ARUP enel

CIRCULAR CITIES

IMPACTS ON DECARBONIZATION AND BEYOND

4th EDITION
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With the scientific contribution of

Contents

Foreword

This fourth edition of the Position Paper on circular cities aims to highlight further the global progress on the subject, both in general terms and, more specifically, in relation to Enel Group activities. Four years have passed since the first edition in 2018 and in a relatively short space of time we have seen numerous developments. The theme of circular cities, an extremely niche theme initially, has now acquired great momentum and relevance in global and local agendas.

This report has been jointly produced with Arup, a leading professional services firm working across all aspects of the built environment. Arup and Enel share a strong commitment to the circular economy, particularly in the context of cities and urban environments, with particular reference to the urban context. Collaboration between different sectors is fundamental to rethinking cities, as is that between countries such as the collaboration between Italy and UK for the organization of COP26 events.

The timing of the release of this study, concurrently with COP26 and with the pandemic unfortunately still underway – even if one can be more optimistic than a year ago – perhaps intertwines the two events that most questioned our model of society and consequently also the role of cities. Despite the criticality of the context, the positive aspect is that cities are facing this challenge by assuming a proactive and guiding role, accelerating their transformation process and coordinating and collaborating among them on a global level.

The focus of this study wants to deepen this dimension, analyzing what is the real impact that cities have on the crisis in terms of direct and indirect emissions and what levers the circular economy offers to reduce them, at the same time pursuing, also through decarbonization, a better quality of life for all citizens and greater resilience.

This context pushes the Enel Group to further strengthen its commitment to a sustainable business model. Not only in general terms, through a paradigm based on renewables, smart grids and innovative electric technologies and with the circular economy as a framework for rethinking all the value chains, but also more specifically in the urban context. We have developed dedicated solutions implemented globally such as electric bus fleets, city analytics, urban circularity metrics and projects like Urban Futurability where digitalization, cutting edge technologies and new business models enhance smart grids' contribution to the circular economy.

Even with the awareness that we are still at the beginning of this transition, I believe that the theme of the circular economy has now reached a relevance and solidity that would have been unexpected even a year ago. The evolution of the theme made clear the possibility of a redesign of the entire economic model, and consequently of society in a broader sense, with tangible benefits in terms of quality of life and social impacts. I believe that this represents one of the most important messages of this study: to understand that the challenge today no longer concerns single actions or specific objectives but a deeper and more ambitious transition that affects us all.

Michele Crisostomo
Chairman of Enel and Chair of the Advisory Board of the Enel Foundation

Today, no-one has to look far for real evidence that we are in the middle of a climate crisis. It is not just to be found in dense reports from climate scientists, but it features in our media every day as reports show us yet more images of floods, droughts, forest fires and the damage these disasters inflict on local populations, particularly the poorest in our society.

We also know that our towns and cities are a major source of the greenhouse gas emissions (GHGs) that fuel this crisis. With global projections indicating that there will be another two billion on the planet by the time we reach the 2050 target for Net Zero, it is clear that we need to tackle the GHGs in the built environment if we want to have any chance of mitigating the worst of the climate impacts to come. That's why this report represents such an important step in taking on the climate challenge.

Embedding circular economy thinking into the fabric of how we design our towns and cities will be critical in the Race to Zero and this work sets out some of the practical progress we will need to make a change.
Circular economy thinking is a recognition that we can no longer be indifferent to the finite resources of our planet. It is a recognition that we can – and must – develop the new business models and tools that will support a more resilient future.

Perhaps most importantly, the report also recognizes that circular thinking is already driving practical change, showcasing some of the success stories that demonstrate that we really can make a difference if we have access to the right tools and a willingness to take action.

I am extremely proud that Enel and Arup have been able to work together in this critical area. The challenge now will be to bring as many willing partners as possible with us to transform circular thinking into 'business as usual' practices.

In the short time we have to try and meet our Paris ambitions, we must ensure that circular economy thinking becomes integral to how we think about our cities and their design.

Indeed, it is imperative that we succeed. Because today, quite frankly we are generating waste at a pace that is entirely unsustainable. The planet simply cannot afford our thoughtless and inefficient use of the finite resources we have. So, it's very clear that action is needed from developers and contractors; from investors and designers; from governments and regulators; from manufacturers and consumers; and from society as a whole.

We already know there are thousands of effective interventions we can make across the life cycles of multiple supply chains. But to really scale things up, we need to think about the tools and data we need to support change; the new business models we require; the use of Building Information Management (BIM) and big data; the introduction of materials passports; and the application of regenerative design and modular construction techniques.

That's what inspired Arup to work with the likes of the C40 Cities Climate Leadership Group, the Ellen MacArthur Foundation, and progressive firms like Enel. We know that no single group can make the change on their own. We must work to forge these critical links together.

By working in partnership, we can change mindsets and change the future of the planet. Through linking the pieces in the circular chain, we will curb emissions and scale up the transition at the pace required to build a more resilient future.

So, I wholeheartedly commend this report. I thank our partners for their generous support. And I hope it will act as a catalyst for further urgent action, helping to spread a positive message to governments, regulators, businesses, consumers, and other partners that there is a better way ahead.

Alan Belfield
Group Chair Arup

Executive Summary

Background

Climate change and environmental restoration are top priority for countries and cities around the world. The damaging consequences of rising temperatures and the increased frequency of extreme weather events are impacting on social, economic and environmental systems. Cities account for 70% of global carbon emissions, 60% of resource use and produce 50% of global waste and in this context, they are a part of the problem. Cities, however, are also playing a key role in addressing the effects of climate change and can be a significant element of the solution, largely achieved through climate protection and adaptation measures. Given the increasing pressures, cities can and need to adopt further measures and principles, including the circular economy, as this study shows.

Aims of the study

A circular economy, as defined by the Ellen MacArthur Foundation, is restorative and regenerative by design and aims to eliminate the concept of waste. These characteristics present new ways to reduce consumption-based emissions while creating added value in terms of resilience and quality of life.

This study investigates the impacts of a range of interventions aimed at reducing in emissions in three high-impact sectors in cities: built environment, mobility, and sustainable energy systems. It does so by focusing on four cities around the world that are pioneering circular economy solutions (Bogotá, Glasgow, Genoa and Milan), and uses a GTAP-modelling approach developed by C40, Arup and the University of Leeds to assess impacts on production- and consumption-based emissions of these interventions in these cities.

Each city is unique, and the relevance and impact of each intervention depends on the specific city context. The analysis indicates the potential scale of reduction in greenhouse gas emissions that could be possible with the implementation of interventions in each of the focus sectors at an ambitious but realistic level of adoption by 2030, and this evidence supports several conclusions and recommendations for city leaders and decision makers.

Circular economy principles accelerating the shift to net zero

Key interventions tested for the built environment include enhancing capacity utilization (to avoid new build), switching to renewable and low-carbon materials, increasing overall material efficiency, and operational interventions such as energy efficiency retrofit and implementing low-carbon building energy systems. For the mobility sector, interventions include modal shift, car sharing and pooling, the electrification of transport, and circular vehicle design. For energy systems, interventions include end-use electrification fuelled by renewables, and the adoption of digital solutions such as smart meters.

The study shows that:

- Greenhouse gas emissions occurring outside the cities because of their consumption of electricity, goods, and products (Scopes 2 and 3) can be far greater than those occurring within city limits (Scope 1) and therefore need to be considered when designing policy and action on emissions.
- The distribution of a city's emissions depends on the balance between imports and exports, but in this study's four focus cities, emissions occurring outside city boundaries account for about 80% of the total.
- The built environment interventions alone could reduce a city's total emissions up to 10% depending on the existing context. This includes a reduction in Scope 1 emissions from buildings of up to 56% and a reduction in Scope 3 emissions embodied in the construction up to 27%.
- The mobility interventions studied could reduce a city's carbon footprint up to 6%, including a reduction in Scope 1 transport emissions up to 49% and a reduction in the Scope 3 emissions embodied in purchased vehicles up to 14%.
- The energy systems interventions modeled could cut a city's overall emissions up to 4%, including a reduction in the Scope 2 emissions of up to 57%.
- From interviews with city stakeholders, interventions that directly support achieving net zero can enable further benefits such as improved access to green space, improved air quality, reduced traffic congestion, new green job opportunities, greater resilience through local supply chains, and lower costs owing to efficiency gains.

Circular economy interventions across these three sectors will make an important contribution to achieving decarbonisation targets, but action is required across all sectors and the study presents a perspective on the practical actions that city leaders can adopt and promote to accelerate the transition towards a circular economy in their cities.

City governance enabling the circular transition

To put circular economy principles into practice, cities must adopt new governance models that stimulate new ecosystems in which policymakers, industries, NGOs, universities and citizens can collaborate. Through policy analysis and interviews with key stakeholders in each city, we have identified a set of key governance principals that provide a useful framework for city leaders and policy makers.

1. **Set out a citywide vision for the circular economy.** The vision should show a spatial awareness of challenges and opportunities in different areas of the city. Whilst the overall vision should be long-term, clear steps for achieving the vision should be set out with measurable interim targets.
2. **Embed circular strategies in overall city planning.** City land use plans and planning policies should facilitate circular economy principals in decision making, such as the concepts of densification, localism and 15-minute neighborhoods.
3. **Set circular targets and metrics.** Monitoring progress towards becoming a circular city requires a new set of multi-faceted indicators that go beyond traditional development metrics. These include the monitoring of waste, material flows, building occupancy, natural environment condition, health, education, economic and energy security, governance, and basic rights.
4. **Use new finance opportunities.** Cities should utilise and promote new finance initiatives that can support the transition to a circular economy and support circular businesses initiatives. These include circular public procurement, circular business support funds, subsidised finance such as loans, grants and equity investments.
5. **Increase the awareness and inclusion of stakeholders and citizens.** Through the philosophy of co-creation, local governments can engage citizens and stakeholders throughout the lifecycle of the circular transition, from initial design through to implementation, decision making and governance. This fosters a shared sense of responsibility, ownership, and pride.
6. **Build capacity and share knowledge.** To achieve the scale of actions required, cities need to build skills and knowledge capacity through increasing the availability of circular economy learning and training pathways for citizens. Knowledge should also be transferred between cities, with an emphasis on sharing both successes and failures.

Introduction

Cities generate around 70% of global carbon emissions, account for over 60% of resource use[1] and produce 50% of global waste[2]. Considering that by 2050 about two thirds of the world's population will live in cities[3], they will play a key role in addressing the effects of climate change.

More and more cities today understand the importance of their role in the global process of decarbonization, and leverage the principles of circularity in applying their strategies. Fostering the spread of renewable energy and end-use electrification, reducing waste and the promotion of sharing and reuse of goods are the distinctive elements of circular cities.

Circular economy plans and strategies that encompass all sectors of urban life are key characteristics of municipalities that aim for sustainable development and improving the quality of life for their inhabitants.

Building on a history of joint research in the field of the circular economy, climate change and cities, Arup and Enel, with the Enel Foundation as a scientific partner, have collaborated on a research project with Bocconi University - GREEN[4] in Milan (Italy), Universidad de los Andes[5] in Bogotá (Colombia) and University of Genoa[6] (Italy). Together we have sought to evaluate the impact of the implementation of circular economy principles in cities in terms of carbon emissions, quality of life, and resilience. Using an in-house city emissions modeling methodology[7] we established a baseline model of the emissions associated with each city's consumption of goods and services, before performing quantitative analyses of linear and circular interventions based on evidence from stakeholder interviews and literature review. Further details on the methodology used to produce this study will be available in the methodology document to be published as Appendix to the present study.

[1] https://www.un.org/sustainabledevelopment/cities/

[2] https://www.oecd.org/cfe/regionaldevelopment/circular-economy-cities.htm

[3] https://www.worldbank.org/en/topic/urbandevelopment/overview

[4] https://www.green.unibocconi.eu/

[5] https://uniandes.edu.co/

[6] https://unige.it/it/

[7] https://c40-production-images.s3.amazonaws.com/other_uploads/images/2257_2Method_Report_Final_2019-06-13.original.pdf?1560879858

This study focuses on three key sectors in which Arup and Enel have specific expertise and experience: built environment, mobility, and sustainable energy systems. A vision for a circular city across these sectors is established, and key interventions to achieve that vision are identified.

The project contextualizes the circular city vision in four cities that were chosen for their commitment to a circular transition, and addresses the key governance actions required to facilitate this transition. They are Bogotá, the capital of Colombia and a South American lighthouse city for the circular economy; the historic port city of Genoa, leading Mediterranean port, which is leveraging circularity to redesign itself; Glasgow, a leading post-industrial city and Milan, the most dynamic city for Italian economy and another circular economy frontrunner.

The main aims of the study can be summarized as follows:

- Provide a vision for a circular city in 2030, focusing on how the built environment, mobility, and sustainable energy systems are key to aiding this transition, considering synergies between interventions and cross-sector collaboration.

- To provide evidence-based recommendations to city leaders and main decision-makers illustrating how the circular economy helps unlock the potential to greatly reduce emissions, to provide evidence-based recommendations to city leaders and decision-makers, and suggest possible co-benefits that could be achieved through a circular transition (e.g. greater resilience and quality of life).

- Identify successful circular actions to decarbonize the economy and deliver benefits at scale; suggest priority actions to be deployed and methods of engaging public and private actors as well as levers to enable implementation.

The study consists of the following chapters:

Chapter 1 introduces the concepts underpinning this research and introduces the vision for a more circular city system in 2030.

Chapter 2 discusses the context of the four cities and explores key circular governance policies adopted by each municipality.

Chapter 3 discusses the application of the circular vision to the three focus sectors, and presents the potential decarbonisation impacts of proposed interventions within the context of each study city.

