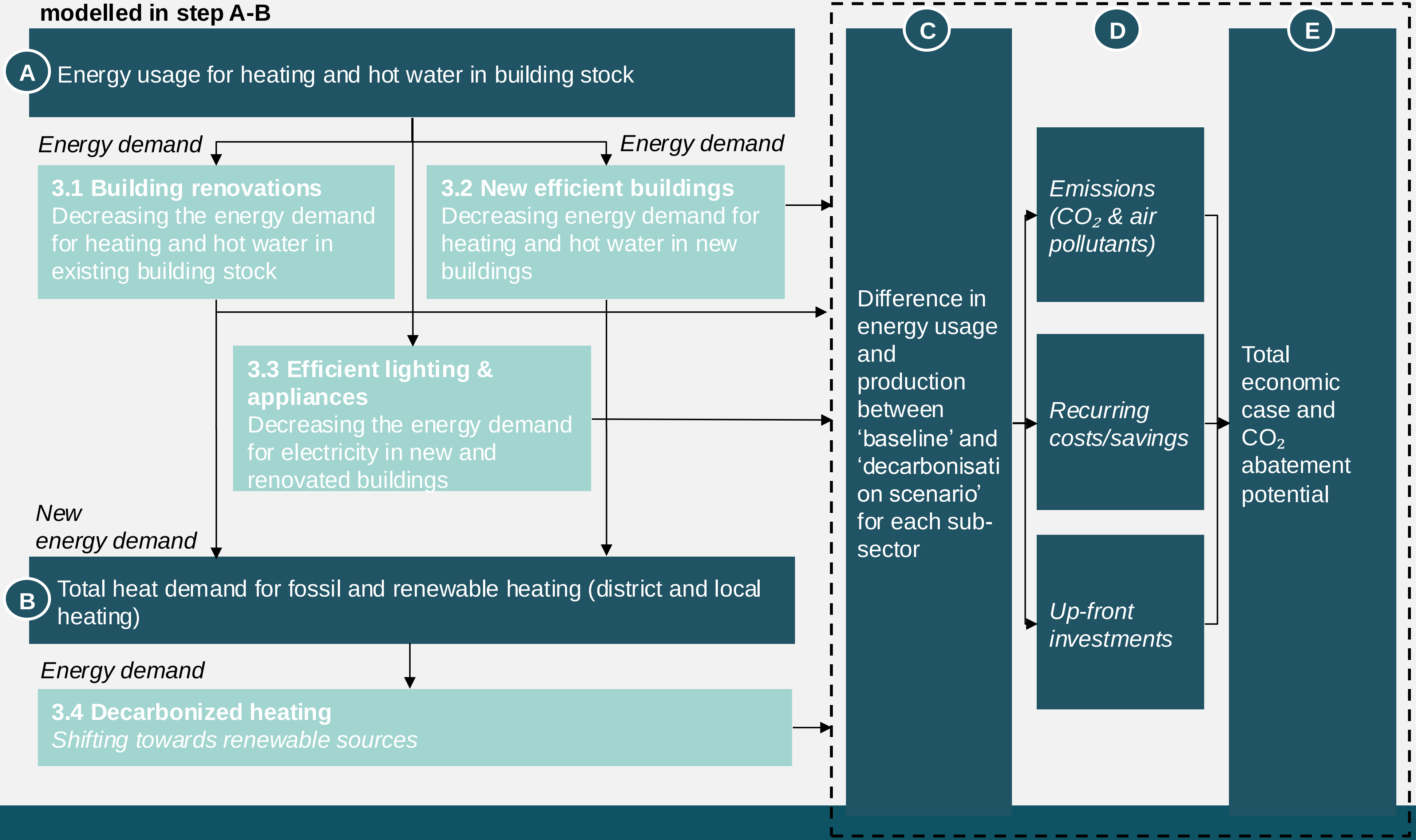
BUILDINGS AND HEATING

Overview of modelling methodology

■ Main modelling steps ■ Sub-sectors

The sub-sectors' impact on energy usage and production modelled in step A-B

Economic case calculated for each sub-sectors, in step C-E



A Energy usage for heating and hot water in building stock

Energy demand

Energy demand

3.1 Building renovations
Decreasing the energy demand for heating and hot water in existing building stock

3.2 New efficient buildings
Decreasing energy demand for heating and hot water in new buildings

3.3 Efficient lighting & appliances
Decreasing the energy demand for electricity in new and renovated buildings

New energy demand

B Total heat demand for fossil and renewable heating (district and local heating)

