City Climate Finance Gap Fund

GAP FUND TECHNICAL NOTES

CARBON CREDITING & URBAN CLIMATE CHANGE MITIGATION: ASSESSING POTENTIAL IMPACTS

JUNE 2023

Carbon Crediting and Urban Climate Change Mitigation

Assessing Potential Impacts

Gap Fund Technical Note[1]

Introduction

Carbon crediting and urban climate change mitigation

Approximately 70% of greenhouse gas emissions are generated through consumption in urban areas,[2] which means that decarbonization of cities is essential to limit climate change to 1.5 to 2 °C. While per capita emissions in low- and middle-income countries remain low so far, prompt action is needed to ensure that cities in these countries remain on a low-carbon pathway, before rapid urbanization and increases in consumption lock in high emissions for decades. Technically feasible actions can cut up to 90% of emissions in cities globally between now and 2050. However, the infrastructure investments necessary to do this would cost USD 1.8 trillion each year, by one estimate.[3]

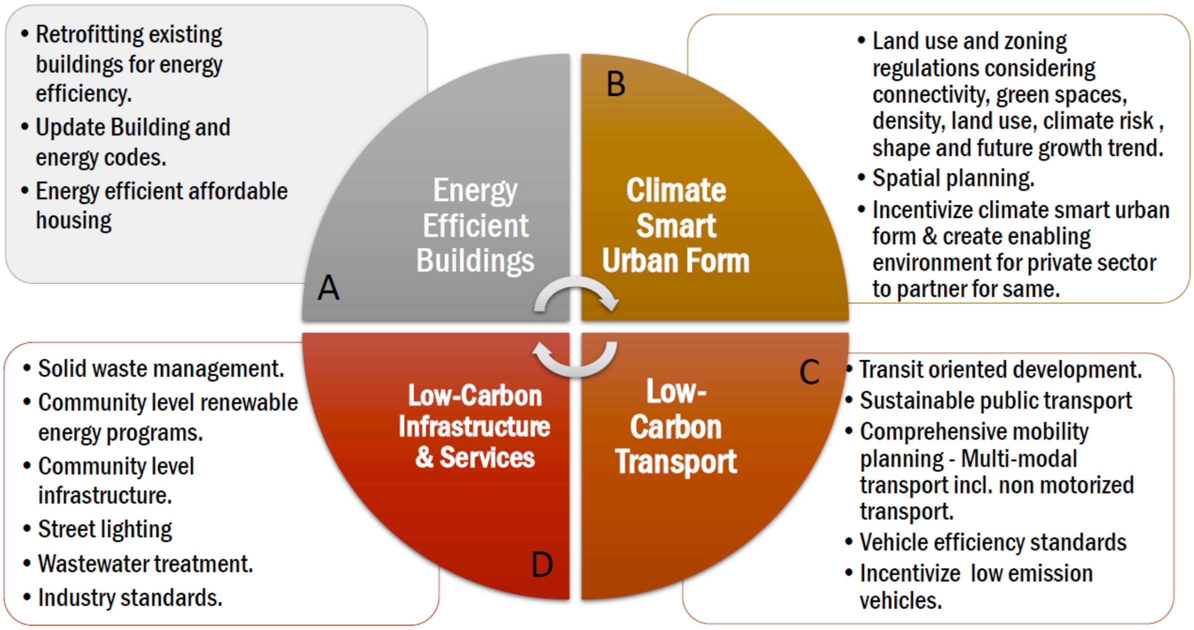
Carbon crediting is one approach to increase funding for mitigation activities. Carbon crediting refers to a system in which tradable credits are generated through activities that reduce carbon emissions or remove carbon from the atmosphere. Each credit typically represents a metric ton of carbon dioxide equivalent avoided or removed. Businesses and other organizations can generate carbon credits (and hence revenue) by demonstrating that emissions have been reduced or sequestered relative to a counterfactual baseline.[4]

According to the Transformative Carbon Asset Facility (TCAF) *Urban Crediting Framework*, carbon crediting for urban areas can increase funding for infrastructure improvements needed in cities

[1] The analysis discussed in this note was conducted by Daniel Hoornweg and David Wotten under the guidance of Augustin Maria. This version of the note was drafted by Chandan Deuskar, with inputs from Daniel Hoornweg, David Wotten, and Augustin Maria. The analysis benefited from discussions with Zarrina Azizova, Vanessa Alexandra Velasco Bernal, Xiaoyu Chang, David Sislen, Lorraine Sugar, and Nuyi Tao.
[2] IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001
[3] Coalition for Urban Transitions. 2019. Climate Emergency, Urban Opportunity. World Resources Institute (WRI) Ross Center for Sustainable Cities and C40 Cities Climate Leadership Group. London and Washington, DC.
[4] The World Bank (2022) "State and Trends of Carbon Pricing 2022" (May), World Bank, Washington, DC. Doi: 10.1596/978-1-4648-1895-0. License: Creative Commons Attribution CC BY 3.0 IGO

while accelerating urban emissions reductions.[5] TCAF identifies four broad areas of GHG emission reduction in urban areas that may fall under the purview of city or sub-national governments, namely energy efficient buildings, climate smart urban form, low carbon transport and low carbon infrastructure and services (Figure 1).

Figure 1 - Four broad areas to reduce GHG emissions in cities



Source: Sachdeva and Rogers (2021)

Ideally, the funding from carbon crediting mechanisms would make it possible for cities to invest in actions that would not otherwise be financially feasible. To assess whether this would be the case, it is necessary to first estimate the net cost per ton[6] of carbon for various urban climate change mitigation actions and compare these costs to the prevailing price per ton of carbon credits. This would indicate whether the availability to cities of funds from carbon crediting is likely to spur urban climate mitigation actions. To take a hypothetical example, if the prevailing price of a carbon credit is USD 10 per ton, and a mitigation action in a city costs USD 30 per ton, the credit may make a significant difference to the financial feasibility of the action. If the action costs USD 1000 per ton, the credit may be too small to matter.

The analysis in this note estimates the net cost per ton of several common urban mitigation activities in two middle-income cities: Istanbul, Turkey and Bogota, Colombia. In doing so, this analysis identifies the activities which might become financially feasible with carbon credits priced within the range of prices in existing programs (up to roughly USD 100 per ton).[7]

[5] Sachdeva, Swati and Rogers, John.2021. *Urban Crediting framework- A guide for government leaders and development professionals working in urban areas*. World Bank, Washington, DC.
[6] Tons throughout this document refer to metric tons (tonnes).
[7] https://carbonpricingdashboard.worldbank.org/map_data

Methodology

Formulas used to calculate the emissions reductions potential and costs per ton are presented in Annex 1. The data used to make these calculations is taken from a wide range of publicly available sources. As the accuracy of input data may vary, as well as due to fluctuations in the cost of electricity and other variables over time, the results are indicative, order of magnitude frameworks.