Chapter 4 highlights the key principals of circular governance and actions that municipalities can take in pursuit of circularity.

1. Circular city: a path forward to 2030

The need for change

Temperatures have risen more rapidly since the 1970s than over the previous 2000 years and the latest UN report highlights emissions need to be cut by 55% by 2030[8]. Temperatures as well as extreme weather events are increasing at an even faster speed than previously assumed. At the political level, climate change has become more and more central to the debate in recent years. At COP21 in 2015, commitments were made within the Paris Agreement as a global framework to fight climate change, setting a goal of limiting global warming to well below 2°C, and preferably to 1.5°C above pre-industrial levels.

Civil society movements such as Fridays for Future, the spontaneous youth movement gathering millions of people striking for climate action, have given a significant further impetus and urgency to critical reflection on the vulnerability of planet Earth, and to the question of how to conceive a more resilient and sustainable future. The urgency of climate action has gained significant momentum, which is crucial as climate stabilization requires a strong, rapid and sustained reduction in emissions and this requires the coordinated effort of everyone from governments to civil society to the individual citizen. To address these critical issues and meet international targets, change is needed.

[8] www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf
https://www.unep.org/resources/emissions-gap-report-2021

The role of the circular economy

The journey to net zero goes beyond decarbonization measures: it requires a complete transformation of the economic model, and the way we produce and consume. The linear development model, based on take-make-waste principles, has caused negative effects on the environment, contributing to the climate crisis and transgression of multiple planetary boundaries.

The circular economy represents a new economic system based on eliminating waste and pollution, keeping products and materials in use and regenerating natural systems, offering better outcomes for people and the environment. These principles are key to reduce emissions and tackle climate change. Applying the principles of the circular economy requires a structural change aimed at a complete rethink of how raw materials and energy are utilized. It requires the redefinition of growth, the decoupling of economic activities from the consumption of finite resources, and the generation of economic, natural, and social capital in an even way[9].

For example, applying circular economy strategies to the production of key materials (cement, aluminum...) is seen as a key enabler to the decarbonisation of these industries. The Ellen MacArthur Foundation estimate that circular principals could reduce emissions associated with the production of these materials by 40% by 2050[10].

The circular economy represents a system-level approach, reappraising the entire economic model and encompassing the entire value chain. Reflections on the benefits of applying a circular model become evident at the urban level where the city can be represented as a system of flows.

Cities are the place where most goods and energy flows are consumed, as well as the place where most people live and work. The adoption of a linear growth model has led to a series of negative externalities related to excessive consumption of resources and space, including high volumes of waste and inadequate living conditions for citizens. The growing awareness of the link between a linear consumption model and the negative environmental impacts is leading many cities to apply the principles of the circular economy. Incorporating the principles of circularity from the definition of policies to the management of the city allows policymakers to redefine the choice, use and procurement of goods and materials in pursuit of economic development "that supports prosperity, jobs, health and communities"[11].

The transition to a circular city needs to encompass all major urban sectors, including transportation, waste, food, public space management and energy, as well as foster the involvement of citizens and key stakeholders alike.

[9] https://www.ellenmacarthurfoundation.org/circular-economy/concept

[10] Completing The Picture - How The Circular Economy Tackles Climate Change - Ellen MacArthur Foundation 2019 https://emf.thirdlight.com/link/2j2gtyion7ia-n3q5ey/@/preview/1

[11] City government and their role enabling a circular economy transition – Ellen MacArthur Foundation - March 2019 https://emf.thirdlight.com/link/26rz4yyd3pc5-s68dar/@/preview/1?o

The circular city

Circular cities completely rethink the way in which products, materials and assets are used so that waste is generally avoided, the resource value is kept at the highest possible level throughout many life cycles, and systems are regenerated.

Cities are an ideal setting to pioneer the circular transition due to the close proximity between citizens, innovators and decision-makers, and the concentration of activities across multiple sectors.

Leveraging this knowledge, buildings and infrastructure are maintained, refurbished, and repaired at the individual, community and commercial level to extend their useful life. Designs are durable, adaptable, modular, easy to maintain and repurpose, and waste is designed out. Materials are non-harmful and sourced locally and sustainably. One of the most effective levers for the diffusion of this circular approach at the city level is, for example, the introduction of circularity principles into public procurement standards and requirements. A distributed system of resource management facilitates the return, sorting, and reuse of products so that materials remain in the value chain.

A circular city is powered by renewable energy supplies and the environmental pollution is designed out resulting in environmental and health benefits for citizens. The use of space is reimagined so that there is greater accessibility to services and recreation areas. The economy relies more on local value chains and skills, increasing employment opportunities for local communities, closing loops at a local level and facilitating industrial symbiosis by locating industries in dedicated areas: cities will become more thriving, livable, and resilient.

In fact, while cities are particularly vulnerable to large-scale potential damage due to their concentration of people and assets, they are also the best equipped entities to address these risks on a structural level.

The principles of the circular economy can unlock positive effects in terms of socio-ecological resilience and the capacity of urban ecosystems to withstand shocks and retain their original and stable state of self-organization[12]. For instance, implementing renewable or closed loop material principles can shorten the supply chain and foster local supply, thereby improving resilience to external shocks. Adopting nature-based solutions and greener city ecosystems can mitigate both effects of extreme weather events, improve air quality and reduce noise pollution.

The Paris Agreement itself recognizes the role of cities and other sub-national entities in stepping up efforts to reduce emissions, decrease vulnerability to the adverse effects of climate change, and encourage regional and international cooperation[13]. This was recently reaffirmed by the G20, which considers cities to be "strategic partners" in tackling climate change[14].

[12] Gunderson, L. H. (2000). Ecological resilience: In theory and application. Annual Review of Ecology and Systematics. Vol. 31, pp.425-439

[13] https://ec.europa.eu/clima/eu-action/international-action-climate-change/climate-negotiations/paris-agreement_en

[14] ENERGY TRANSITION AND CLIMATE SUSTAINABILITY WORKING GROUPS Joint G20 Energy-Climate Ministerial Communiqué JULY, 23 2021

A joint effort by all cities in guiding the transition to circularity starting from three key sectors can in fact contribute to reaching important decarbonization objectives by 2030, as shown by this study.

Cities can intervene effectively not only in terms of reducing direct emissions, for example by curtailing the use of the most polluting vehicles, but they can also have a significant impact on emissions related to the entire value chain of products and materials that are produced elsewhere and consumed in urban areas. This is the case with interventions in the construction sector and related materials consumption, which affect emissions in different scopes[15]. They can do so by adopting policies and measures that address the demands of the municipalities and their citizens.

As illustrated by this study, the benefits of applying circular economy principles to the city are not limited to decarbonization, but affect many aspects of citizens' lives, providing them with better living conditions and greater opportunities.

[15] According to the" Greenhouse Gas Protocol - Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)", Scope 1, Scope 2 and Scope 3 are defined as follows:
SCOPE 1: GHG emissions from sources located within the city boundary
SCOPE 2: GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary
SCOPE 3: All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary

2. Overview of the four case study cities

This chapter provides an overview of the four cities considered in the study, i.e. Bogotá, Genoa, Glasgow and Milan.

Both Milan and Glasgow, which hosted pre-COP26 and COP26 respectively, have set ambitious circular economy agendas. The port city of Genoa has recently carried out an urban redesign including circular economy principles, while Bogotá is a pioneer of the circular economy in South America. All four cities have made official commitments to reduce CO_2 emissions in their cities with ambitious targets.

The analysis reported in this chapter is based on the cities' public policies and strategies, key considerations that emerged from interviews with key stakeholders, and assessment of actions implemented and planned in the framework of the circular economy. This first part of the analysis also takes a look at each city's emissions, applying a modeling approach developed for the Arup/C40 report that studied "The Future of Urban Consumption in a 1.5°C World"[16].

[16] https://www.c40.org/consumption

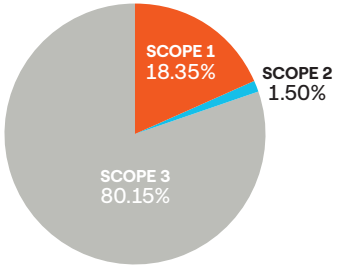
Bogotá
A pioneer of the circular economy in South America

Bogotá D.C. is Colombia's capital city; it is home to around 15% of the Colombian population, contributes 20% of the national GDP, and has a GDP growth rate 3.6% higher than the regional average of 0.1%. Bogotá is Latin America's fourth largest city and is one of the cities in Latin America that has been adopting measures to reduce emissions and air pollution, plant more trees and encourage changes in people's habits in order to limit impacts on nature. However prosperous it is, Bogotá is also a city with severe social inequalities, poor air quality, and waste management and mobility problems.

It is estimated that in 2019 about a third of the population in Bogotá lived below the poverty line; this number is expected to be greater now, due to the pandemic and increased migration from nearby conflict zones.

EMISSIONS SCOPE

2017 Baseline Emissions (tCO_2e)



TOTAL 43,784,000 (tCO_2e)

Equal to emissions per capita (tCO_2e/pax) per year

1.10 for SCOPE 1
0.09 for SCOPE 2
4.78 for SCOPE 3

Total **5.97** tCO_2e/pax

KEY STATISTICS	VALUES
National population (# of inhabitants)	50,911,747
City population (# of inhabitants)	8,380,801
Metropolitan area (km^2)	1,630
Public charging stations (number/1,000 inhabitants)	0.004
Electric public transit (% of all public transportation, including electric buses, trams, metro/rapid transit, etc.)	7%
Electric vehicles (% of total city vehicles)	0.02%
Bike paths (meters/inhabitant)	0.07

KEY SECTORS	% OF EMPLOYEES
Trade and repair of vehicles	19%
Public administration	14%
Manufacturing industries	14%
Professional activities	13%
Artistic activities	8%

Governance and policies

In line with the approval of a national circular economy strategy, the Bogotá Mayor's Office presented the Climate Action Plan - PAC 2020-2050[17], a roadmap for the next 30 years that will allow the city to meet ambitious goals of mitigation and adaptation to climate change: reducing greenhouse gas emissions (GHG) by 15% by 2024 and up to 50% by 2030, obtaining carbon neutrality by 2050 and increasing resilience. To support the city's circular transition, the Bogotá Development Plan[18] contains initiatives aimed at consolidating agroecological routes; developing the District Green Growth Strategy with a focus on environmental sustainability, innovation and the circular economy; and addressing the sustainable management of all waste generated in Bogotá, through circular economy schemes.

Bogotá supports the transition to a circular economy model through various governance tools and initiatives. One of the main governance tools is the latest development plan (DDA 2020-2024), called the "new social and environmental contract for the 21st century"[19], which has the goal of reducing greenhouse gas emissions by 15% by 2024. The plan is recognized as one of Colombia's climate promises by the United Nations Development Program (UNDP) and includes several initiatives, such as encouraging the use of environmentally friendly transportation and improving air quality.

The clear identification of Bogotá District's Environment Secretariat, the Habitat Secretariat, the Planning Secretariat, and the Economic Development Secretariat as subjects who coordinate efforts, set goals and allocate financial resources to achieve the circular economy in the city is a very important order to establish a clear governance on the topic.

Involving key stakeholders, the business sector, and citizens in the city's circular transformation is an important lever for Bogota. Strategic allies such as ANDI (Asociación Nacional de Empresarios de Colombia - National Business Association of Colombia), the Chamber of Commerce, and FENALCO (Federación Nacional de Comerciantes - National Federation of Merchants) can help to spread the principles of the circular economy to the production processes of small and medium-sized enterprises.

Decarbonization is an issue that is closely connected and widely embraced by the private sector in Bogotá. Companies are strongly committed to this process, seeking to improve their production cycles, reduce emissions and at the same time increase the competitiveness of their business models. Consumers further drive this process, demanding increasingly sustainable and energy efficient products.

Bogotá promotes a circular construction model, encouraging circularity in the choice of construction materials in the designing phase and throughout their useful life, with the goal of reducing the use of natural resources and improving citizens' quality of life.

Bogotá is already able to collect a lot of information about the circular economy process in the city: the important challenge for the future is how to manage this information for use in decision-making, as it needs to be grouped and compared so that it can be used by policymakers. As Bogotá continues with plans to advance circularity, there is an opportunity to begin building integrated databases that identify priorities and monitor interventions.

[17] https://bogota.gov.co/en/international/bogota-presents-climate-action-plan-world-earth-day-celebration

[18] https://bogota.gov.co/yo-participo/plan-desarrollo-claudia-lopez-2020-2024/#estructura

[19] https://bogota.gov.co/en/international/mayor-claudia-lopez-sanctions-new-four-year-development-plan

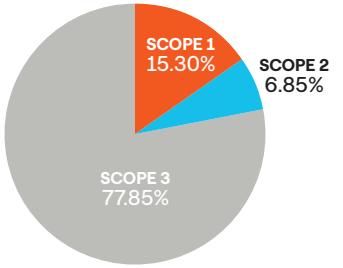
Genoa
Leading Mediterranean port

Genoa is the capital of the region of Liguria, in northwest Italy. Its economy has undergone considerable changes in recent decades, gradually shifting from purely industrial, linked to its port activities, to an economy based more on services (advanced tertiary, tourism, trade, etc.). However, the port remains fundamental for the economy of the city and beyond. In fact, the port of Genoa is the largest and most important Italian port in terms of size and number of shipping lines and container handling[20].