Energy demand

3.4 Decarbonized heating
Shifting towards renewable sources

C Difference in energy usage and production between 'baseline' and 'decarbonisation scenario' for each sub-sector

D *Emissions (CO_2 & air pollutants)*

Recurring costs/savings

Up-front investments

E Total economic case and CO_2 abatement potential

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

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 rebuilt[2]
- 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

- CO_2 emissions (100%) and air pollutants (100% NOx 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% improvements[1]) are increased from 15% to 25% of total, with the rest being “minor renovations (15% improvements[1]).

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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 €/m2[1]
  - The costs of minor renovations are assumed to be constant until 2030 and extensive renovations are assumed to decrease by 1% per year[3]

Net recurring costs/savings

- Assuming no recurring costs.
- Cost savings from reduced energy consumption (based on cost of heating of 76 EUR/MWh[4])

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 PM[5]

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

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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 rebuilt[2]
- 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
- CO_2 emissions (100%) and air pollutants (100% NOx and combustion-related PM) are reduced as the building stock’s energy consumption reduces.

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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 perfoming 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 2030[2].

Net recurring costs/savings

- Assuming no recurring costs.
- Cost savings from reduced energy consumption (based on cost of heating of 76 EUR/MWh[4])

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 PM[5]

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

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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 rebuilt[4]
- 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
- CO_2 emissions (100%) and air pollutants (100% NOx and combustion-related PM) are reduced as the building stock’s energy consumption reduces.

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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 & appliance[5].
- These costs are assumed to decrease at same rate as minor heating renovations (1% per year) until 2030[4].

Net recurring costs/savings

- Cost savings from reduced electricity consumption (based on cost of electricity of 0.17 EUR/kWh[6])

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 PM[7]

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

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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% biobased[1]

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 CO_2 emissions from shift from fossil fuels, and improved air quality with shift towards electricity-based production (net improvements)

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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/MWh[2], 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 Europe[3], assuming lifetime of 20[4] years (50 for network[5]) 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/MWh[2]

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 PM[5].

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

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

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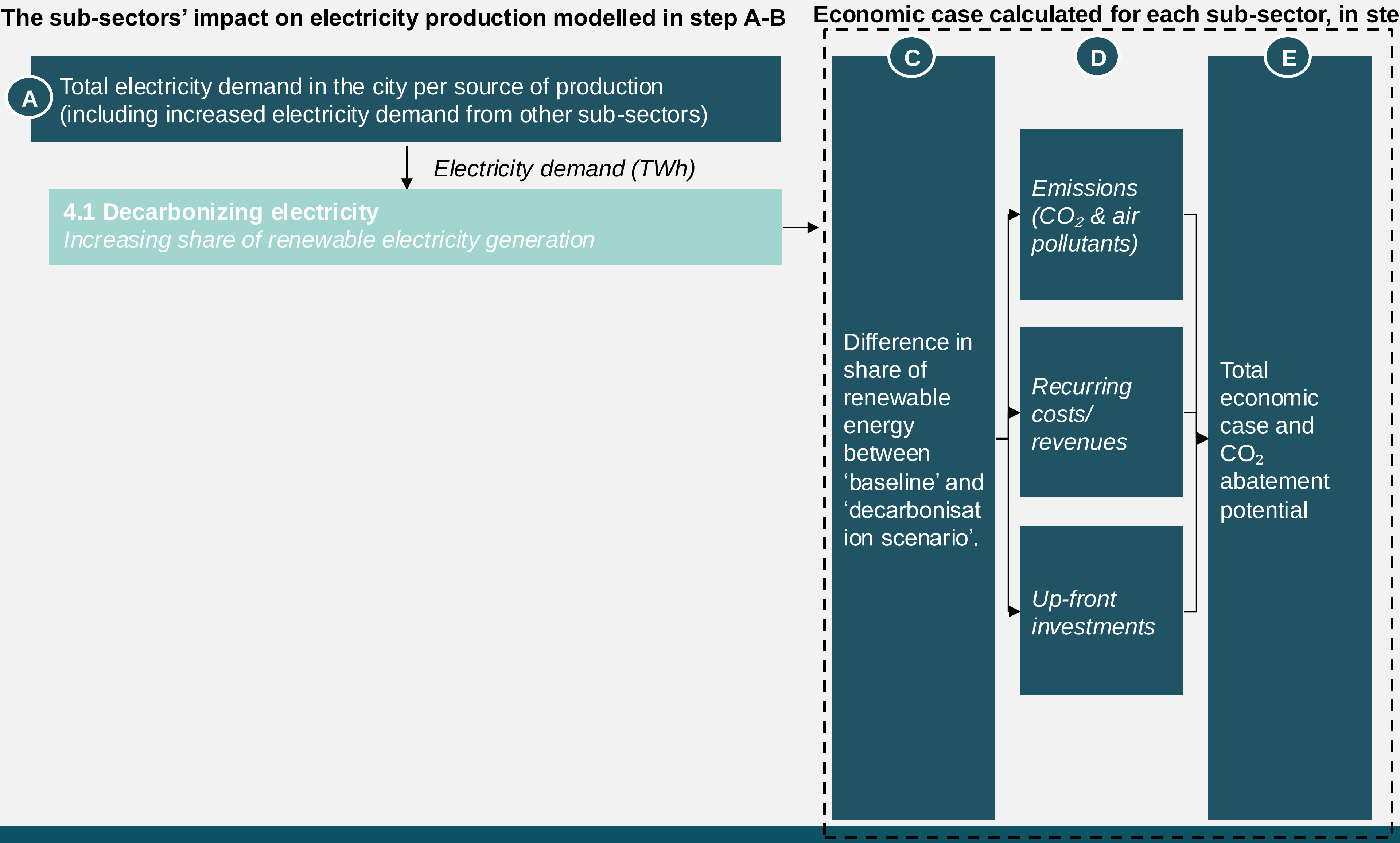
ELECTRICITY