City-level emissions for Istanbul and Bogota are estimated as the share of the national emissions of their respective country that is equivalent to the average of the city's share of national GDP and the city's share of national population. E.g., if a city has 5% of its country's population and 15% of its GDP, it is estimated to be responsible for 10% of its country's emissions. Emissions inventories are presented in Annex 2.

Results

Istanbul, Türkiye

- Population: 15.5 million
- Annual greenhouse gas emissions: 101.3 MtCO2e (2020 est.)

Istanbul's emissions (approximately 101 Mt CO2e/year, or 6.5 tons per capita per year) are driven mostly by fossil fuel combustion, especially from coal. Table 1 shows the annual estimated emissions reductions and the costs, savings, and net costs (costs minus savings) per year for Istanbul. The results suggest that the largest potential annual reductions among evaluated activities would accrue from space heating (7.7 Mt CO2e), hot water retrofit (4.6 Mt), and electrical efficiencies in buildings (4.16 Mt), largely due to Istanbul's relatively cold climate and high-carbon electricity. The upfront cost of the investments per ton of emissions reduced is relatively high, but these costs would be more than offset by savings to households from lower energy consumption due to the high price of electricity in Istanbul, resulting in net savings of over USD 100 per ton. For these activities, whether carbon credits would make the upfront investments feasible depends on the prevailing rate. A price of USD 10-30 per year may not be sufficient, while a price closer to USD 100 would cover over half the upfront costs.

Updating building codes has the potential to reduce an estimated 3.2 Mt tons annually, which is less than for the other activities in the building sector, but at a much lower upfront cost of USD 9/ton, which means that this cost could potentially be entirely paid for by carbon credits.

Composting of organic waste could be a promising way to reduce emissions via carbon crediting, due to its reasonably high mitigation potential and low net annual cost (USD 85/ton). Other low-cost activities such as landfill gas collection and electrification of waste collection vehicles have lower mitigation potential, according to this analysis.

Shifting public or private vehicles to EVs provides a relatively low mitigation potential due to the high carbon intensity of electricity, and higher upfront costs. While public transport systems have many benefits beyond emissions reductions, their high costs relative to emissions reductions mean that they may not be amenable for carbon crediting support.

Table 1: Estimated emissions reductions and costs - Istanbul, Türkiye

	Potential Reduction per year (MtCO2e/a)	Annual Cost Per Ton of Carbon Reduced (USD/t CO2e)	Annual Savings Per Ton of Carbon Reduced (USD/t CO2e)	Net Annual Cost Per Ton of Carbon Reduced (USD/t CO2e)
Energy Efficient & Safe Buildings				
Space Heating & Cooling Retrofit	7.7	$222	$325	-$102
Hot Water Retrofit	4.6	$166	$282	-$116
Electrical Efficiencies in Buildings	4.2	$177	$282	-$105
Update Building Code	3.2	$9	$240	-$231
Cooking From Natural Gas to Electricity	-0.4	N/A	N/A	N/A
Low-Carbon Transport				
Sustainable Public Transport - LRT	0.8	$4,518	$3,534	$984
EV Public Transport - City Bus Diesel to BEV	0.1	$391	$316	$75
EV Incentive Private Sector	0.2	$323	-$1,630	$1,953
Low-Carbon Infrastructure & Services				
Change Waste Collection Vehicle - Diesel to BEV	0.3	$79	$260	-$181
Composting of Organic Waste	1.3	$167	$83	$85
Landfill Gas Collection & Control	0.1	$7	$0	$7
Community Level Renewable Energy - PV	1.0	$97	$233	-$136
Street Light Energy Efficiency	0.0	$46	$217	-$172

Bogota, Colombia

- Population: 10.9 million
- Annual greenhouse gas emissions: 43.5 MtCO2e (2020 est.)

Bogota's total emissions are relatively low (44 Mt CO2e/year, 4.04 tCO2e/person). The results of this analysis suggest that the largest annual potential reductions in Bogota would accrue from composting organic waste and community-level renewable energy (Table 2). Composting would reduce an estimated 1.1 Mt CO2e, with an estimated upfront cost of USD 97/ton and a net cost of USD 69/ton, for which carbon credits of USD 10-30/ton could make a significant difference. Community-level renewable energy would also reduce an estimated 1.1 Mt, at an estimated upfront cost of USD 205/ton, which may be too high for carbon credits at prevailing rates to matter, but a net saving of USD 745/t.

The relatively low carbon intensity of Bogota's electricity provides little mitigation potential for building retrofits. Access to clean cooking technology is already high, which limits the mitigation potential of further action on clean cooking. Due to Bogota's mild climate, building heating and cooling emissions are relatively low. As in Istanbul, low-cost activities such as landfill gas collection and electrification of waste collection vehicles have relatively low mitigation potential.

Table 2: Estimated emissions reductions and costs – Bogota, Colombia

	Potential Reduction per year (MtCO2e/a)	Annual Cost Per Ton of Carbon Reduced (USD/t CO2e /a)	Annual Savings Per Ton of Carbon Reduced (USD/t CO2e/ a)	Net Annual Cost Per Ton of Carbon Reduced (USD/t CO2e /a)
Energy Efficient & Safe Buildings				
Space Heating & Cooling Retrofit	*** Due to Mild Climate in Bogota Buildings Heating or Cooling emissions are insignificant.			
Hot Water Retrofit NG to Elect.	0.2	$200	-$1,631	$1,832
Electrical Efficiencies Buildings - PV Generation no storage	0.8	$201	$951	-$750
Update Building Code w Hot Water & PV	0.0	$102	-$166	$269
Cooking From Natural Gas to Electricity	*** World Bank Data indicates 93% of Colombia has access to clean cooking technology so CO2e mitigation action will have negligible effect.			
Low-Carbon Transport				
Sustainable Public Transport - LRT	0.3	$3,196	$2,154	$1,042
EV Public Transport - City Bus Diesel to BEV	0.1	$477	$226	$251
EV Incentive Private Sector	0.2	$264	-$1,444	$1,707
Low-Carbon Infrastructure & Services				
Change Waste Collection Vehicle - Diesel to BEV	0.0	$67	$80	-$13
Composting of Organic Waste	1.1	$97	$28	$69
Landfill Gas Collection & Control	0.0	$7	$0	$7
Community Level Renewable Energy - PV	1.1	$205	$951	-$745
Street Light Energy Efficiency	0.0	$99	$742	-$643

Conclusion

The results of this analysis for two cities should be interpreted with caution due to the unverified and variable nature of the underlying data. However, these indicative results suggest the following:

- There is no universal prescription for low-cost carbon mitigation in cities. The mitigation potential and associated costs of activities will vary between cities based on factors including climate, transportation mode shares, access to clean cooking technology, and others.
- The carbon intensity of a city's electricity (existing and future) is an important factor in determining the mitigation potential of activities. For example, in a city with high-carbon electricity, electrification of vehicles has lower mitigation potential, whereas energy

efficiency retrofits of buildings which reduce electricity consumption have higher mitigation potential. The opposite is true in cities with low-carbon electricity.