[20] https://web.archive.org/web/20141020212142/http://www.assoporti.it/associati/portoGenova

EMISSIONS SCOPE

2017 Baseline Emissions (tCO_2e)



TOTAL 6,487,000 (tCO_2e)

Equal to emissions per capita (tCO_2e/pax) per year

1.71 for SCOPE 1
0.77 for SCOPE 2
8.71 for SCOPE 3

Total **11.19 tCO_2e/pax**

KEY STATISTICS	VALUES
National population (# of inhabitants)	59,641,488
City population (# of inhabitants)	565,752
Metropolitan area (km^2)	240
Public charging stations points (number/1,000 inhabitants)	0.3
Electric public transport (% of all public transport, including electric buses, trams, metro/rapid transit, etc.)	8%
Electric vehicles (% of total city vehicles)	0.3%
Bike paths (meters/inhabitant)	0.02

KEY SECTORS	% OF EMPLOYEES
Manufacturing	21%
Wholesale and retail trade; repair of motor vehicles and motorcycles	16%
Administrative and support service activities	13%
Transportation and storage	13%
Professional, scientific and technical activities	8%

Governance and policies

In recent years, Genoa has made great efforts to develop a path of decarbonization, improve the quality of life of its citizens and increase resilience. The need for resilience took on special importance in response to the dramatic collapse of the Morandi bridge in 2018, which caused significant damage as well as pain for all citizens. Since 2009, the city has joined the Covenant of Mayors and has developed the Sustainable Energy Action Plan (SEAP[21]), which sets targets in terms of decarbonization by analyzing the different sectors of the city, demonstrating its level of commitment to this topic. In line with the European framework, it supports the elaboration of the Sustainable Energy and Climate Action Plan (SECAP[22]), planning interventions for the reduction of greenhouse gas emissions by 2030.

Through its plans and strategies, Genoa aims to reduce greenhouse gas emissions by 40% by 2030[23]. In particular, the new sustainable urban mobility plan "PUMS" (Piano Urbano Mobilità Sostenibile[24]) enables the construction of new bike paths, the promotion of micro-mobility and the electrification of public transportation. The Municipality of Genoa's energy policy includes regulatory activities in the construction/urban sector and the PEC (Piano Energetico Comunale), Genoa's Municipal Energy Strategy.

Genoa has launched the Genoa Lighthouse City program, which aims to increase the involvement and awareness of the local population: it is an action plan for sustainability, adaptation and mitigation of climate change and the improvement of quality of life through a holistic and inclusive approach. It is a very important step, since the concept of a circular city still tends to remain distant from the people and successful results often require decisive measures to modify citizens' behavior (e.g., reduction of public parking and reuse of space for other purposes). Moreover, in order to involve stakeholders and citizens, the city has established territorial committees to listen to the needs and requirements of communities and improve the local quality of life. The commitments of intermediate social bodies (parishes, unions, clubs, etc.) are essential to influence people and raise awareness of environmental issues.

Genoa has also developed a system of indicators to measure the city's progress in the elements it wants to increase (inclusivity, sustainability, attractiveness, focus on development, livability). It is worth highlighting that the city is also working on the reuse of waste as a material, especially organic fraction to produce biomethane, and the recovery of plastic, wood, paper, etc.

[21] http://www.comune.genova.it/content/seap

[22] http://www.comune.genova.it/content/secap

[23] A reduction of at least 40% of greenhouse gas emissions compared to 2005 levels, in particular through improved energy efficiency and increased use of renewable energy sources. Source: SECAP- Sustainable Energy and Climate Action Plan

[24] https://pums.cittametropolitana.genova.it/

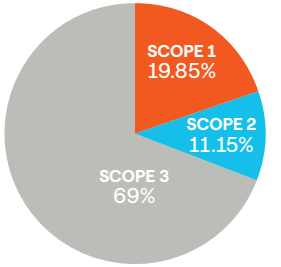
Glasgow
Lighthouse city of post-industrial transformation

In recent decades, Glasgow has transformed itself from a post-industrial city to one known for its technical and social innovation with a growing reputation as a center for the new green economy. The circular economy is at the heart of the city's ambitions for a nurturing and low carbon local economy and green recovery from Covid-19. Hosting the COP26 international climate conference in November 2021 places Glasgow at the center of the debate around positive transformation. In recognition of the city's progress towards circularity, Glasgow has been included as a case study for circular best practices and experiences in the OECD's program on "The Circular Economy in Cities and Regions", which aims to support public governments in their circular transition[25].

[25] https://www.oecd.org/regional/regional-policy/circular-economy-cities.htm

EMISSIONS SCOPE

2017 Baseline Emissions (tCO_2e)



TOTAL 8,890,000 (tCO_2e)

Equal to emissions per capita (tCO_2e/pax) per year

2.84 for SCOPE 1
1.59 for SCOPE 2
9.88 for SCOPE 3

Total **14.31 tCO_2e/pax**

KEY STATISTICS	VALUES
National population (# of inhabitants)	5,424,800
City population (# of inhabitants)	621,020
Metropolitan area (km^2)	176
Public charging stations (number/1,000 inhabitants)	0.3
Electric vehicles (% of total city vehicles)	0.7%
Bike paths (meters/inhabitant)	0.5

KEY SECTORS	% OF EMPLOYEES
Public administration, education and health	33%
Hotels, restaurants, distribution of goods/services, logistics	21%
Banking, finance and insurance	15%
Transport and communication	9%
Manufacturing	6%

Governance and policies

Glasgow and Scotland have set ambitious policy targets at a city and national level. In 2019, the city of Glasgow set a target to become carbon neutral by 2030[26] and achieve city circularity[27] in line with Scotland's national ambition for net zero carbon by 2045[28]. In April 2021, Glasgow became the first city in the UK to sign the Circular Cities Declaration[29].

Glasgow City Council is already implementing an array of governance tools which aim to lead the city's transition to a circular city. These include partnerships between the City Council and key local and national stakeholders to facilitate the development of innovative business models. Flagship projects include Circular Glasgow[30], which was set up in 2017 by the Glasgow Chamber of Commerce in partnership with Zero Waste Scotland and Glasgow City Council and outlines steps for Glasgow's business community and companies across the city to adopt circular strategies and models. ProCirc, part of the EU North Sea Region Interregional Program, also provides a Circular Procurement Mentoring Support program for public and private organizations[31].

In 2020, Glasgow City Council officially partnered with the London Waste and Recycling Board to scale up the adoption of circular construction techniques at a city level through a series of best practice, knowledge and skill sharing activities[32]. The City Council's local heat and energy efficiency strategy, which is currently under development, also aims to supply all council properties with 100% renewable energy, ensure the council operates a decarbonized fleet that is fueled by sustainable energy and assist in the uptake of Community Energy projects.

The importance that the city places on circular economy education and upskilling for the local community is highlighted by the integration of Zero Waste Scotland's Circular Economy Education & Skills Hub and the development of circular economy modules for construction in partnership with the City of Glasgow College and Glasgow Caledonian University[33].

Glasgow is also a living lab for a collaborative smart city program (called "Ruggedised") which is being developed in collaboration with the cities of Rotterdam, Umeå, Parma, Brno and Gdansk through the European Union's Horizon 2020 program. Glasgow's program focuses on the development of a Smart Street pilot program in an area of mixed residential, academic, community, retail, and industrial buildings. It aims to address the challenges Glasgow faces from aging infrastructure, fuel poverty and air pollution through integrating planned regeneration and development with smart city capabilities[34].

Glasgow's Circular Economy Route Map outlines 30 important governance initiatives that can further drive the circular transition across policy, planning, production, people, private and public actions. This set of actions provides a valuable case study for other cities embarking on the transition to becoming a circular city.

[26] https://www.glasgow.gov.uk/article/25066/Council-Sets-Target-of-Carbon-Neutral-Glasgow-by-2030

[27] https://www.glasgow.gov.uk/councillorsandcommittees/viewSelectedDocument.asp?c=P62AFQDNDX2UT1NTNT#:~:text=This%20Circular%20Economy%20Route%20Map%20sets%20out%20a%20framework%20to,embrace%20a%20sustainable%20economic%20future.&text=Our%20Communities%20%E2%80%93%20by%20localising%20the,wealth%20creation%20with%20those%20communities.

[28] https://www.parliament.scot/bills-and-laws/bills/climate-change-emissions-reduction-target-scotland-bill

[29] https://www.glasgow.gov.uk/index.aspx?articleid=27227

[30] https://www.circularglasgow.com/

[31] https://northsearegion.eu/procirc/

[32] https://www.circularglasgow.com/partnership-between-glasgow-and-london-launched-to-help-the-uk-achieve-ambitious-year-of-climate-change/

[33] https://www.cityofglasgowcollege.ac.uk/circular-construction

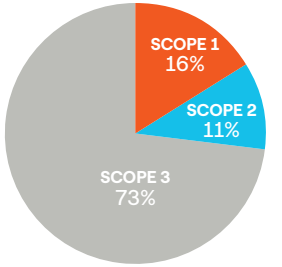
[34] https://ruggedised.eu/cities/glasgow/

Milan
Financial center and city of fashion and design

Milan is the second most populous municipality in Italy and the country's most important economic and financial center. Hosting the Headquarters of the Italian Stock Exchange (Piazza Affari), the city is considered part of the economic heart of Europe and is recognized as one of the economic capitals of Europe. Alongside finance, the city's economy is strongly focused on the tertiary and service sectors, so it is home to numerous multinationals operating in Italy. The city is also at the forefront of the fashion industry, as well as the design, publishing, construction and real estate sectors.

EMISSIONS SCOPE

2017 Baseline Emissions (tCO_2e)



TOTAL 19,145,000 (tCO_2e)

Equal to emissions per capita (tCO_2e/pax) per year

2.30 for SCOPE 1
1.52 for SCOPE 2
10.22 for SCOPE 3

Total **14.04** tCO_2e/pax

KEY STATISTICS	VALUES
National population (# of inhabitants)	59,641,488
City population (# of inhabitants)	1,406,242
Metropolitan area (km^2)	182
Public charging stations (number/1,000 inhabitants)	0.3
Electric public transport (% of all public transport, including electric buses, trams, metro/rapid transit, etc.)	75%
Electric vehicles (% of total city vehicles)	0.2%
Bike paths (meters/inhabitant)	0.2

KEY SECTORS	% OF EMPLOYEES
Rental, travel agencies, business support services	18%
Wholesale and retail trade; repair of motor vehicles and motorcycles	18%
Professional, scientific and technical activities	13%
Manufacturing activities	12%
Information and communication services	7%

Governance and policies

Milan is a leading city on circular issues not only nationally, but also globally. To promote the urban decarbonization process, the Municipality of Milan joined the C40 "Deadline 2020[35]" program in 2017, pledging to become a carbon neutral city by 2050.

The city also renewed its commitments through the Covenant of Mayors[36] for Climate and Energy in 2019, increasing its GHG reduction targets to 40% by 2030. After joining the new Pact, the Municipality has raised its target of CO_2 reduction for 2030 to 45%. The new GHG reduction target is also mentioned in the Air and Climate Plan (ACP)[37], adopted in 2020 to address the challenges of climate change mitigation and of air pollution. It includes a specific target relating to the circular economy, setting measures aimed at reducing consumption of raw materials and energy in various supply chains, for the entire life cycle of products and services, acting in the most significant areas of urban metabolism based on a circular economy model.

In order to achieve its circularity, energy transition, mitigation, adaptation and resilience goals, a dedicated governance structure has been created: the Department and Directorate for Environmental Transition, which is under the direct responsibility of the Mayor.

The city of Milan is strongly motivated to promote urban transformation in a resilient and sustainable way, using a circular economy approach. The city has developed urban policy plans for different sectors, defining a regulatory framework and development strategies from a sustainable perspective: from waste management with a circular approach, to local food supply and the enhancement of local production chains, limiting the impacts of transport. The concept of "Milano Lenta" (Slow Milan) is gaining traction in the city: its goal is to promote an appreciation of slowness, especially after Covid 19, which showed us the possibility of increasing the quality of life with slower, but still energy efficient, approaches.

Milan will become a city where people can move around using different types of integrated mobility services flexibly, a city where public space is transformed, with wider sidewalks and shared street spaces, and where integration is real. The street must become a place of life and relationships, and the city must resemble smaller Cities where public space and private space meet in the idea of the "15-Minute City".

Milan has also taken on international commitments as part of the C40 on the circular economy, such as waste recovery with 95% of waste reuse by 2030, evolution of waste supply chains, development of clean construction, and urban regeneration and recovery.

[35] https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5ab410fb74c4833febe6c81a/5ad4d7ee74c4837def5d3d45/files/Deadline_2020_Programme_flyer__August_2017.pdf?1541690065

[36] https://www.covenantofmayors.eu/about/covenant-community/signatories.html

[37] To date, the ACP has not yet been definitively approved by the Municipality of Milan, but it outlines the strategic political outlook of the local Administration. The plan is available at: https://www.comune.milano.it/piano-aria-clima

3. Sectoral focus

The circular city vision encompasses several key urban sectors, as it aims to redefine energy and material flows. Given the need to prioritize, this study focuses on three of them: mobility, built environment, and sustainable energy systems. They were chosen for their likely impact on decarbonization[38] and emissions reductions within Scopes 1, 2 and 3. As well, Enel's and Arup's vast global experience can provide a pragmatic lens through which to assess the complexity of implementation and the governance required to leverage the interventions.

An overview of the definitions used for these sectors are set out below:

- Built environment: This sector comprises a) direct emissions from the operation of buildings and infrastructure, b) emissions associated with energy efficiency interventions and building electrification, and c) supply chain emissions associated with the construction of buildings within each city;

- Mobility: this sector comprises direct emissions from vehicles, indirect emissions associated with vehicle electrification, and supply chain emissions from the manufacturing, maintenance and disposal of vehicles;

- Sustainable energy systems: this sector focuses on a) production, distribution and supply of electricity to end customers to power operations within the city, b) emissions associated with the supply chain to build this infrastructure, and c) digitalization as an enabler of circularity.