Overview of modelling methodology

🟦 Main modelling steps 🟩 Sub-sectors



The sub-sectors' impact on electricity production modelled in step A-B

Economic case calculated for each sub-sector, in step C-E

A Total electricity demand in the city per source of production (including increased electricity demand from other sub-sectors)

Electricity demand (TWh)

4.1 Decarbonizing electricity
Increasing share of renewable electricity generation

C Difference in share of renewable energy between 'baseline' and 'decarbonisation scenario'.

D

Emissions (CO_2 & air pollutants)

Recurring costs/ revenues

Up-front investments

E Total economic case and CO_2 abatement potential

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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/wind[1]

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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/MWh[2], 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 Europe[3], assuming lifetime of 20[4] years (50 for network[5]) 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/MWh[2]

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 PM[5].

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

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- Freight transport levers
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- **Waste levers**
- Appendix: Lever sensitivities

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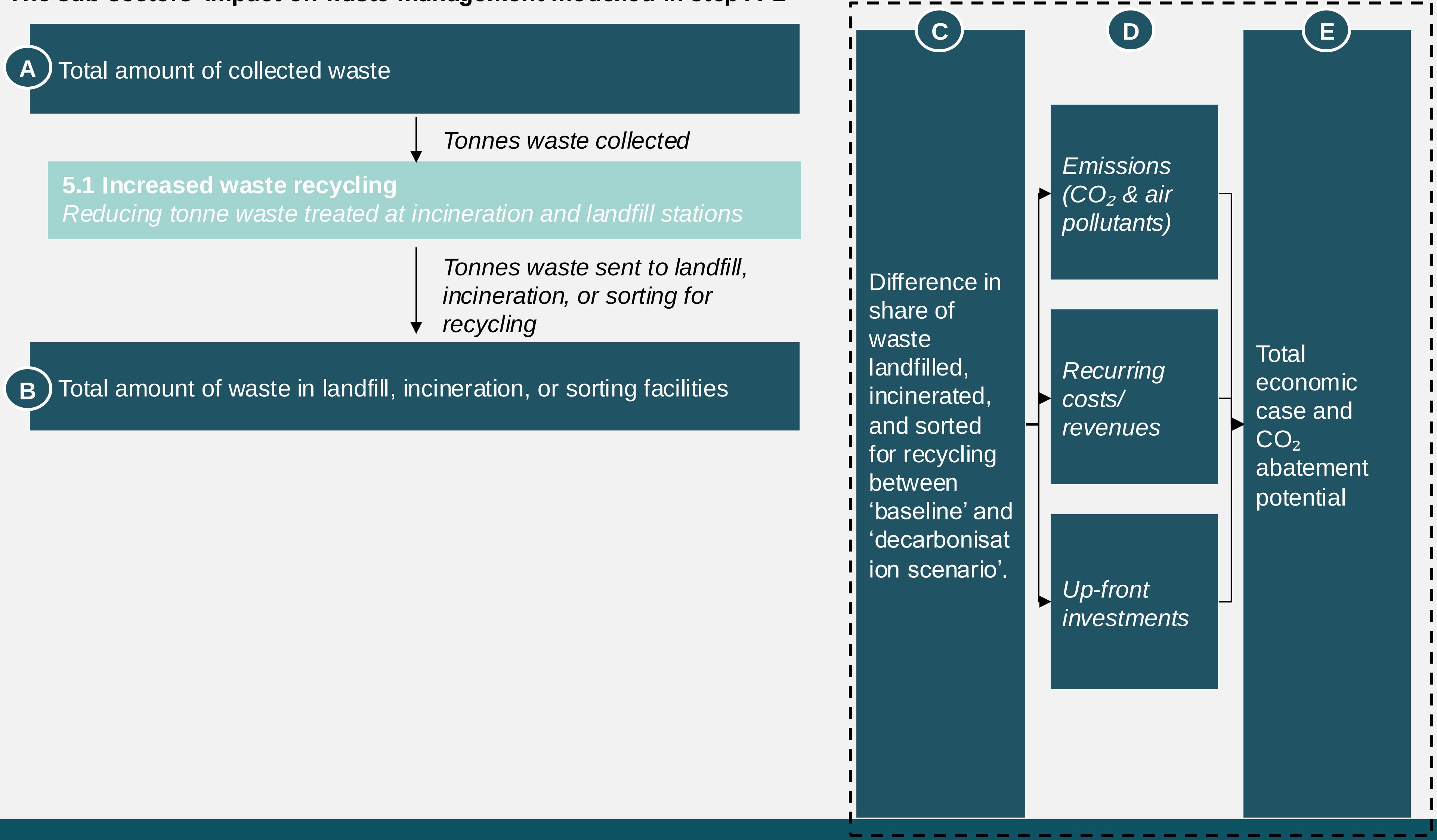
WASTE MANAGEMENT

Overview of modelling methodology

■ Main modelling steps ■ Sub-sectors

The sub-sectors' impact on waste management modelled in step A-B

Economic case calculated for each sub-sectors, in step C-E



A Total amount of collected waste

Tonnes waste collected

5.1 Increased waste recycling
Reducing tonne waste treated at incineration and landfill stations

Tonnes waste sent to landfill, incineration, or sorting for recycling

B Total amount of waste in landfill, incineration, or sorting facilities

C Difference in share of waste landfilled, incinerated, and sorted for recycling between 'baseline' and 'decarbonisation scenario'.

D

Emissions (CO_2 & air pollutants)