- Analysis such as this can be useful in identifying the mitigation activities that fall into the "sweet spot" in which mitigation potential is high enough to matter but costs are low enough that carbon crediting may be worth pursuing, e.g., composting of organic waste in both cities.
- Even in the case of actions with high mitigation potential which pay for themselves over time, e.g., building retrofits in Istanbul, carbon crediting may be useful in covering the upfront cost, thereby "unlocking" both the emissions reductions and future financial savings and prioritizing the activity.
- The activities which are least expensive per ton of mitigation, with costs which could be substantially or completely covered by carbon credits at prevailing rates, may not be worth implementing, at least not for the sake of emissions reductions alone, due to their low total mitigation potential, e.g., landfill gas collection and electrification of waste collection vehicles in both cities.

Finally, it is important to note that the calculations above focus on reductions in current emissions. Some of these actions, as well as others beyond these, could have a significant impact on avoiding future emissions, particularly in rapidly growing cities. Additional analysis and discussion would be needed to evaluate the long-term benefits of such actions, as well as discussing how these benefits could be considered when issuing carbon credits.

Annexes

1. *List of assessed activities – detailed calculations*

CATEGORY 1: ENERGY EFFICIENT BUILDINGS

ACTIVITY 1A - RETROFIT EXISTING BUILDINGS - EFFICIENCY OF SPACE HEATING & COOLING

PUBLIC

INDUSTRIAL & COMMERCIAL

RESIDENTIAL

Buildings divided by asset class and typical ownership.

Potential Carbon Reductions (excludes benefits of increased resilience, improved comfort and air quality)

Carbon Reduction Potential (tCO_2e) = Floor Space (m^2) X Emissions Reductions ($tCO_2e/m^2/a$)

Cost

Carbon Reduced ($\$/tCO_2e$) = Heat & Cooling retrofit ($\$/m^2/a$) / Emissions Reductions ($tCO_2e/m^2/a$)

Cost of Carbon Reduced (Net)

Carbon Reduced ($\$/CO_2e$, Net) = Carbon Reduced ($\$/CO_2e$) - Savings per CO_2e reduced ($\$/CO_2e$)

Estimates & Assumptions

Floor space (e.g., Public, Industrial & Commercial or residential building) retrofitted in square meters (m^2);

Net Potential Emissions Reductions ($tCO_2e/m^2/a$) = Potential energy savings from retrofit in ($kWh/m^2/a$) X emissions factor of the energy system used (CO_2e/kWh) - emissions caused by the retrofit ($tCO_2e/m^2/a$) annualized over life of retrofit (e.g., material / embodied carbon of insulation used)

Cost of Heat & or Cooling retrofit averaged over life ($\$/m^2/a$) = Equivalent annual cost of capital ($/a) +/- change in annual maintenance cost($/a), divided by the floor area of sector being retrofitted (m^2)

Savings per ton of CO_2e reduced ($\$/CO_2e$) = Cost of current energy ($/kWh) times the energy saved from retrofit ($kWh/m^2/a$) / Net Potential Emissions reductions ($tCO_2e/m^2/a$)

ACTIVITY 1B- RETROFIT EXISTING BUILDINGS - RETROFIT EFFICIENCY OF HOT WATER SYSTEMS

PUBLIC

INDUSTRIAL & COMMERCIAL

RESIDENTIAL

Buildings divided by asset class and typical ownership.

Potential Carbon Reductions

Carbon reduction potential per sector (tCO_2e) = Floor Space of Building Sector (m^2) X Net Potential Emissions Savings of Hot Water Retrofit ($tCO_2e/m^2/a$)

Cost

Cost of Carbon reduced ($\$/tCO_2e$) = Annualized cost of Hot Water retrofit ($\$/m^2/a$) / Net Potential Emissions Savings ($tCO_2e/m^2/a$)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($\$/CO_2e$) = Cost of Carbon Reduced ($\$/CO_2e$) - Savings of CO_2e reduced ($\$/CO_2e$)

Estimates & Assumptions

Net Potential Emissions Reductions of hot water retrofit ($tCO_2e/m^2/a$) = The potential annualized energy saving from retrofit in ($kWh/m^2/a$) times the emissions factor of the current energy system used (CO_2e/kWh) less any emissions caused by the retrofit ($tCO_2e/m^2/a$) e.g., material carbon of Boiler used

Cost of Hot Water retrofit averaged over life ($\$/m^2/a$) = Equivalent annual cost of capital for hot water retrofit ($/a) +/- change in annual maintenance cost($/a), divided by the floor area of sector being retrofitted (m^2)

Savings of CO_2e reduced ($\$/tCO_2e$) = Cost of energy per kWh ($/kWh) times the energy saved from retrofit ($kWh/m^2/a$) / Net Potential emissions reduction ($tCO_2e/m^2/a$)

ACTIVITY 1C - RETROFIT EXISTING BUILDINGS - RETROFIT EFFICIENCY OF ELECTRICAL DEMAND

PUBLIC

INDUSTRIAL & COMMERCIAL

RESIDENTIAL

Buildings divided by asset class and typical ownership.

Potential Carbon Reductions (excluding enhanced livability, increased resilience)

Carbon reduction potential per sector (tCO2e) = Floor Space of Building Sector (m^2) X Net Potential Emissions Savings of Electrical Retrofit (tCO2e/m^2/a)

Cost

Cost of Carbon per ton reduced ($/tCO2e) = Cost of Electrical retrofit averaged over life ($/$m^2$/a) / Emissions Savings (tCO2e/m^2/a)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/CO2e) = Cost of Carbon Reduced ($/CO2e) - Savings per ton of CO2e reduced ($/CO2e)

Estimates & Assumptions

Net Potential Emissions Reductions (CO2e) of electrical retrofit (tCO2e/m^2/a) = Potential annualized energy savings from retrofit (kWh/m^2/a) times the emissions factor of the energy system (CO2e/kWh) less any emissions caused by the retrofit (tCO2e/m^2/a) e.g., waste heat from LED lighting retrofit is reduced in a heating dominated climate, emissions from the increase in the heating system to make up the shortfall should be included.