[38] ICT's potential to reduce greenhouse gas emissions in 2030 – ERICSSON; ITF Transport Outlook 2021 – OECD; EMF report
https://www.ericsson.com/en/reports-and-papers/research-papers/exploring-the-effects-of-ict-solutions-on-ghg-emissions-in-2030
https://www.oecd.org/publications/itf-transport-outlook-25202367.htm

A circular vision for 2030 is presented for each sector, along with a range of possible interventions to facilitate the transition. This chapter also quantifies the potential benefits of implementing the interventions across the three sectors for Bogotá, Genoa, Glasgow and Milan. The impact of the application of these interventions has been assessed with reference to a 2017 emissions baseline incorporating Scopes 1, 2 and 3.

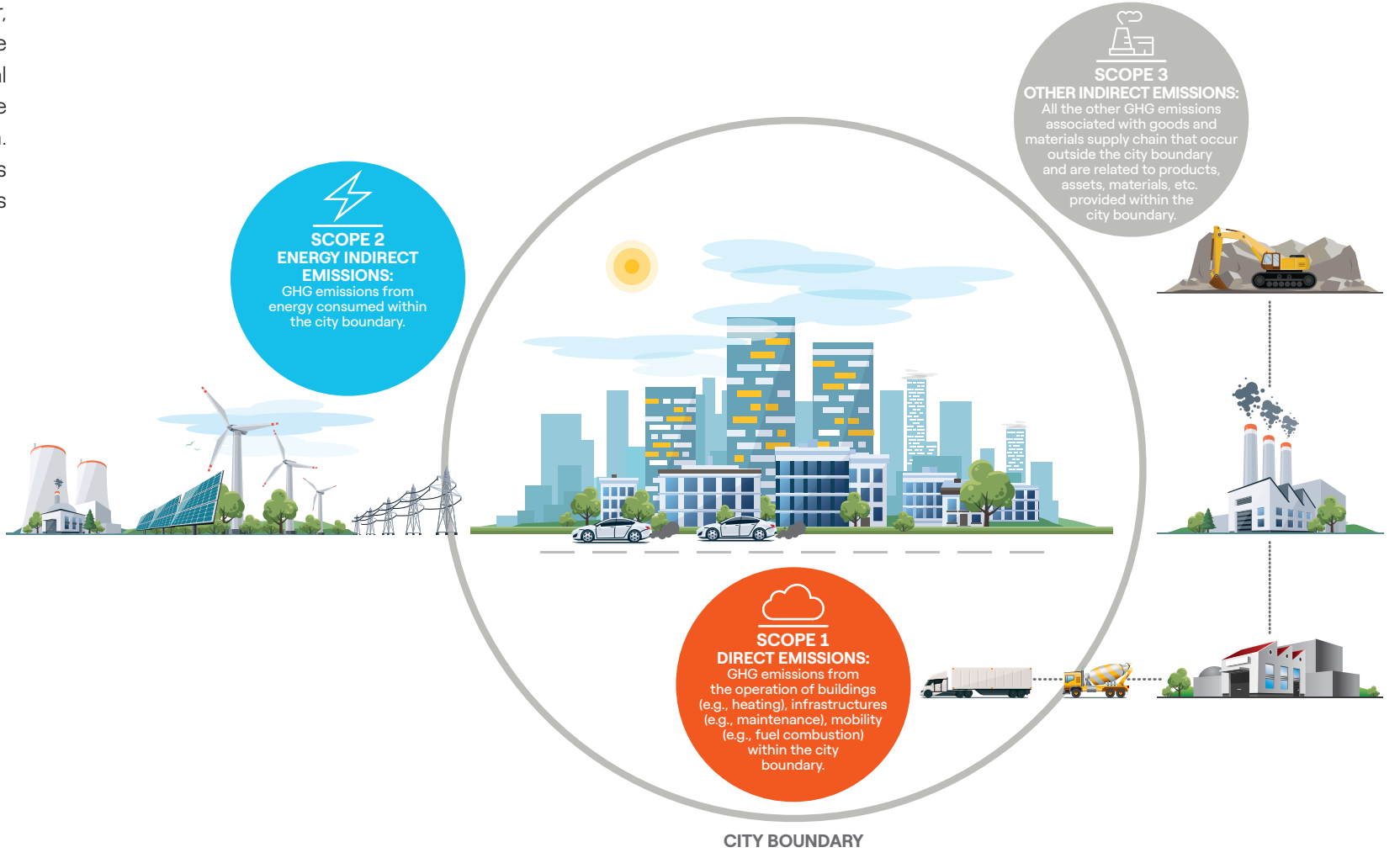


Figure 1 City emissions - The image represents Scope 1, 2 and 3 emissions relative to the perimeter of analysis considered in the study

Built environment

VISION

In a circular city the built environment prioritizes the efficient use of existing assets. Optimizing the use of existing space is vital given that 60.4% of the global population is projected to live in cities by 2030[39]. Therefore, the demand for new buildings and infrastructure is minimized by ensuring that existing assets are fully utilized before new ones are built. The refurbishment and retrofit of vacant properties and unused office spaces due to home working and co-working is prioritized over new construction.

During operations, energy demand is minimized through energy efficiency improvements to the building fabric, and the use of energy efficient equipment and appliances. Nature-based solutions and green infrastructure are used to regulate energy demand, improve resilience to flooding during storm events, and improve citizens' mental and physical health through connection with nature[40]. In climates where buildings require heating and cooling, the electrification of building services, in combination with renewable supplies through the energy system, facilitates the transition towards zero-carbon operations and improves the city's resilience to external shocks in the global energy market.

Where new construction is required, the focus is on building less, but better. Efficient design minimizes the quantity of materials required for construction. Assets are designed to be flexible, accommodating the needs of a range of users throughout a day or week, and buildings can easily be adapted between non-residential and residential use as needed. Modular, off-site construction practices reduce material waste and maximize the potential to reuse components at their end-of-life[41]. The transition to digital twins of built assets and the adoption of digital material passports enhances the recovery of materials and components. Lower-carbon alternatives such as timber and low-carbon cement are preferred to materials such as steel and Portland cement to reduce the embodied carbon emissions in construction materials.

These changes within the sector are supported by progressive governance measures including circular public procurement schemes, mandatory circular design statements for construction projects, and alignment with recognized construction specifications such as PAS 2060[42] and PAS 2080[43] that consider the whole-life carbon impacts of buildings and infrastructure.

39 https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf

40 https://link.springer.com/chapter/10.1007/978-3-319-56091-5_10

41 https://www.portablebuildingsales.co.uk/news/reducing-your-carbon-footprint-how-modular-buildings-can-help-you-meet-your-targets/

42 https://www.carbontrust.com/what-we-do/assurance-and-certification/carbon-neutral-certification

43 https://www.carbontrust.com/what-we-do/assurance-and-certification/pas-2080-carbon-management-in-infrastructure

CURRENT PRACTICES

There are already some good examples of cities transitioning towards a circular built environment, embedding elements of the circular city vision into their planning and procurement standards.

CASE STUDY	SUMMARY
Amsterdam Circular Strategy[44]	Amsterdam has developed a proactive approach to the circular economy with a comprehensive plan to halve the use of raw materials by 2030 and to become a completely circular city by 2050. Its vision is based on staying within planetary boundaries and using the circular processing ladder as a hierarchy for interventions (from "reuse" as the most preferable to "recover" as the least). The city's ambition is to make circular practices in the built environment the 'new normal' with a new circular public procurement policy to set an example for the private sector. The city monitors its progress towards circularity through a range of KPIs related to the Doughnut Economics model[45].
Peoples's Pavilion Eindhoven (circular construction)[46]	The People's Pavilion, designed in collaboration with Arup, is a showcase of circular construction: a 100% circular building with no materials lost or wasted in construction. This creative approach utilized materials from traditional suppliers as well as Eindhoven residents (e.g. plastic household waste), and focused on reusing slabs and tiles from demolished buildings.
1 Triton Square, London commercial building refurbishment[47]	1 Triton Square was originally designed by Arup in the 1990s. Twenty years later, Arup refurbished the building for evolving customer needs. The project demonstrated the benefits of circular refurbishment: the project was completed 30% faster compared to a typical new build, had cost savings of 43%, and saved 40,000 tons of carbon.
Energiesprong net-zero retrofits and long-life warranties[48]	The organization Energiesprong was initially set up as a Dutch government-funded innovation project to provide net-zero energy retrofits to dwellings across the Netherlands through a combination of building fabric, energy efficiency and heating system upgrades, all at zero upfront cost. Energiesprong refurbishments come with a 30-year indoor climate and energy performance warranty and are paid back by occupants in place of their existing energy and building maintenance bills.
Victoria, Australia "Recycled First Policy" for transportation infrastructure[49]	Arup has provided circular economy expertise to help the Victorian Government in Australia to develop reference guides on the use of recycled materials in rail and road infrastructure projects. The guides provide an overview of emerging materials, industry standards and specifications, and approval pathways. East Boundary Road was laid with asphalt made of crumb rubber from used tires, and Mordialloc Freeway noise walls will be made from 75% recycled plastic.

[44] https://www.amsterdam.nl/en/policy/sustainability/circular-economy

[45] https://www.kateraworth.com/2020/04/08/amsterdam-city-doughnut/

[46] https://www.archdaily.com/915977/peoples-pavilion-bureau-sla-plus-overtreders-w

[47] https://www.arup.com/projects/1-triton-square

[48] https://energiesprong.org/

[49] https://bigbuild.vic.gov.au/about/environment

CIRCULAR INTERVENTIONS

These interventions are based on the research and logic developed for the built environment interventions considered in The Future of Urban Consumption in a 1.5C World by C40 Cities, Arup and the University of Leeds[50].

Building construction interventions:

- **Enhance building use and occupation:** this involves reducing demand for new construction by using existing assets more efficiently. This includes opportunities to transform underutilized commercial space into residential spaces, as the demand for office and retail space declines following the transition towards remote working, e-commerce and automation. The intervention also considers the refurbishment, retrofitting and re-occupancy of vacant or disused buildings and the impact of extending and maximizing the lifetime of assets by designing spaces to be adaptable to accommodate changing uses.

- **Switching materials:** this involves a shift from high-carbon construction materials such as concrete and steel to lower-carbon, lightweight, and in some cases renewable materials such as timber or bamboo. However, the emphasis must be on ascertaining that materials are sustainably sourced through appropriate governance to ensure responsible forestry practices[51]. Where traditional materials are used, lower-carbon variants can be selected to reduce the embodied carbon emissions, including low-carbon alternatives to Portland cement[52].

- **Use materials efficiently:** this involves reducing the quantity of materials used during construction through efficient, lightweight design, and reducing waste through off-site, modular construction processes[53]. For example, studies have found that multi-story steel structures could, on average, be built with half the quantity of steel and still meet Eurocode building standards[54].

- **Recover, reuse, repurpose materials:** this involves recovering materials at end-of-life for reuse in future construction projects with minimal processing. While steel recovery rates for the construction sector are estimated at 85%, there is relatively little reuse of components at present[55]. This could be promoted by using standardized, modular building components and digital material passports so that the exact quantity, quality, and usage history of each built component in the city can be easily identified at end-of-life[56]. This can also create business opportunities in the local economy through establishing a "second-hand" material supply chain.

[50] https://www.arup.com/perspectives/publications/research/section/the-future-of-urban-consumption-in-a-1-5c-world

[51] For example, the Forest Stewardship Council (FSC) certification schemes can be used to ensure forestry products meet high environmental and social standards (https://iopscience.iop.org/article/10.1088/1748-9326/ab0fe3)

[52] https://www.istructe.org/resources/guidance/how-to-specify-lower-carbon-concrete/

[53] https://static1.squarespace.com/static/5e190b7bb5698248bf1d6ea2/t/5e5d92a377a9ab3df1ca9ac9/1583190693042/OSMC_Explained.pdf

[54] https://royalsocietypublishing.org/doi/full/10.1098/rspa.2014.0170; https://www.uselessgroup.org/files/construction_prospectus_viewing.pdf

[55] http://autoidlab.cs.adelaide.edu.au/sites/default/files/publications/papers/1-s2.0-S0959652614008786-main.pdf

[56] https://madaster.com/amsterdam-metropolitan-area-uses-material-passports-to-boost-the-circular-economy-in-the-region/

Building operation interventions:

- **Reduce energy demand through retrofitting:** this focuses on reducing the demand for energy for heating and cooling through building fabric improvements to minimize heat loss, increase natural lighting and ventilation, and control solar gains to reduce the need for cooling during summer[57]. However, it is important to prioritize the use of natural or recycled materials such a straw-bale, hempcrete, and wool store to reduce embodied carbon impacts. Cities can also drive efficiency gains by coordinating large-scale retrofits of multiple buildings or entire neighborhoods. In addition, technical barriers need to be overcome, such as retrofitting buildings that are classified as 'hard to treat' due to having solid walls or no loft space, or homes that are in a state of disrepair[58]. Regulatory barriers around retrofitting protected buildings with heritage status also need to be addressed[59].

- **Implement low-carbon building services:** this focuses on the electrification of heating, cooling and ventilation in buildings. For example, heat pumps are a proven technology that can achieve efficiency of over 300%, and have the benefit of providing both heating and cooling services. However, as the temperatures produced by heat pumps (40-50°C) are considerably lower than those produced by gas boilers, installation only becomes feasible following energy efficiency retrofitting to reduce heat losses. Other barriers to heat pump installation include the availability of external space, geological constraints for ground source heat pumps, and the accelerated corrosion of heat exchangers caused by air salinity in coastal locations[60].