Recurring costs/ revenues

Up-front investments

E Total economic case and CO_2 abatement potential

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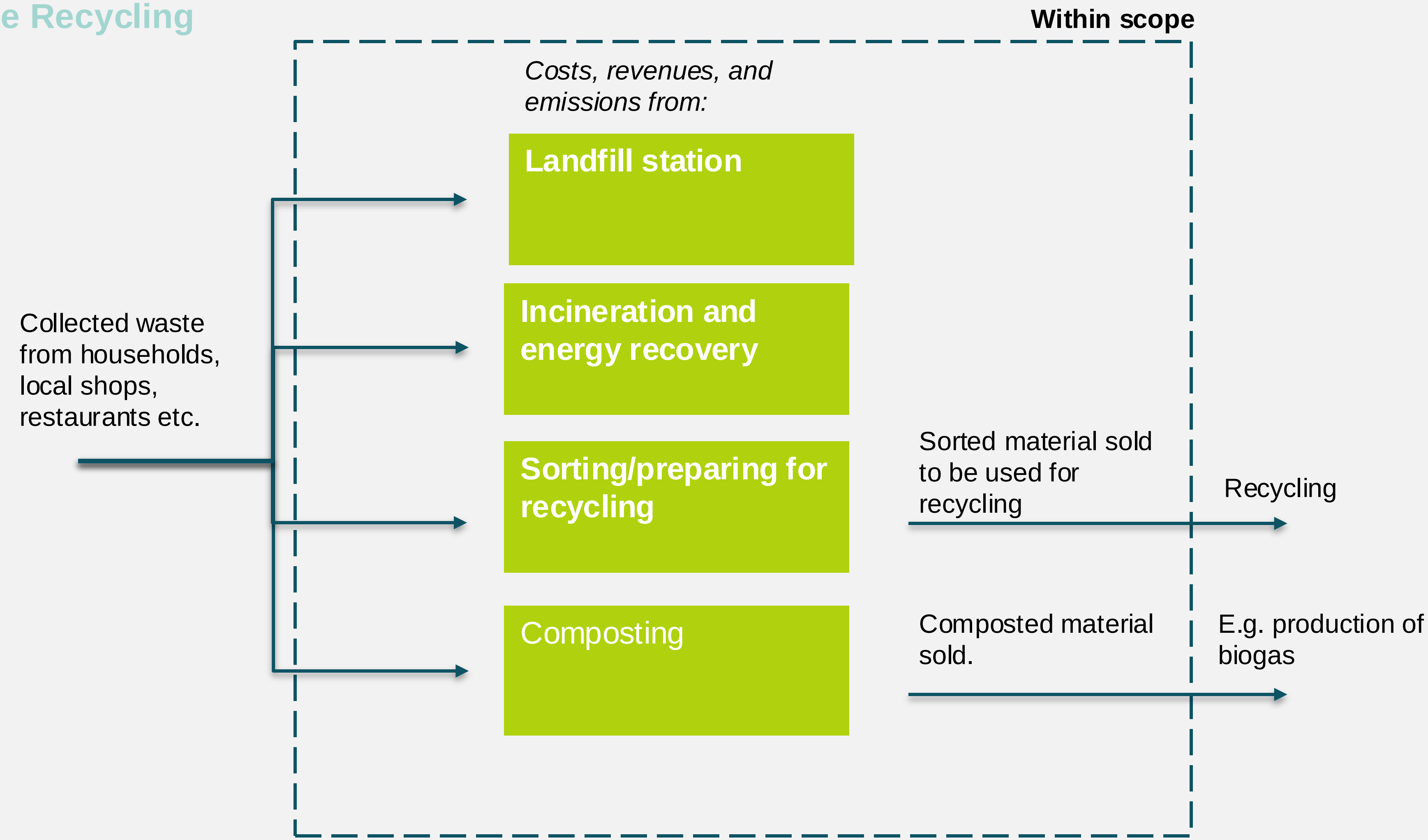
Scope of waste lever

5.1 Waste Recycling



Within scope

Costs, revenues, and emissions from:

Landfill station

Incineration and energy recovery

Sorting/preparing for recycling

Composting

Collected waste from households, local shops, restaurants etc.

Sorted material sold to be used for recycling

Recycling

Composted material sold.

E.g. production of biogas

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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

- CO_2 emissions and air pollutants (NOx 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.

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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 PM[6]

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
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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

- Estimated reduction in passenger kms until 2030

Shift to public & non-motorised transport

- Reduction in car passenger kms until 2030
- Share of kms going to public transport vs walking/cycling
- Health benefits of walking/cycling

Increased car pooling

- Average passengers per car journey in 2030

Electrification of passenger cars

- Share of vehicle kms electrified by 2030
- Up-front cost reduction of EVs vs ICE vehicles over time

Electrification of buses

- Share of vehicle kms electrified by 2030
- Cost reduction of buses until 2030

Optimised logistics

- Average load factor improvement until 2030
- Total vehicle km reduction potential from improved routing by 2030

Electrification of trucks

- Share of vehicle kms electrified by 2030
- Cost reduction of trucks until 2030

Building renovations

- Potential increased annual renovation rate
- Cost per m^2 of different levels of renovations
- Efficiency improvement potential for different levels of renovation

New energy efficient buildings

- Cost per m^2 of different construction standards
- Efficiency improvement potential for different construction standards

Decarbonising heating

- 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

Decarbonising electricity

- 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

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