Cost of Electrical retrofit average over life ($/$m^2$/a) = Equivalent annual cost of Capital for electrical retrofit ($/a) +/- change in annual maintenance cost($/a), divided by the floor area of sector being retrofitted (m^2)

Savings Per Ton CO2e Reduced ($/CO2e) = Cost of energy ($/kWh) times the energy saved from retrofit (kWh/m^2/a) / Net Potential Emissions Reductions (tCO2e/m^2/a)

ACTIVITY 1D- UPDATE BUILDING CODES – SCOPES 1, 2 AND 3 (INCL. EMBODIED EMISSIONS)

PUBLIC

INDUSTRIAL & COMMERCIAL

RESIDENTIAL

Buildings divided by asset class and typical ownership.

Potential Carbon Reductions (excludes increased resilience and utility, improved comfort, IAQ)

Carbon reduction potential (tCO2e) = Floor Area of Sector projected to be built (m^2) X Net Potential Emissions Reductions (tCO2e /m^2/a)

Cost

Cost of Carbon Reduced ($/tCO2e) = Capital Cost of Energy Efficiency ($/$m^2$/a) / Potential Emissions Reductions (tCO2e/m^2/a)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/tCO2e) = Cost of Carbon Reduced ($/tCO2e) - Savings of CO2e reduced ($/tCO2e)

Estimates & Assumptions

Net Potential Emissions Reductions (tCO2e/m^2/a) = Potential Energy Saving resulting from new code (kWh/m^2/a) X the emissions factor of the energy system used (tCO2e/kWh) - annualized emissions from the construction of the building (e.g., embodied carbon emitted from the production of insulation, concrete, steel, siding, etc.) (tCO2e/m^2/a).

Capital Cost of Energy Efficiency ($/$m^2$/a) = Equivalent annual cost of the additional capital expense resulting from the proposed Building code ($/a) + annual additional maintenance cost ($/a) / floor area of sector being retrofitted (m^2);

Savings of CO2e reduced ($/tCO2e) = Potential Energy saved from new building code (kWh/m^2/a) X Cost of Energy per kWh ($/kWh) / Net Potential Emissions Reduction (tCO2e/m^2/a)

ACTIVITY 1E – CLEAN COOKING EFFICIENCY IMPROVEMENT (RESIDENTIAL)

Potential Reductions in carbon emissions (excluding particulates and health benefits)

Carbon Reduction Potential (tCO_2e) = Number of Households (H) X Net Emissions Potential Reductions Per household ($tCO_2e/H/a$)

Cost

Carbon reduced ($\$/tCO_2e$) = Net Capital Cost of Activity for Cooking per household ($/H/a) / Net Emissions Potential Reductions per household per year ($tCO_2e/H/a$)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($\$/CO_2e$) = Cost of Carbon Reduced ($\$/CO_2e$) - Savings per ton of CO_2e reduced ($\$/CO_2e$)

Estimates & Assumptions

Assuming the proposed new cooking activity would be phased in when a new cooking system was required.

In any combustion of fuel, especially wood, black carbon emissions are to be included in CO_2e. Total emissions includes material/ embodied emissions of cooking device, maintenance and operational emissions.

The number of households (X #H) can be disaggregated by type of cooking (e.g., by households cooking with kerosene, wood, gas, etc.);

Net Emissions Potential Reduction Per Household ($tCO_2e/H/a$) = Total Emissions from current method (tCO_2e/m) – Total Emissions from proposed method (tCO_2e/m)) X the number of households per year (#m/H/a).

Net Capital Cost of Activity for Cooking per household ($/H/a) = Capital cost of the proposed cooking activity annualized per household includes cooking appliance and maintenance ($/H/a) - Capital cost of the current cooking activity including maintenance ($/H/a)

Savings per ton of CO_2e reduced ($\$/tCO_2e$) = Cost of current cooking method per meal ($/m) – Cost of proposed cooking method per meal ($/m) X number of cooked meals per household per year (#m/H/a)) / Net Emissions Potential Reduction ($tCO_2e/H/a$)

Assumptions – Building Sector
HVAC – Heating, ventilation and air conditioning
Retrofit activities amortized over 10 - 30 years depending on activity; discount rate and inflation per activity
Buildings divided into three broad categories: residential (self-owned and rented); government and institutional (all levels, mainly public sector ownership and management); industrial and commercial (mainly private sector ownership and operation).
Heating degree and cooling degree days determined by climactic zone.

CATEGORY 2: LOW-CARBON INFRASTRUCTURE & SERVICES

ACTIVITY 2A: SOLID WASTE MANAGEMENT - CHANGES TO COLLECTION FLEET

Potential Carbon Reductions (excluding reduced service requirements, noise and particulate pollution)

Carbon Reduction Potential (tCO_2e/a) = Number of Waste Collection Vehicles (CV) X Net Potential Emissions Reductions per CV (tCO_2e/CV/a)

Cost (assuming the purchase of an existing vehicle vs purchase of a lower or zero emission vehicle)

Cost of Carbon per ton reduced ($/$tCO_2e$) = Net Cost of proposed CV averaged over life ($/CV/a) / Net Potential Emissions Reductions per CV (tCO_2e/CV/a)

Net Cost of Carbon Reduced

Net Cost of Carbon ($/$CO_2e$) = Cost of Carbon Reduced ($/$CO_2e$) less Savings per ton of CO_2e reduced ($/$CO_2e$)

Estimates & Assumptions

Black carbon emissions included through separate activity

Net Potential Emissions Reductions per CV per year (tCO_2e/CV/a) = Average km travelled (km/CV/a) X [Current Emissions Factor per km traveled (including material and operations emissions), (tCO_2e/km) - Proposed Emissions Factor per km traveled (including material and operations emissions) (tCO_2e/km)]

Net Cost of proposed CV averaged over life ($/CV/a) = (Equivalent net annual Capital Cost of proposed CV ($/CV/a) + maintenance and or infrastructure ($/CV/a)) – (Equivalent net annual Capital Cost of current CV ($/CV/a) + maintenance and or infrastructure ($/CV/a))

Savings per ton of CO_2e reduced ($/$CO_2e$) = Average annual km travelled per CV (km/CV/a) X [[(Cost of Current Energy per ($/km) – Cost of New Energy per ($/km)] + any Cost of New Energy per ($/km)] / Potential Emissions Reductions per CV (tCO_2e/CV/a)

ACTIVITY 2B: SOLID WASTE MANAGEMENT - COMPOSTING OF ORGANICS FROM LANDFILL

Potential Carbon Reductions (excludes potential environmental, public safety, and agricultural benefits)

Total Emissions Reduction for Organic Waste (tCO2e/a) = Organic Waste (OW) Diverted from Landfill (tOW) X Net Reduction of CO2e Emission per ton (tCO2e/tOW)

Cost

Cost of Carbon Reduction ($/tCO2e) = Cost of Composting ($/tOW) / CO2e Reductions of Organic Waste (tCO2e/tOW)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/tCO2e) = Cost of Carbon Reduced ($/tCO2e) less Savings per ton of CO2e reduced ($/tCO2e)

Estimates & Assumptions

Potential Organic Waste (OW) that is compostable that can be diverted from landfill sites (tOW) derived from the % of Organic Waste in the Solid waste stream that is not already being composted or managed in another form;

Net Reduction of CO2e (tCO2e/tOW) = CO2e of other greenhouse gasses reduced, including methane resulting from composting activity (tCO2e/tOW), +/- CO2e emissions emitted or sequestered as a result of the composting process respectively (tCO2e/tOW).