[57] https://www.unido.org/sites/default/files/2009-02/Module18_0.pdf
[58] https://core.ac.uk/download/pdf/288378234.pdf
[59] https://www.researchgate.net/publication/307985981_Guidelines_for_Building_Energy_Efficiency_Retrofitting
[60] https://www.gov.scot/publications/technical-feasibility-low-carbon-heating-domestic-buildings-report-scottish-governments-directorate-energy-climate-change/

Co-benefits of these interventions

Adopting the principles of the circular economy for the built environment and implementing circular interventions can have a positive impact on citizens' quality of life. Rethinking spaces and buildings can make a city more livable, for example in terms of public services (schools, hospitals, theaters, etc.), housing and green areas. Flexible spaces facilitate a diverse range of uses and provide opportunities for increased access to space for citizens to engage in education, work, and leisure activities. By reducing the need for new building construction, we can increase the space for parks and other green areas that have physical and mental health benefits[61].

New business models can provide job opportunities, for instance in the field of take-back, repairs or refurbishing. Moreover, the implementation of renewable or 'closed loop' material principles can shorten supply chains and stimulate local economies, which can improve resilience to external shocks. The adoption of 'nature-based solutions' and greener city ecosystems can mitigate the effects of extreme weather events and enrich local biodiversity. At a global level[62] more than 90% of biodiversity loss is due to the extraction and processing of natural resources[63].

Construction and retrofitting to improve building energy performance can reduce heating and cooling costs for residents, which is particularly relevant when millions around the world struggle to pay their utility bills and live in thermal comfort[64]. Modular and modern construction methods can result in more efficient building with fewer flaws, gaps, and modeled airflow thanks to the 'build tight, ventilate right' approach[65]. This will improve indoor air quality and overall human health.

[61] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0203000
[62] https://www.resourcepanel.org/reports/global-resources-outlook
[63] https://ellenmacarthurfoundation.org/topics/biodiversity/overview
[64] https://www.sciencedirect.com/science/article/abs/pii/S0301421516305614
[65] https://www.cibsejournal.com/technical/build-tight-ventilate-right/

Focus on cities and results

The following sections detail the built environment in the four study cities, the level of intervention tested through quantitative analysis, and the scale of opportunity for circular transitions.

The level of intervention was selected based on Arup's experience working in each city as well as input from local stakeholders, and considers criteria such as performance of existing buildings, availability of space, materials use, and local construction methods. The high-level values obtained aim to capture the potential for decarbonization offered by ambitious steps towards circularity.

Bogotá

Bogotá has seen significant development and urban sprawl since the 1970s. There is currently a lack of affordable and suitable housing across the city, particularly in the low-income sector. According to the latest census, 14.1% of households suffer from overcrowding and live in poor quality housing[66]. There has been a disconnect between the types of buildings being constructed and the needs of citizens (e.g. public housing). The overall demand for new construction can be reduced by focusing real estate development on meeting citizen needs, though this potential is lower than for the other study cities.

Bogotá is reliant on high-carbon materials, particularly concrete. Sustainable timber is less readily available than for the other study cities, and the use of alternative materials such as cross-laminated timber (CLT) is rare due to limited industry experience. There is, however, the potential to build with other low-carbon materials, including permeable ecological concrete and bamboo. Colombian cement and concrete manufacturer Argos has developed a permeable, ecological cement (Cemento Verde or Green Cement), which is gaining attention among developers throughout the country[67]. Guadua bamboo, endemic to South America, is a widely used construction material in Colombia. It is fast-growing, durable, has a high level of CO_2 sequestration and favorable dimensions. After the 1999 earthquake, many Guadua-constructed buildings survived or only suffered minor damage[68].

Guadua has since been added to the seismic-resistant Colombian building code[69]. Many buildings and bridges have been constructed in Colombia with bamboo, most famously by the architect Simon Velez.

The potential for a transition to modular, circular construction with low-carbon materials also depends on capacity building and re-training within the architectural sector. Using material passports and Building Information Modeling (BIM) systems are suggested as circular routes for the future, however in Bogotá training and mechanization levels as well as recycling practices need improvement. The sector is less rigorously monitored and regulated compared with the other case study cities, indicating significant potential for waste reduction in everyday construction practices. In addition, more detailed planning and thoughtful construction could help to increase the lifetime of buildings in Bogotá, where many are often replaced before their end-of-life.

With a growing portfolio of renewable energy and a mild climate year-round (temperatures are typically between 11-20°C[70]), the potential for reducing building operational emissions is less significant than in the other case study cities. In the residential sector, energy is mainly used for refrigeration, television, lighting and cooking, as few homes have heating or cooling systems[71]. Consequently, Scope 1 emissions from the built environment are limited and most energy demand is met by electricity. Potential improvements to device efficiency were not considered in this assessment, though it is estimated that over 85% of the population own inefficient equipment (TVs, fridges/freezers, washing machines).

Implementing the focused real estate and construction interventions outlined in the table on page 32 would reduce Bogotá's Scope 3 emissions by 2% (612 $ktCO_2e$). This constitutes a 20% reduction in emissions associated with Bogotá's global construction supply chain. Building operation interventions were not modeled, due to Bogotá's minimal use of energy for indoor heating and cooling.

66 https://data2.unhcr.org/es/documents/download/83819
https://www.un.org/en/development/desa/population/publications/pdf/ageing/household_size_and_composition_around_the_world_2017_data_booklet.pdf

67 https://argos.co/en/green-solutions-conscious-innovation/

68 https://researchportal.bath.ac.uk/en/publications/low-carbon-construction-using-guadua-bamboo-in-colombia

69 https://www.unisdr.org/campaign/resilientcities/uploads/city/attachments/3871-10684.pdf

70 https://www.weather-atlas.com/en/colombia/bogota-climate

71 https://www1.upme.gov.co/DemandaEnergetica/MarcoNormatividad/PAI_PROURE_2017-2022.pdf

SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

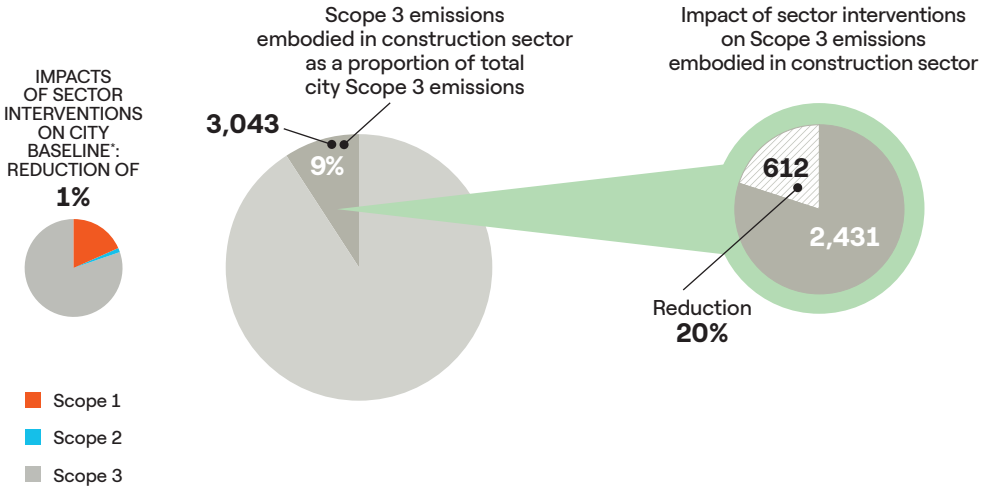
5%	reduction in demand for new construction due to enhanced utilization and occupation of existing assets
50% **30%**	of residential buildings and of commercial buildings *built using bamboo as a substitute for steel and concrete components*
20% **32%**	reduction in the use of steel and reduction in concrete use *by more efficient materials use*
11%	reduction in virgin steel use in construction by increasing the direct reuse of steel components

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from built environment interventions of 612 $ktCO_2e$	(1.4%)
Scope 1 decrease of 0 $ktCO_2e$	(0%)*
Scope 2 decrease of 0 $ktCO_2e$	(0%)*
Scope 3 decrease of 612 $ktCO_2e$	(1.7%)

* Interventions focus on construction supply chain emissions; building operation emissions are less relevant due to the local climate context.

BOGOTÁ IMPACT OF INTERVENTIONS IN THE BUILT ENVIRONMENT SECTOR ($ktCO_2e$)



* See page 16 of Chapter 2

Genoa

Genoa's historic center, including Strade Nuove and Palazzi dei Rolli, has been designated a UNESCO World Heritage site. This presents a challenge for building modification and repopulation, despite the large number of under-utilized buildings in the city center, which represents 20% of the urban area but houses 50% of Genoa's inhabitants[72]. The management, optimization and redevelopment of existing buildings is crucial to the city's transition. Over 2,000 buildings are subject to historical and artistic constraints[73] and all works require permits from the Ministry of Cultural and Environmental Heritage[74], so there is limited potential for new construction: enhancing utilization and retrofitting existing buildings will therefore be key for Genoa.

Despite the challenges, Genoa is committed to applying circular economy principles and has signed the EU Circular Cities Declaration[75]. An innovative collaborative approach was employed to develop the new Verrina railway station, which included repurposed steel beams from the dismantled Verrina industrial complex nearby. This saved money, materials, and transportation-related emissions[76]. The Municipality of Genoa has launched a campaign aimed at the general public to encourage steel recycling and to raise awareness of the circular economy among residents[77].

[72] http://www.comune.genova.it/content/seap

[73] Soprintendenza belle arti e paesaggio della Liguria - Elenco immobili sottoposti alle disposizioni di tutela della Parte Seconda del D. Lgs. 42/200 - Città di Genova

[74] http://www.urbancenter.comune.genova.it/sites/default/files/archivio/allegati/SEAP%20summary_0.pdf

[75] https://circularcitiesdeclaration.eu/

[76] https://reader.elsevier.com/reader/sd/pii/S0921344914000561?token=6568D54213581FD9AAD71A95E523B95FCE6CE2A398F76ADB1FE048DEFB8DC6900795BC9EB2B1C1C9EAC4020D8E92E5AF&originRegion=eu-west-1&originCreation=20211021155254

[77] https://pledgetimes.com/genoa-launches-a-campaign-for-the-collection-of-steel-today-it-recovers-5-times-less-than-the-italian-average/

Genoa's progress towards circularity and decarbonization is guided by Italy's national Minimal Environmental Criteria (CAM)[78]. However, progress in the nearby city of Savona — Europe's first LEED-certified city — within the Liguria region indicates an ambition to go beyond the national standard, and the possibility of knowledge sharing across the region[79]. While no precedent has been set for construction with timber and other low-carbon materials, any transition in materials and techniques should take Genoa's resilience into consideration: the city is located in a mountainous and flood-prone area, so integrating green infrastructure and minimizing the risk of damage during flooding is essential. Genoa is seeing improvements in operational emissions, primarily due to a switch from gas heating to electric heating and heat pumps. Where retrofitting occurs, the city is witnessing a trend towards using organic-based fibers and recycled plastics for insulation.

Implementing the built environment interventions considered in the study would cut Genoa's overall consumption-based emissions by an estimated 8%. This includes a 34% reduction in Scope 1 emissions through improved building energy efficiency and increased building electrification. However, due to the high energy efficiency of Genoa's existing building stock[80], the increase in electricity demand from heating outweighs the potential reduction in demand from energy efficiency improvements, resulting in a net 11% increase in Scope 2 emissions. An overall 3% reduction in Scope 3 emissions is also modeled, including a 21% reduction in construction supply-chain emissions due to reduced demand for building materials and a switch to low-carbon alternatives.

[78] https://www.mite.gov.it/pagina/i-criteri-ambientali-minimi

[79] https://www.gbcitalia.org/-/savona-prima-citta-certificata-leed-in-europa-

[80] http://www.ireliguria.it/files/Certificazione%20energetica/Analisi_statistiche_APE_2010_2014.pdf

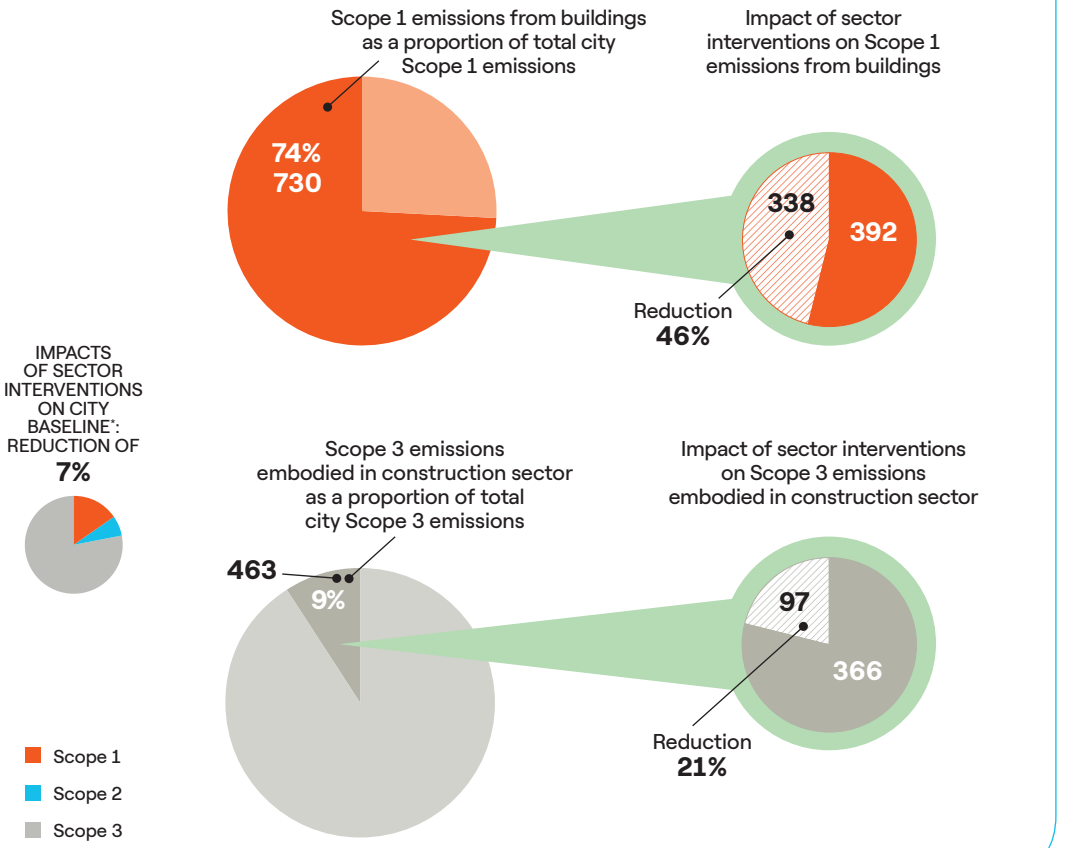
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