Cost of Composting ($/tOW) = Capital Cost of the composting facility divided by the annual processing capacity in tons($/tOW) + operating and maintenance cost ($/tOW) (excluding transport to site)

Savings ($/tCO2e) = Savings of Compost activity includes the avoided disposal fees ($/tOW) + (Revenue from sales of finished compost ($/a) / Organic Waste processed (tOW)) / Net Reduction emissions (tCO2e/tOW)

ACTIVITY 2C: SOLID WASTE MANAGEMENT - LANDFILL GAS (LFG) CAPTURE / USE

Potential Carbon Reductions (excluding potential safety benefits)

Total Emissions Reduction Potential for LGF ($tCO2e/a$) = Annual Tons of Solid Waste (SW) going to Landfill (tSW/a) X Net Emissions Reduction Potential ($tCO2e/tSW$)

Cost

Cost of Carbon Reduction ($\$/tCO2e$) = Cost of LFG Capture ($\$/tSW$) / CO2e Reductions Potential of LFG ($CO2e/tSW$)

Net Cost of Carbon Reduced (with GWP of methane – 86 over 20 years)

Net Cost of Carbon Reduced ($\$/CO2e$) = Cost of Carbon Reduced ($\$/CO2e$) less Savings per ton of CO2e reduced ($\$/CO2e$)

Estimates & Assumptions

Net Emissions Reduction Potential ($tCO2e/tSW$) = [Landfill gas emissions ($tCO2e/tSW$) + (Methane Emissions (tCH_4/tSW) X Global Warming Potential Emissions Factor for CH_4 (GWP) ($tCO2e/tCH_4$)) x GWP ($tCO2e/tBC$))] - Carbon equivalent emissions from the capture or use of the LGF ($tCO2e/tSW$)

Cost of Carbon Reduced per ton ($\$/tCO2e$) = [(Capital cost of LFG capture facility ($\$C/a$) / tons of SW capacity per year (tSW/a)) + facilities Operating ($\$/tSW$)] / Emissions Reduction potential ($tCO2e/tSW$)

Savings Potential of CO2e reduced ($\$/CO2e$) = [(Potential revenue from the LFG (kWh/a) X price of energy ($\$/kWh$)) / tons of SW per year (tSW/a)] / Net Emissions Reduction potential ($CO2e/tSW$)

ACTIVITY 2D: COMMUNITY LEVEL RENEWABLE ENERGY

Potential Carbon Reductions

Carbon Reduction Potential (tCO2e) = Size of Renewable Energy project (kWh/a) X Net Emissions Reduction Potential energy system (tCO2e/kWh)

Cost

Cost of Carbon ($/tCO2e) = Cost of Renewable Energy System ($/kWh/a) / Net Emissions Reduction Potential of energy system (tCO2e/kWh)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/CO2e) = Cost of Carbon Reduced ($/CO2e) - Potential Savings of CO2e reduced ($/CO2e)

Estimates & Assumptions

Assumes the system offsets existing energy production and not additional new production. If net new energy production, then cost of new fossil fuel system energy generation system included in calculations for net cost. Energy storage not included.

Net Emissions Reduction from potential energy system (tCO2e/kWh) = Emissions factor of current energy system (Scope 1,2,3) excluding previous construction (tCO2e/kWh) - Emissions factor of proposed Renewable Electricity system (Scopes 1,2,3) (tCO2e/kWh) including emissions associated with manufacture and maintenance. (tCO2e/kWh).

Cost of Renewable Energy System ($/kWh) = Annualized Capital Cost of Renewable energy system ($/kWh) (excluding residual value) + maintenance of system ($/kWh)

Potential Savings per ton CO2e reduced ($/tCO2e) = Cost of Current Electrical Energy being offset ($/kWh) / Net Emission Reduction Potential (tCO2e/kWh)

ACTIVITY 2E: STREET LIGHTING – ENERGY EFFICIENCY IMPROVEMENT

Potential Carbon Reductions

Carbon Reduction Potential (tCO_2e) = Number of Street Lights (#SL) X Energy Reduction Potential (kWh/SL/a) X Emissions factor of electricity (tCO_2e/kWh)

Cost

Cost of Carbon per ton reduced ($/$tCO_2e$) = Cost of Street Light ($/SL/a) / Annual emissions Savings per SL (tCO_2e/SL/a)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/$CO_2e$) = Cost of Carbon Reduced ($/$CO_2e$) - Savings from CO_2e reduced ($/$CO_2e$)

Estimates & Assumptions

Energy Reduction Potential (kWh/SL/a) = Energy Use per Street Light (SL)(kW) X hours used per day (H/day) X 365 days per year X Energy efficiency improvement from current light to proposed light (%)

Cost of Street Light Energy Efficiency ($/SL/a) = Annual capital cost of proposed street lights ($/SL/a) + annual maintenance ($/SL/a)

Emissions Savings per SL (t CO_2e/SL/a) = Energy Reduction Potential (kWh/SL/a) x Emissions factor of electricity (t CO_2e/kWh) (assuming using the same energy source)

Potential Savings per ($/t CO_2e) = Energy Efficiency Reduction Potential (kWh/SL/y) X Cost of Energy ($/kWh) / Emissions savings per SL per year (tCO_2e/SL/a)

ACTIVITY 2F: METHANE MITIGATION – COMMUNITY-WIDE PROGRAM

Potential Carbon Reductions (CO_2e from methane)

Carbon Reduction Potential (tCO_2e) = Current practice X Carbon Reduction Potential (CO_2e)

Cost

Cost per ton reduced ($/$tCO_2e$) = Annual cost of activity ($/a) / Emissions reductions (tCO_2e/a)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/$CO_2e$) = Cost of Carbon Reduced ($/$CO_2e$) - Savings per ton of CO_2e reduced ($/$CO_2e$)

Estimates & Assumptions

Key focus: (i) organic waste (landfill gas avoidance and/or collection and combustion; composting/digestion; improved collection – avoiding anaerobic digestion in waterways; urban livestock management [in addition to activities outlined in Activities 2B and 2C]); (ii) wastewater treatment – avoidance, collection and combustion of methane, and; (iii) reduced fugitive emissions in gas pipelines and appliances.