15%	reduction in demand for new construction due to enhanced utilization and occupation of existing assets
20% **30%**	of residential buildings and of commercial buildings *constructed using timber as a substitute for steel and concrete components*
20% **32%**	reduction in steel use and reduction in concrete use *due to using materials more efficiently*
11%	reduction in virgin steel use in construction by increasing the direct reuse of steel components
	All residential buildings achieve an EPC B rating, with an **80%** success rate by 2030. All non-residential buildings achieve an EPC C rating
	Using heat pumps to electrify **60%** of the city's residential heating demand, which is currently met by gas

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from built environment interventions of 429 $ktCO_2e$	(6.6%)
Scope 1 decrease of 338 $ktCO_2e$	(34%)
Scope 2 increase of 51 $ktCO_2e$	(11%)
Scope 3 decrease of 142 $ktCO_2e$	(2.8%)
Reduction in construction supply chain emissions of **21%** (97 $ktCO_2e$)	

GENOA IMPACT OF INTERVENTIONS IN THE BUILT ENVIRONMENT SECTOR ($ktCO_2e$)



*See page 18 of Chapter 2

Glasgow

Glasgow's built environment is a product of its history. During its transition from an industrial to a service-based economy the focus was on regenerating inner city areas, including the former docklands along the River Clyde[81]. However, over 1,000 hectares of unused buildings and land remain across the city[82], presenting opportunities for further redevelopment. The Glasgow City Council has demonstrated the potential for enhanced building occupation by introducing space standards and flexible work schemes[83] that reduced their central city locations from 19 to six. If private companies follow suit this could free up space, facilitate growth, and meet housing needs using the existing building stock.

Energy retrofitting is a challenge in Glasgow, given its strong history and heritage. The city has 1,800 listed buildings[84] and has an aging, and in many cases degraded, housing stock with over 40% of dwellings built before 1945. Much of the poorest housing is in deprived areas, and there are challenges around allocating responsibility for maintenance and repair of pre-1919 tenement apartments[85]. While the Scottish Government has set out minimum energy efficiency requirements for all social and privately rented housing[86], these do not match the standards required by new buildings, and no legislated minimum standards exist for owner-occupied homes and non-residential buildings. Glasgow is heavily reliant on gas for space and water heating[87] and large carbon savings could be made through energy efficiency improvements and switching to low-carbon heating systems.

The next decade will bring further investment in Glasgow's built environment. This includes £470 million in grant funding through the city's Strategic Housing Investment Plan, and £400 million for city center renewal through the Glasgow City Region Deal[88]. It is imperative that circular principles are implemented throughout the delivery of these projects.

Applying circular economy and decarbonization principles to the built environment as outlined in the table below, could reduce Glasgow's overall consumption-based emissions by 7%. The majority of these reductions (85%) are from building operation interventions. A further reduction of 91 $ktCO_2e$ or 27% of Glasgow's construction supply chain emissions stems from interventions focused on building construction.

81 https://www.glasgow.gov.uk/CHttpHandler.ashx?id=49640&p=0

82 https://www.glasgow.gov.uk/Councillorsandcommittees/viewSelectedDocument.asp?c=P62AFQDN0GT10G81DN

83 https://www.glasgow.gov.uk/CHttpHandler.ashx?id=49640&p=0

84 https://www.glasgow.gov.uk/index.aspx?articleid=17771

85 https://www.glasgow.gov.uk/CHttpHandler.ashx?id=5587&p=0

86 https://www.gov.scot/policies/energy-efficiency/energy-efficiency-in-homes/

87 https://www.glasgow.gov.uk/councillorsandcommittees/viewSelectedDocument.asp?c=P62AFQUTZ32UDN0G

88 https://glasgowcityregion.co.uk/

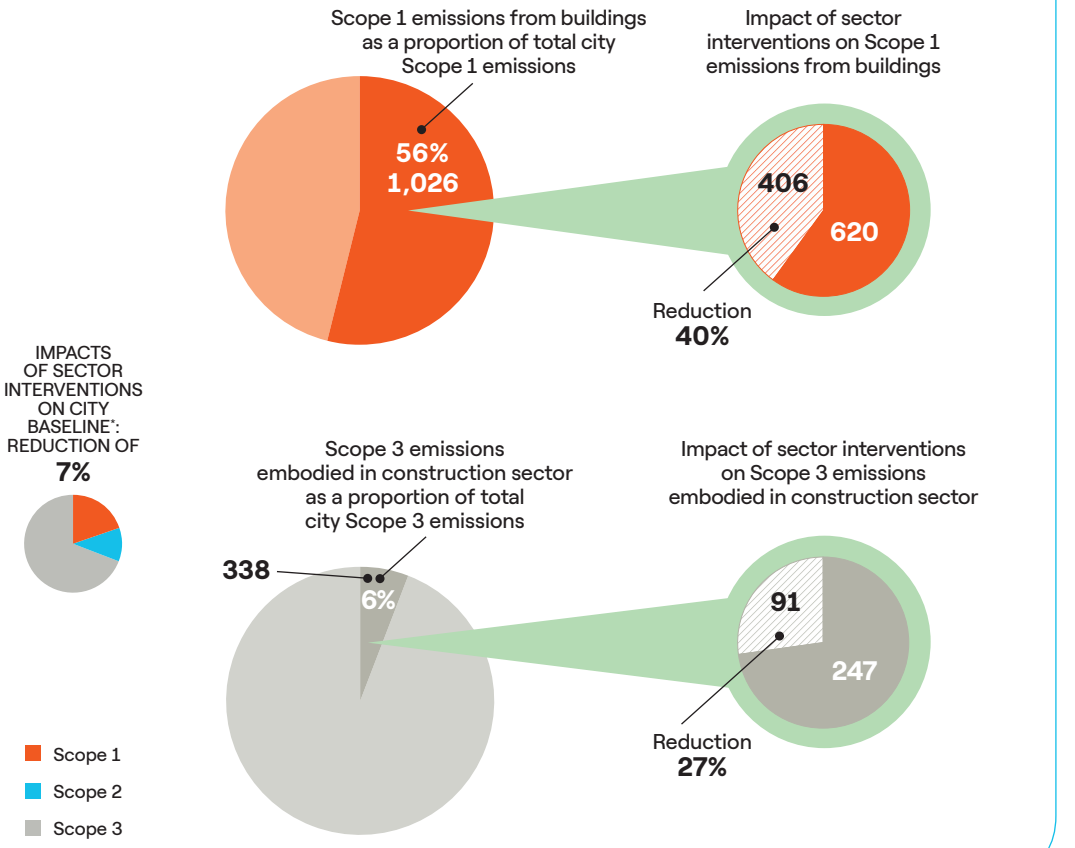
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

20%	reduction in demand for new construction due to enhanced utilization and occupation of existing assets
75% **50%**	of residential buildings and of commercial buildings *built using timber as a substitute for steel and concrete components*
20% **32%**	reduction in steel use and reduction in concrete use *due to using materials more efficiently*
11%	reduction in virgin steel use through increasing the direct reuse of steel components
	All residential buildings achieve an EPC B rating, with an **80%** success rate by 2030. All non-residential buildings achieve an EPC C rating
	Using heat pumps to electrify **50%** of the city's residential heating demand that is currently met by gas

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from built environment interventions of 588 $ktCO_2e$	(6.8%)
Scope 1 decrease of 406 $ktCO_2e$	(22%)
Scope 2 decrease of 23 $ktCO_2e$	(3.2%)
Scope 3 decrease of 159 $ktCO_2e$	(2.6%)
Reduction in construction supply chain emissions of **26.8%** (91 $ktCO_2e$)	

GLASGOW IMPACT OF INTERVENTIONS IN THE BUILT ENVIRONMENT SECTOR ($ktCO_2e$)



*See page 20 of Chapter 2

Milan

Milan's built environment is a unique blend of historic landmarks and modern, experimental districts and architecture. The city is using projects such as L'INNESTO (the first zero-carbon public housing project in Italy) and Bosco Verticale to experiment with low-carbon and circular interventions. There is also a significant number of empty and underutilized buildings. In 2019, prior to the pandemic, vacant office space in Milan totaled 1.3 million m^2. In the city center, approximately 6% of offices were reported vacant, with vacancy levels of 16% and 21% in the outskirts and hinterland respectively[89]. Since 2014, the city administration has been mapping this stock to avoid further degradation, and to prioritize regeneration, the city is taking part in the C40 'Reinventing Cities' competition[90]. The accelerated change in work patterns over the past 18 months has further increased the volume of underutilized space, providing opportunities to retrofit for residential or other uses.

In terms of new construction, Milan has established targets and introduced a new Green Public Procurement plan, which will go beyond the Minimum Environmental Criteria set by Italian law. The city's Territorial Governance Plan (TGP)[91] addresses the need to embed nature-based solutions within the built environment, including green roofs and walls, and encouraging de-paving and soil permeability. The circular economy is central to Milan's built environment strategy, and it actively promotes off-site manufacturing and pre-fabrication.

To fund the ambitions set out in the TGP, a Zero Carbon Fund has been created to support carbon neutral new builds, demolitions and reconstructions[92]. While construction with high-carbon materials is still commonplace, these measures aim to promote construction with timber and other low-carbon alternatives. Coima, a leading developer in Italy, is expanding timber use in construction, using CLT on major projects in Italy and internationally[93]. It is hoped that funding and new procurement schemes will act as incentives for other developers to follow suit. Individual developers within the industry are showing increasing enthusiasm for pre-fabrication, but policy instruments and targets for modular construction would further promote the transition.

Milan has also stipulated that all new buildings, except for public housing, and major renovations must be "Class A" Energy Efficient, while energy efficiency retrofits of older buildings are seeing a 50% reduction in energy usage. The city is also developing district heating networks, installing PVs on municipal buildings, and using groundwater for heat pumps to further reduce building operational emissions. Its goal is to eliminate diesel and gas consumption within the city's building stock. These measures are part of the Sustainable Energy Action Plan (SEAP) adopted in 2018 as a part of the Covenant of Mayors initiative[94].

By implementing the built environment interventions described in the table on page 38, Milan could see a 10% reduction in consumption-based emissions. Largely driven by improving the energy efficiency of buildings and increasing the uptake of heat pumps in residential buildings, which would cut 1,660 $ktCO_2e$ of emissions. An additional reduction of 260 $ktCO_2e$ or 26% of the city's construction supply chain emission has been modeled through interventions focused on building construction.

89 https://www.pwc.com/it/it/publications/assets/docs/pwc-real-estate-2019.pdf

90 https://www.c40reinventingcities.org/

91 https://www.pgt.comune.milano.it/

92 https://www.comune.milano.it/piano-aria-clima

93 https://www.coima.com/en/homepage

94 https://www.comune.milano.it/aree-tematiche/ambiente/energia/paes-piano-di-azione-per-l-energia-sostenibile

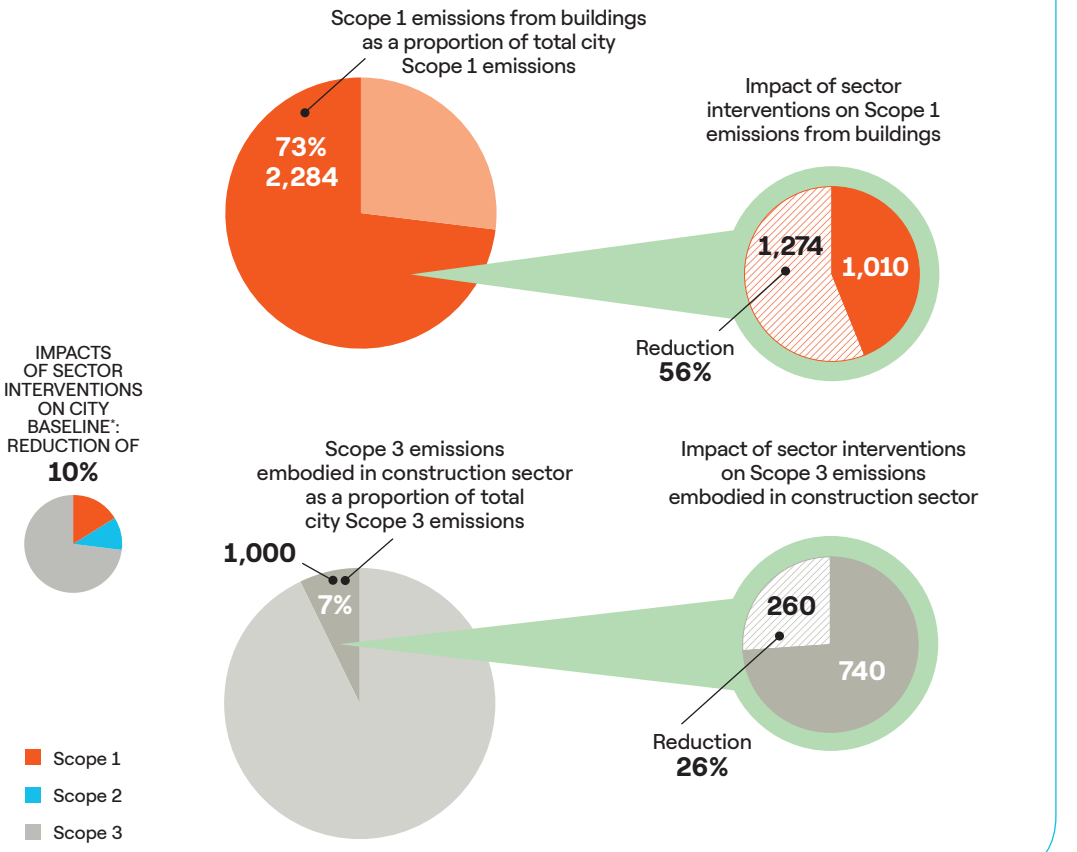
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

20%	reduction in demand for new construction due to enhanced utilization and occupation of existing assets
50% **30%**	of residential buildings and of commercial buildings *constructed with timber instead of steel and concrete components*
20% **32%**	reduction in steel use and reduction in concrete use *by using materials more efficiently*
11%	reduction in virgin steel use by increasing the direct reuse of steel components
	All residential buildings achieve an EPC B rating or above, with an **80%** success rate by 2030. All non-residential buildings achieve an EPC C rating
	Using heat pumps to electrify **60%** of the city's residential heating demand that is currently met with gas

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from built environment interventions of 1,920 $ktCO_2e$	(10%)
Scope 1 decrease of 1,274 $ktCO_2e$	(40.6%)
Scope 2 decrease of 228 $ktCO_2e$	(11%)
Scope 3 decrease of 418 $ktCO_2e$	(3%)
Reduction in construction supply chain emissions of **26%** (260 $ktCO_2e$)	

MILAN IMPACT OF INTERVENTIONS IN THE BUILT ENVIRONMENT SECTOR ($ktCO_2e$)



*See page 22 of Chapter 2

Mobility

VISION

Mobility is commonly referred to as a hard-to-decarbonize sector, and progress towards net zero has been much slower than in other sectors[95]. The proliferation of private cars has dominated 20th-century mobility, and reliance on cars on a daily basis — including for short trips — is a barrier to achieving the circular city vision. The dominance of the car has had negative consequences for public spaces, which are allocated to roads and parking rather than to green and social uses.

[95] IPCC Special report on 1.5degrees, Ch2. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf

[96] https://www.euro.who.int/__data/assets/pdf_file/0006/74715/E86650.pdf

[97] https://www.rtpi.org.uk/find-your-rtpi/rtpi-english-regions/rtpi-london/london-calling-newsletter/15-minute-cities20-minute-neighbourhoods/

[98] https://decarbon8.org.uk/work-from-home-if-you-can/

It has also led to air quality issues[96] and lack of physical activity through a promotion of sedentary lifestyles. Addressing the negative impacts of modern transportation requires a policy mix: a combination of interventions to reduce the demand for travel, shift to more efficient and healthy modes of transportation, and improve the materials and fuels used in our vehicle fleets.

A circular vision for the mobility sector in 2030 would involve a massive transformation. Transit-oriented development and the development of 15-minute neighborhoods would shorten distances between citizens and key amenities[97]. Home-working and flexible work schemes would lower the number of commutes and encourage people to eschew car ownership in favor of access models (e.g. car sharing and pooling)[98]. This is would in turn decrease GHG emissions and limit city traffic, improving quality of life. By 2030 it is envisaged that most short, local trips could be made by walking, cycling and other micro-mobility modes such as shared e-scooters, contributing to the transition towards zero carbon emissions. Longer trips beyond a reasonable distance would be made by public transportation – rail, bus, and tram – on decarbonized networks. Cities can intervene directly by electrifying local public transportation or using strategic levers to influence the choices of their citizens in favor of electric mobility (e.g. traffic zones accessible only to electric cars, reducing taxes for EVs, etc.).

By 2030, a circular city would have fewer private cars and less public space dedicated to parking. Vehicles in 2030 would be designed efficiently and modularly to facilitate parts and components recovery, using recycled and renewable materials to reduce scrap and waste and extend the average vehicle lifespan.

Improved vehicle design and manufacture are interventions beyond a city's direct control but can be influenced by proactive policies and collaboration with industry. In coming years, due to strong engagement with car manufacturers along the value chain – from raw materials to manufacturing to closing the loop at the end-of-life – there will likely be a significant improvement in terms of circularity and therefore a reduction in materials consumption. Some manufacturers are already beginning to develop circular business models and innovation labs, but a circular transportation sector will require ambitious industry-wide improvements and stringent targets for the entire value-chain.

CURRENT PRACTICES

CASE STUDY	SUMMARY
Transmilenio - Bogotà[99]	Starting from 2019, through the collaboration with Enel X, the city of Bogotà (Colombia) launched the Transmilenio project, aimed at the electrification of public transport, which now involves the construction of 2 additional electro-terminals to charge electric buses in addition to 4 existing electrified ones, 412 charging stations and the expansion of the electric bus fleet up to 878 vehicles.
Expanding Barcelona's superblock concept[100]	Barcelona is expanding its famous superblock concept to create green, car-free islands to improve air quality and public health and safety: 21 streets in the city's Eixample district will no longer be accessible by car, but will contain pedestrian plazas that will also improve city resilience. Guidance insists that at least 80% of the streets should be shaded by trees, 20% of surfacing should be permeable, and half of the total area planted with grass to improve flood resilience.
Cityringen: modular design for Copenhagen's metro system[101]	The new City Circle Line (Cityringen) subway expands the city's existing system, and is a key part of its drive to become carbon neutral by 2025. Arup has helped deliver 17 minimalist, light-filled stations inspired by the Scandinavian visual tradition and designed as modular kits – a cost-effective construction system with rational use of materials. The compact driverless trains on the existing Copenhagen subway allowed the team to design smaller platforms, helping shrink the overall footprint of the underground stations and minimizing the need for demolitions and worksites throughout the city.
Bridges of Laminated Timber (BoLT) on Dutch highways[102]	This project in the Netherlands utilized Arup's Bridges of Laminated Timber (BoLT) concept, which focuses on longevity, modularity and re-use. The bridge replaces traditional concrete superstructure with laminated timber, with 75% of the superstructure's total weight made from renewable material. Using timber makes the entire structure CO_2 neutral, yielding an Environmental Cost Indicator reduction (ECI or Milieu Kosten Indicator in Dutch) of 70% and reducing the use of primary abiotic materials by up to 90%. The bridge is also designed to last, with a theoretical lifespan of at least 100 years, as it is fully protected from rain and aligned with future Eurocode standards for Timber Bridges.
Sugar highways – paving the way to more sustainable roads in Australia[103]	Arup has been working with universities and infrastructure providers in Queensland, Australia to investigate the potential for using waste products on roads to reduce the requirement for Portland cement. Australia produces a substantial amount of sugar each year, and sugarcane bagasse ash (SBA), an industry byproduct, has been identified as a material to reduce the carbon footprint of Queensland's road infrastructure.

99 https://corporate.enelx.com/en/stories/2021/05/driving-emobility-transition-latin-america

100 https://www.bloomberg.com/news/articles/2020-11-11/barcelona-s-new-car-free-superblock-will-be-big

101 https://www.arup.com/projects/copenhagen-metro

102 https://www.arup.com/news-and-events/arup-consortium-develops-innovative-timber-bridge-design

103 https://www.arup.com/projects/sugar-highways-paving-our-way-to-more-sustainable-roads

CIRCULAR INTERVENTIONS

In the mobility sector, opportunities for change are plentiful. Emissions can be reduced through a series of interventions, including a shift towards shared, active, and public mobility and flexible working models. The optimization of the supply chain represents an opportunity for waste minimization due to the reuse and recovery of components and materials. A set of key interventions have been identified according to current best practices and consistent with the recent "Think 2030" policy paper[104], the EMF report with circular guidelines for policy makers[105] , and "The Future of Urban Consumption in a 1.5C World" report by C40 Cities[106]:

- **Modal shift:** reducing private vehicle use and replacing it with sustainable modes of transportation (public transit, active mobility, shared mobility and micro-mobility) to reduce Scope 1 and Scope 3 emissions. Actions could include: extending limited traffic/low emission zones; strengthening local and regional public transit and bicycle networks; expanding bike/e-bike/e-scooter schemes across the city; and promoting co-working and remote working[107].

- **Vehicle sharing and pooling:** this would limit the number of cars on the road and the purchase of private vehicles, reducing emissions and improving air quality[108]. Increasing the number of people traveling together through 'pay per use' solutions (car sharing) implies that fewer vehicles are required to provide the same mobility services (therefore reducing Scope 3 emissions associated with the value chain). Municipalities can support these interventions in a number of ways: providing dedicated shared mobility lanes; allowing access to emissions zones; and introducing city bike and car sharing schemes.[109].

- **Transport electrification:** cities are rapidly renovating their transportation fleets in an effort to decarbonize, primarily by switching to electric bus fleets and developing or expanding subway and light rail systems[110]. Municipalities are also encouraging the decarbonization of private mobility through supportive measures for electric mobility, such as access to low emissions zones, financial incentives for charging and parking, and facilitating public charging stations throughout the city[111]. A further important measure is supporting the installation and operation of private charging infrastructure through grants and subsidies[112]. The electrification of transport will completely eliminate direct emissions (Scope 1) from traditional vehicles by replacing them with EVs. Residual emissions are related to an increase in indirect Scope 2 and 3 emissions due to electricity consumption, and in Scope 3 emissions due to the embodied emissions of an EVs lifecycle. These residual emissions can be eliminated or dramatically reduced by increasing the share of renewables in the energy mix and by adopting a circular approach to design and materials. This is especially crucial in terms of batteries, which are a key enabling technology in the automotive sector's strategy for a clean transition. There is a strong focus on next-generation batteries at the EU level[113] in order to establish a large-scale, sustainable and competitive battery industry.

[104] Valeche-Altinel C., Wachholz C. and Engström M. (2021) A low-carbon and circular industry for Europe. Think 2030 policy paper by Ellen MacArthur Foundation and the Institute for European Environmental Policy.

[105] https://ellenmacarthurfoundation.org/covid-policymakers

[106] https://www.arup.com/perspectives/publications/research/section/the-futureof-urban-consumption-in-a-1-5c-world

[107] https://www.sciencedirect.com/science/article/pii/S0965856414002493?via%3Dihub

[108] https://www.sciencedirect.com/science/article/pii/S0959652620319168

[109] https://www.sciencedirect.com/science/article/pii/S2590198219300557

[110] https://www.politico.eu/article/europe-city-tram-networks-mobility-cut-transport-emissions/

[111] https://www.sciencedirect.com/science/article/pii/S1361920913001065

[112] https://www.gov.uk/government/collections/government-grants-for-low-emission-vehicles

[113] https://ec.europa.eu/growth/industry/strategy/industrial-alliances/european-battery-alliance_en

- **Circular design in vehicle manufacturing** can reduce upstream GHG emissions associated with the production of vehicles (Scope 3) through choice of materials, ease of repair/replacement of components, and durability. Circular design factors that can reduce CO_2 emissions throughout a vehicle's life cycle[114] include the use of recycled and renewable materials (such as bio-based materials), the efficiency of disassembly and the recovery rates of components (especially batteries).

Further circular interventions regarding vehicles could be implemented and promoted, and the quantification of their impacts could be analyzed in further studies. These include:

- **Fleet renovation**, i.e. renovating private/public vehicle fleets by substituting existing vehicles with more efficient ones;
- **Recover, reuse, repurpose of materials** to promote the recovery of vehicle parts and components (including batteries);
- **Extend vehicle life** by designing them in a more efficient way and for durability (production side) and/or enhancing their maintenance and repair (consumer side);
- **Promote flexible work schemes** to reduce mobility needs and optimize commuting times for workers.

[114] https://www.weforum.org/agenda/2020/12/how-the-circular-economy-could-forever-change-how-cars-are-made/

[115] https://injuryprevention.bmj.com/content/26/Suppl_2/i46

[116] https://theicct.org/news/health-impacts-transport-sector-pr-20190227

[117] https://www.nbt.nhs.uk/about-us/news-media/latest-news/road-collisions-responsible-one-five-trauma-admissions-hospitals

Co-benefits of the interventions

Providing circular, low-carbon transportation services in cities contributes to achieving a variety of goals that improve overall quality of life for residents. First, reducing the number of private vehicles will improve air quality and reduce mortality[115] from air pollution. The circulation of vehicles in cities is responsible for approximately one third of the overall emissions of nitrogen oxides (NOx), particulate matter (PM2.5 and PM10), volatile organic compounds (VOCs), non-exhaust emissions (NEEs) and other pollutants, causing premature deaths and respiratory diseases[116]. Reduced private vehicle use would allow for parking spaces to be converted to other public uses. Promoting efficient and sustainable public transit and active mobility also has wider benefits in terms of healthier lifestyles and fewer accidents[117], with positive externalities on healthcare systems. Designing cities for people - not vehicles - makes them more accessible for vulnerable citizens, including children and the elderly. Finally, lower traffic congestion reduces stress, improves work-life balance and increases productivity. Moreover, an efficient mobility system is an important factor for social inclusion and for a better balance between the city center and peripheral areas, allowing for easier access to essential services and increasing cultural exchange. Reducing car ownership also reduces the need to extract materials for vehicle manufacture.