Calculated case-by-case

ACTIVITY 2G: BLACK CARBON REDUCTION – COMMUNITY-WIDE PROGRAM

Potential Carbon Reductions (CO2e from black carbon)

Carbon Reduction Potential (tCO2e) = Current practice X Carbon Reduction Potential (CO2e)

Cost

Cost per ton reduced ($/tCO2e) = Annual cost of activity ($/a) / Emissions reductions (tCO2e/a)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/CO2e) = Cost of Carbon Reduced ($/CO2e) - Savings per ton of CO2e reduced ($/CO2e)

Estimates & Assumptions

Key focus: (i) solid waste management (reduced open burning); (ii) reduced burning of crop residue and forests (within and near to city); (iii) improved manufacturing practices, e.g. brickmaking, and (iv) improved efficiency of internal combustion engines.

Calculated case-by-case

CATEGORY 3: LOW-CARBON TRANSPORT

ACTIVITY 3A: SUSTAINABLE PUBLIC TRANSPORT

SUBWAY

LIGHT RAPID TRANSIT (LRT)

BUS RAPID TRANSIT (BRT)

Potential Carbon Reductions (excludes benefits of improved mobility, e.g. economic and health)

Carbon Reduction Potential (t CO_2e/a) = Potential Number of Reduced Vehicle Kilometers Traveled (km/a) X Net Carbon Emissions Reduction in transport modes per passenger (tCO_2e/p-km)

Cost

Cost of Carbon ($/t$CO_2e$) = Cost of Subway or LRT per passenger km ($/p-km) / Net Carbon Emissions Reduction (tCO_2e/p-km)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced = Cost of Carbon Reduced ($/$CO_2e$) less Savings per ton of CO_2e reduced ($/$CO_2e$)

Estimates & Assumptions

Net Carbon Emissions Reduction in transportation mode (t CO_2e/km/p) = (Emission Factor of Current Personal Vehicle per km (t CO_2e/km) / Average number of people in a Personal Vehicle (PV A#p)) – Emission Factor (Subway-LRT-BRT) Vehicle per passenger km (tCO_2e/p-km)

Cost of Subway or LRT averaged over system life per passenger km ($/p-km) = Equalized annual Capital Cost of Subway LRT-BRT system averaged over life per passenger km ($/p-km) + annual operation and maintenance cost ($/p-km)

Potential Savings ($/t$CO_2e$) = Savings of Reduced Personal Vehicle Kilometers Traveled per passenger ($/p-km) / Net Emissions Reduction in transport mode per passenger (tCO_2e/p-km)

Note: For improved accuracy, Carbon Life cycle analysis of material and energy sources should be included in calculations.

ACTIVITY 3B: SUSTAINABLE PUBLIC TRANSPORT – RIDE SHARE

Potential Carbon Reductions

Carbon Reduction Potential (tCO_2e) = Potential Number of Reduced Vehicle Kilometers Traveled (km/a) X Net Carbon Emissions Reduction Potential by Passengers (p)(tCO_2e/km/p) x Current average number of People per Personal Vehicle (C #p)

Cost

Cost of Carbon per ton reduced (\$/t CO_2e) = Cost of Ride Share averaged over life per passenger km (\$/km/p) / Net Carbon Emissions Reduction Potential per passenger (t CO_2e/km/p)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced = Cost of Carbon Reduced (\$/CO_2e) - Savings per ton of CO_2e reduced (\$/CO_2e)

Estimates & Assumptions

Net Carbon Emissions Reduction Potential (t CO_2e/km/p) = (Emission Factor of Vehicle per km (t CO_2e/km) / Current average number of passengers (C #p)) – (Emission Factor Vehicle per km (t CO_2e/km) / Potential average number of passengers (P #p)).

Cost of Ride Share averaged over system life per passenger km (\$/km/p) = Equalized annual Capital Cost of Ride Share program averaged over life per passenger km (\$/km/a/p) + annual operation and maintenance cost (\$/km/a/p)

Potential Savings (\$/t CO_2e) = Cost of Reduced Personal Vehicle Kilometers Traveled per passenger (\$/km/p) / Net Emissions Reduction Potential per passenger (t CO_2e/km/p)

ACTIVITY 3C: SUSTAINABLE PUBLIC TRANSPORT – EVS PUBLIC VEHICLES

Potential Carbon Reductions

Carbon Reduction Potential (t CO2e) = Potential Number of Reduced Vehicle Kilometers Traveled (km/a) X Net Carbon Emissions Reductions (t CO2e/km)

Cost

Cost of Carbon per ton reduced ($/t CO2e) = Net Cost of EV Vehicle & Infrastructure averaged over life ($/km) / Net Carbon Emissions Reduction (t CO2e/km)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced ($/CO2e) = Cost of Carbon Reduced ($/CO2e) - Savings per ton of CO2e reduced ($/CO2e)

Estimates & Assumptions

Assuming public vehicle needs to be purchased and the option is between current vehicle and electric equivalent vehicle.

Net Carbon Emissions Reduction Potential (t CO2e/km) = Emission Factor of Current Vehicle per km Current Fuel including material, maintenance and operations (t CO2e/km) – Emission Factor Vehicle per km on Electrical Grid including material, charging infrastructure, maintenance and operations (t CO2e/km)

Emission Factor of Current Vehicle per km Current Fuel including material, maintenance and operations (t CO2e/km) = (Emissions Factor of Fuel (t CO2e/l) / Vehicle Efficiency (km/l)) + equalized annual emissions of the material to make and maintain the vehicle (t CO2e/km)

Emission Factor of Vehicle per km on Electrical Grid (t CO2e/km) = (Emissions Factor of Electricity Grid (t CO2e/kWh) / Vehicle Efficiency (km/kWh)) + equalized annual emissions of the material to make and maintain the vehicle (t CO2e/km)

Net Cost of EV Vehicle & Infrastructure averaged over life ($/km) = (Equalized annual Capital Cost of Electric Vehicle averaged over life ($/km) + Equalized annual Capital Cost of Charging Infrastructure averaged over life($/km) + Maintenance ($/km)) – (Equalized annual Capital Cost of Current Vehicle averaged over life ($/km) + Equalized annual Capital Cost of Infrastructure averaged over life($/km) + Maintenance ($/km))

Potential Savings ($/t CO2e) = (Savings from Reduced Fuel ($/km) / Net Carbon Emissions Reduction (t CO2e/km)

Savings from Reduced Fuel ($/km) = Cost of Fossil fuel per km ($/km) – Cost of Electricity per km ($/km)

ACTIVITY 3D: SUSTAINABLE PUBLIC TRANSPORT – EV INCENTIVE TO PRIVATE SECTOR

Potential Reductions

Carbon Reduction Potential (t CO_2e) = Potential Number of Reduced Vehicle Kilometers Traveled with Incentive (km/a) X Net Carbon Emissions Reduction Potential (tCO_2e/km)

Cost

Cost of Carbon per ton reduced ($/t CO_2e) = Cost of EV Vehicle & Infrastructure Incentive averaged over life ($/km) / Net Carbon Emissions Reduction Potential (t CO_2e/km)

Net Cost of Carbon Reduced

Net Cost of Carbon Reduced = Cost of Carbon Reduced ($/$CO_2e$) - Savings per ton of CO_2e reduced ($/$CO_2e$)

Estimates & Assumptions

Net Carbon Emissions Reduction Potential (t CO_2e/km) = Emission Factor of Current Vehicle per km Current Fuel including material, maintenance and operations (t CO_2e/km) – Emission Factor Vehicle per km on Electrical Grid including material, charging infrastructure, maintenance and operations (t CO_2e/km)

Emission Factor of Current Vehicle per km Current Fuel including material, maintenance and operations (t CO_2e/km) = (Emissions Factor of Fuel (t CO_2e/l) / Vehicle Efficiency (km/l)) + equalized annual emissions of the material to make and maintain the vehicle (t CO_2e/km)

Emission Factor of Vehicle per km on Electrical Grid (t CO_2e/km) = (Emissions Factor of Electricity Grid (t CO_2e/kWh) / Vehicle Efficiency (km/kWh)) + equalized annual emissions of the material to make and maintain the vehicle (t CO_2e/km)

Cost of EV Vehicle & Infrastructure Incentive averaged over life ($/km) = Equalized annual cost of Vehicle Incentive averaged over life ($/km) + Equalized annual cost of Charging Infrastructure Incentive averaged over life($/km)

Potential Savings ($/t CO_2e) = (Savings of Reduced Fuel ($/km) + Savings of Reduced Maintenance ($/km)) / Net Carbon Emissions Reduction (t CO_2e/km)

Savings of Reduced Fuel ($/km) = Cost of Fossil fuel per km ($/km) – Cost of Electricity per km ($/km)

Savings of Reduced Maintenance ($/km) = Maintenance Cost Fossil Fuel Vehicle & Infrastructure ($/km) – Maintenance Cost Electric Vehicle & Infrastructure ($/km)

ACTIVITY 3E: SUSTAINABLE PUBLIC TRANSPORT – CONGESTION PRICING

Potential Carbon Reductions (excluding benefits from improved mobility)

Carbon Reduction Potential (t CO2e/a) = Potential Number of Reduced Vehicle Kilometers Traveled resulting from Congestion Pricing (km/a) X Net Carbon Emissions Reduction per passenger (t CO2e/p-km)

Cost

Cost of Carbon per ton reduced ($/t CO2e) = Cost of The Congestion Pricing Per km Reduced ($/p-km) + Cost of Public Transport ($/p-km) / Net Carbon Emissions Reduction (tCO2e)p-km)

Net Cost of Carbon Conserved/Reduced

Net Cost of Carbon Reduced = Cost of Carbon Reduced ($/CO2e) – Potential Savings per ton of CO2e reduced ($/CO2e)

Estimates & Assumptions

People in personal vehicle will take most convenient public transportation mode to work to avoid congestion fees;

Average of available public transit systems will be used to calculate the emissions factor per km per passenger in below calculations.

Net Carbon Emissions Reduction per Passenger (t CO2e/km/p) = (Emission Factor of Current Vehicle per km (tCO2e/km) / Current average number of people per Personal Vehicle (PV A#p)) – Emission Factor Avg Public Transit Vehicle per person km (t CO2e/p-km)

Reduction % = Potential Number of Reduced Personal Vehicle Kilometers Traveled resulting from Congestion Pricing (km) / Current Personal Vehicle Kilometers Travelled in the Proposed Congestion Charge Zone (km)

Cost of Congestion Pricing Per km Reduced per passenger ($/p-km) = Congestion Charge ($/p-km) * (1 - Reduction%) / Reduction%

Potential Savings per ton CO2e ($/t CO2e) = (Savings of fossil fuel Reduced ($/p-km) + Savings of Reduced Maintenance ($/p-km)) / Net Carbon Emissions Reduction (t CO2e/p-km)

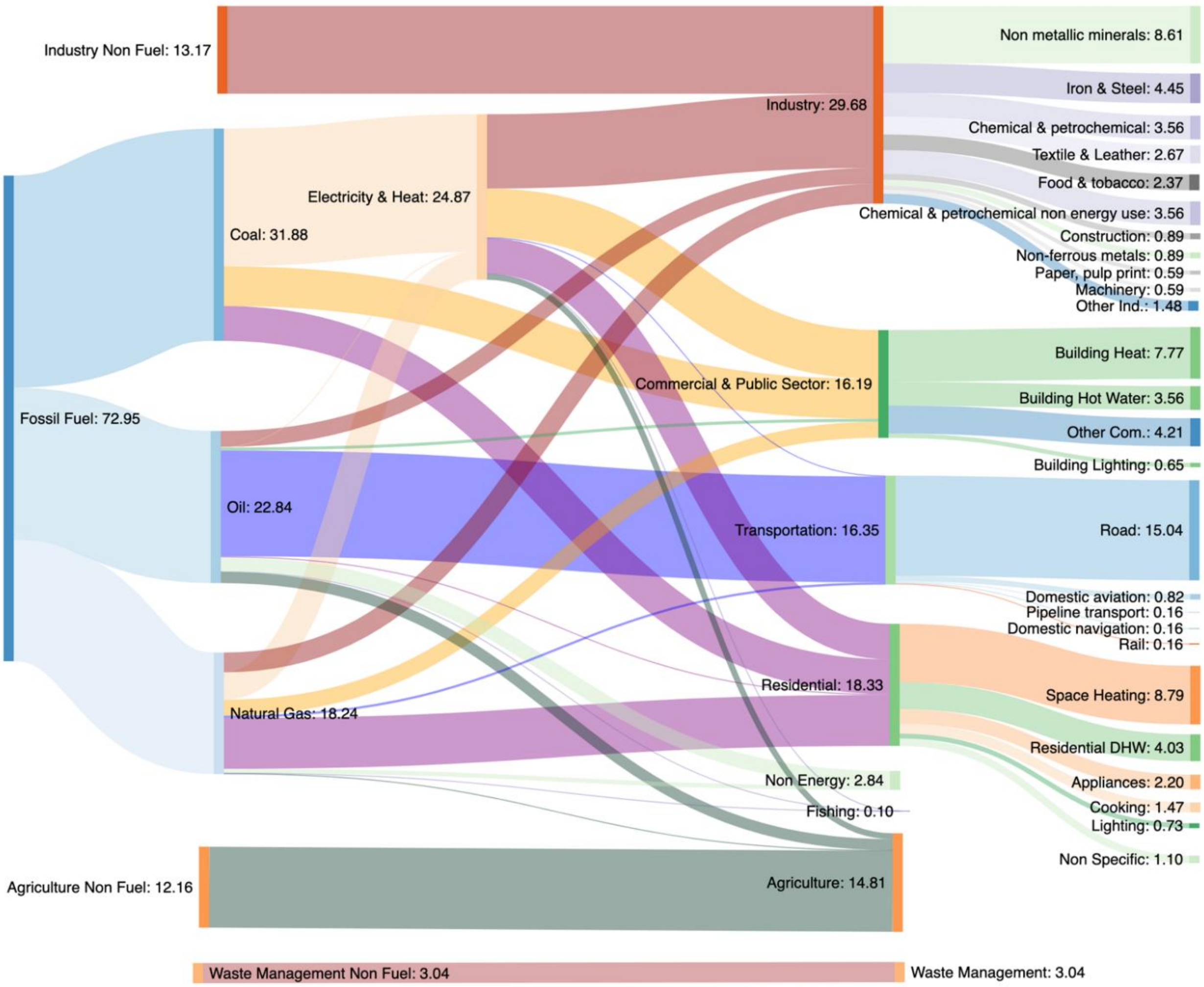
2. *Emissions inventories and Sankey diagrams*

Istanbul

Table 3 - Emissions inventory, Istanbul, Turkiye

GPC ref No.	GHG Emissions Source (By Sector and Sub-sector)	Total GHGs (Million tons CO2e)		
		Scope 1	Scope 2	Scope 3
I	STATIONARY ENERGY			
I.1	Residential buildings	13	5	
I.2	Commercial and institutional buildings and facilities	9	7	
I.3	Manufacturing industries and construction	5	11	
I.4.1/2/3	Energy industries			
I.4.4	*Energy generation supplied to the grid*			
I.5	Agriculture, forestry and fishing activities	2	1	
I.6	Non-specified sources	3		
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal			
I.8	Fugitive emissions from oil and natural gas systems			
SUB-TOTAL		32	25	0
II	TRANSPORTATION			
II.1	On-road transportation	15	0.1	
II.2	Railways	0.2		
II.3	Waterborne navigation			
II.4	Aviation	1		
II.5	Off-road transportation	0.2		
\		16	0	0
III	WASTE			
III.1.1/2	Solid waste generated in the city	3		
III.2.1/2	Biological waste generated in the city			
III.3.1/2	Incinerated and burned waste generated in the city			
III.4.1/2	Wastewater generated in the city			
III.1.3	*Solid waste generated outside the city*			
III.2.3	*Biological waste generated outside the city*			
III.3.3	*Incinerated and burned waste generated outside city*			
III.4.3	*Wastewater generated outside the city*			
SUB-TOTAL		3		0
IV	INDUSTRIAL PROCESSES and PRODUCT USES			
IV.1	Emissions from industrial processes occurring in the city boundary			13
IV.2	Emissions from product use occurring within the city boundary			
SUB-TOTAL		0		13
V	AGRICULTURE, FORESTRY and OTHER LAND USE			
V.1	Emissions from livestock			12
V.2	Emissions from land			
V.3	Emissions from aggregate sources and non-CO2e emission sources on land			
SUB-TOTAL		0		12
VI	OTHER SCOPE 3			
VI.1	Energy not included In I.7 & I.8			
VI.2	Building Material			
VI.3	Food not included in V			
VI.4	Mobility / Connectivity not included in II.5			
VI.5	Water			
VI.6	Waste/Sewage Management not included in III			
VI.7	Key Infrastructure			
VI.8	Other Scope 3			
SUB-TOTAL				0
TOTAL		51	25	25

Figure 2 - Sankey diagram, Istanbul, Turkiye



Bogota

Table 4 - Emissions inventory, Bogota, Colombia

GPC ref No.	GHG Emissions Source (By Sector and Sub-sector)	Total GHGs (Million tons CO2e)		
		Scope 1	Scope 2	Scope 3
I	**STATIONARY ENERGY**			
I.1	**Residential buildings**	2	1	
I.2	**Commercial and institutional buildings and facilities**	1	1	
I.3	**Manufacturing industries and construction**	5	1	
I.4.1/2/3	**Energy industries**			
I.4.4	*Energy generation supplied to the grid*			
I.5	**Agriculture, forestry and fishing activities**		0.05	
I.6	**Non-specified sources**		0.2	
I.7	**Fugitive emissions from mining, processing, storage, and transportation of coal**			
I.8	**Fugitive emissions from oil and natural gas systems**			
SUB-TOTAL		**7**	**4**	**0**
II	**TRANSPORTATION**			
II.1	**On-road transportation**	8	0.01	
II.2	**Railways**			
II.3	**Waterborne navigation**			
II.4	**Aviation**	1		
II.5	**Off-road transportation**			
SUB-TOTAL		**9**	**0.01**	**0**
III	**WASTE**			
III.1.1/2	**Solid waste generated in the city**			
III.2.1/2	**Biological waste generated in the city**			
III.3.1/2	**Incinerated and burned waste generated in the city**			
III.4.1/2	**Wastewater generated in the city**			
III.1.3	*Solid waste generated outside the city*			
III.2.3	*Biological waste generated outside the city*			
III.3.3	*Incinerated and burned waste generated outside city*			
III.4.3	*Wastewater generated outside the city*			
SUB-TOTAL		**0**		**0**
IV	**INDUSTRIAL PROCESSES and PRODUCT USES**			
IV.1	**Emissions from industrial processes occurring in the city boundary**			2
IV.2	**Emissions from product use occurring within the city boundary**			
SUB-TOTAL		**0**		**2**
V	**AGRICULTURE, FORESTRY and OTHER LAND USE**			
V.1	**Emissions from livestock**			11
V.2	**Emissions from land**			6
V.3	**Emissions from aggregate sources and non-CO2e emission sources on land**			1
SUB-TOTAL		**0**		**19**
VI	**OTHER SCOPE 3**			
VI.1	**Energy not included In I.7 & I.8**			
VI.2	**Building Material**			
VI.3	**Food not included in V**			
VI.4	**Mobility / Connectivity not included in II.5**			
VI.5	**Water**			
VI.6	**Waste/Sewage Management not included in III**			
VI.7	**Key Infrastructure**			
VI.8	**Other Scope 3**			
SUB-TOTAL				**0**
TOTAL		**16**	**4**	**21**

Figure 3 - Sankey diagram, Bogota, Colombia