Improved public transportation services can also enhance resilience to disruptive shocks such as the ongoing Covid-19 pandemic[118]. The mobility sector is exposed to a variety of stressors, such as extreme weather events brought about by climate change, that can disrupt its operations. A resilient public transit system is one that allows residents to safely move around the city based on their needs, provides viable alternatives (e.g. in case of accidents or road maintenance), responds to peaks in demand, and operates despite limited resource availability (oil or gasoline, electricity, construction materials) or price increases.

Focus on cities and results

The following sections present the mobility context for the selected cities, the interventions and measures tested through quantitative analysis, and the results in terms of ambitions and opportunities offered by the circular economy.

The level of ambition chosen for each city has been selected based on Bocconi University - GREEN's experience in the mobility sector and inputs from dedicated interviews with main local stakeholders, discussions with study partners, and inputs from collaborative international projects among the most ambitious cities. It considers criteria such as the state of the existing transportation infrastructure and services, the opportunities arising from new technologies, and the current level of adoption of sustainable transportation modes, electric vehicles, and innovative technologies to improve vehicle manufacturing.

These values aim to capture the potential decarbonization opportunity offered by strategic policy measures and action plans already defined by local administrations and additional interventions that if implemented could facilitate the transition towards circularity.

[118] https://www.sciencedirect.com/science/article/pii/S2590198220300622?via%3Dihub

Bogotá

Bogota's transport system is underpinned by the TransMilenio, the city's Bus Rapid Transit (BRT) system. Despite its size, Bogota does not have a metro system, but relies on an extensive 350 km network of direct bus priority corridors and feeder routes. The TransMilenio provides essential services for 2.56 million passengers a day, and has been critical to reducing congestion and emissions associated with private vehicle use.

In 2011, ten Latin American countries including Colombia signed the Bogotá Declaration on Sustainable Transport Objectives (BDSTO), which outlines strategies to promote sustainable, efficient and healthy transport systems according to the 'avoid, shift and improve' framework. This has accelerated the development of plans by the city government to promote active and public transport to support the BRT system. The municipality plans to improve its public transportation infrastructure by constructing a two-line subway system that is expected to be in operation in 2028 (construction of the first subway line started in 2021)[119]. Bogotá also promotes active mobility and micro-mobility: the mass transit of citizens by bicycle is sustained with public investment and the construction of bike paths throughout the city.

City experts have estimated that the effect of these measures in contributing to a modal shift in Bogotá could reduce passenger vehicle transportation by 20%.

Transport electrification is one of the main interventions for the city in terms of potential decarbonization and can have a great impact on reducing direct emissions. For Bogotá, this intervention was modeled only through the electrification of public transportation, as there is no set goal for the expansion of private electric vehicles and there could be affordability issues. Also, given the low car ownership rates in Bogotá, vehicle sharing and pooling was not modeled for the city, as the intervention appears not to be applicable in this context.

From the relevant city plans, it is estimated the complete electrification of the TransMilenio BRT system would reduce emissions by 155 $ktCO_2e$. The electrification of Bogotá's entire bus fleet would imply a 22% reduction in direct Scope 1 emissions. The noticeably large impact can be explained due to the large number of buses considered in the electrification process, as well as the high emissions factor of circulating buses. However these would be partially compensated by a 13.7% increase in indirect Scope 2 emissions due to higher electricity consumption and a minimal Scope 3 increase due to embodied emissions in manufacturing new assets to support the transition.

[119] https://www.railway-technology.com/news/colombia-rail-yard-construction/#:~:text=The%20first%20line%2C%20which%20will,public%20transportation%20in%20the%20city.

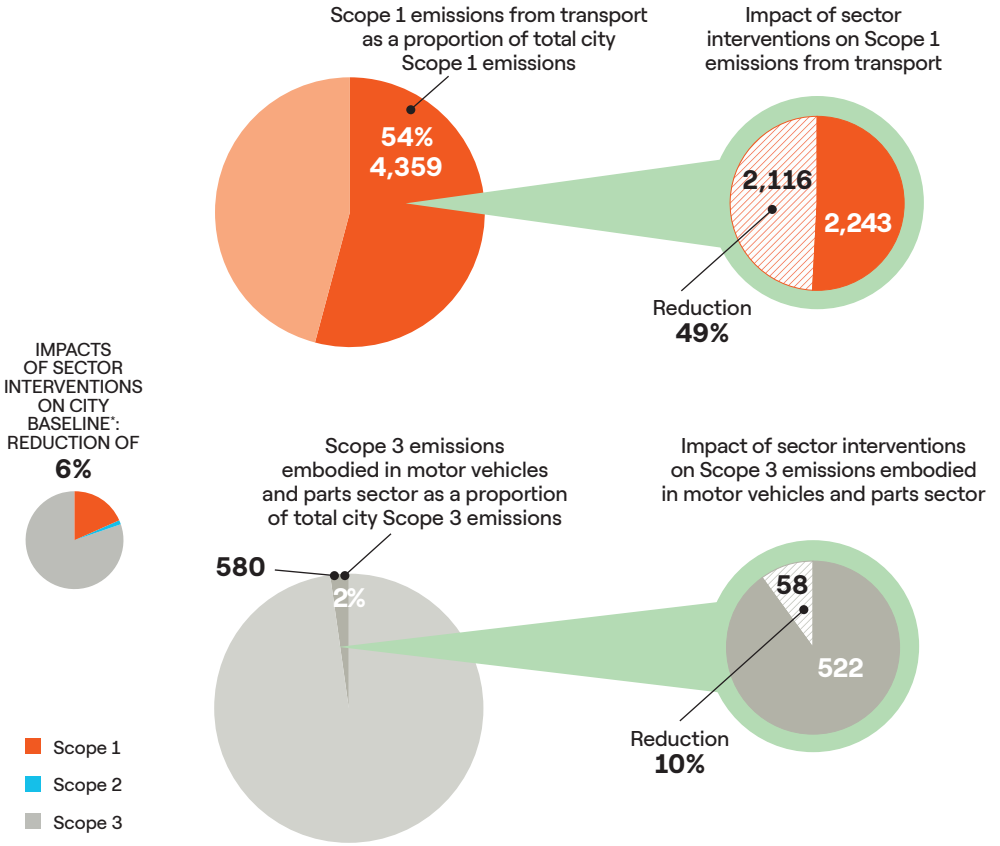
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

Modal shift: (Scope 1) reduction in CO_2 emissions due to a 20% reduction of private vehicle use, replaced by sustainable transport modes (public transport, active mobility, shared mobility and micro-mobility); (Scope 3) decrease in indirect emissions along the fuel supply chain.
Electrification of transport: (Scope 1) 100% reduction in tailpipe CO_2 emissions of substituted vehicles due to electrification; (Scope 2) Increase in indirect Scope 2 emissions due to higher electricity consumption from EVs; (Scope 3) change in indirect Scope 3 emissions due to variations in demand for EVs, electricity and fuel use
Circular vehicle manufacturing design: 50% reduction in materials consumption (steel and plastics) due to more efficient design

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from mobility interventions of 2,481 $ktCO_2e$	(5.7%)
Scope 1 decrease of 2,116 $ktCO_2e$	(26.3%)
Scope 2 increase of 90 $ktCO_2e$	(13.7%)
Scope 3 decrease of 455 $ktCO_2e$	(1.3%)

BOGOTÁ IMPACT OF INTERVENTIONS IN THE MOBILITY SECTOR ($ktCO_2e$)



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Genoa

Genoa is strategically located in terms of connections to other cities and is a node for important national highways. The city's public transportation is managed by local public transit company AMT, which in 2019 handled over 238 million passengers[120]. In addition to several bus (both traditional and electric) and trolley lines, there is an eight-stop subway that connects strategic tourist spots, a ferry line, and several vertical cable cars. The City of Genoa is working to promote the electrification of private and public transit, installing 160 EV charging columns and fostering micro-mobility through bike, scooter and car sharing schemes. The city's new Sustainable Urban Mobility Plan (PUMS) provides for the construction of new bike paths and the installation of electric charging stations.

The city's Sustainable Energy and Climate Action Plan (SECAP) contains several measures to foster a modal shift. Their combined effect, including shared mobility, would cut 55 $ktCO_2e$ of emissions.

The electrification of public and private transportation would reduce the city's direct Scope 1 emissions by 5% (although this effect would be partially offset by a 4% increase of indirect Scope 2 emissions due to higher electricity consumption).

Improved shared mobility and carpooling services could reduce private vehicle ownership — modeled as in the other cities as a 4% drop in household expenditures on new private vehicles — and this would reduce Scope 3 emissions slightly, by 6 $ktCO_2e$ or 0.12%.

[120] https://www.amt.genova.it/amt/

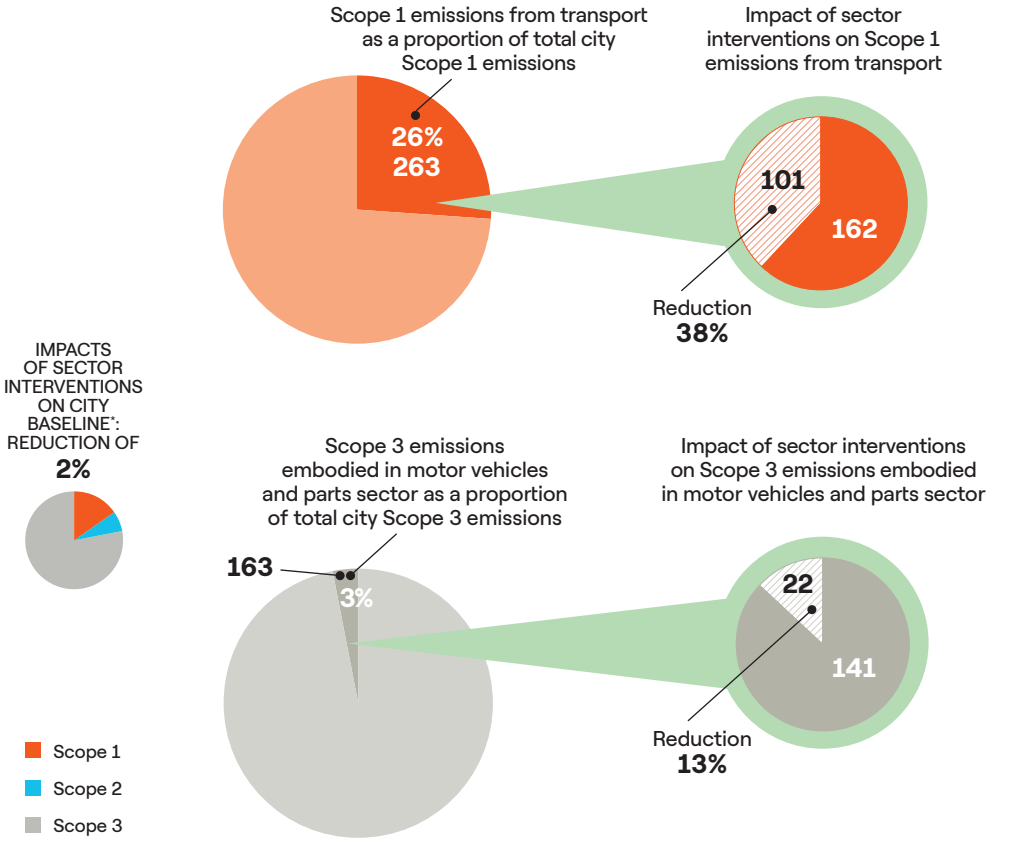
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

Modal shift: (Scope 1) CO_2 emissions drop by 55 kilotons due to reduced private vehicle use and replacement by sustainable transportation modes (local public transit, active mobility, shared mobility and micro-mobility); (Scope 3) decrease in indirect emissions along the fuel supply chain
Car sharing and pooling: (Scope 3) 4% reduction in household expenditures on private vehicles
Electrification of transport: (Scope 1) 100% reduction in tailpipe CO_2 emissions of substituted vehicles due to electrification; (Scope 2) increase in indirect Scope 2 emissions due to higher electricity consumption from EVs; (Scope 3) change in indirect Scope 3 emissions due to variations in demand for electricity and fuel use
Circular design in vehicle manufacturing: 50% reduction in materials consumption (steel and plastics) due to more efficient design

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from mobility interventions of 162 $ktCO_2e$	(2.5%)
Scope 1 decrease of 101 $ktCO_2e$	(10.2%)
Scope 2 increase of 17 $ktCO_2e$	(3.8%)
Scope 3 decrease of 78 $ktCO_2e$	(1.5%)

GENOA IMPACT OF INTERVENTIONS IN THE MOBILITY SECTOR ($ktCO_2e$)



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Glasgow

In Glasgow, transportation is dominated by cars and vans (49%)[121]. However, Glasgow City Council has outlined several initiatives to promote a shift from private cars to public and active transportation. These include 20mph zones, a low emissions zone, promoting park and ride schemes, and expanding local and regional public transit and bike path networks.[122]

Currently, roads make up 25% of Glasgow's land area, but there is a call to reduce this allocation and to increase the share of public green space and social amenities[123]. The availability of parking in the city center is being reduced through the "Avenues Project", with under-utilized parking spaces being transformed into active travel infrastructure. Glasgow's City Centre Transport Strategy outlines a commitment to extend and improve the city's Fastlink BRT service[124] in order to connect those in the North and the East of the city, where a gap exists in the subway system, via fast and reliable local public transportation. Glasgow's Circular Economy Roadmap suggests the city could go further and make public transit free for all residents[125] as has been done elsewhere, for example in Luxembourg[126]. Greater utilization of a zero emissions public transit system is central to the Connecting Glasgow strategy, which states that mass transit allows for the most efficient use of land space[127].

[121] https://www.transport.gov.scot/publication/transport-and-travel-in-scotland-2017/

[122] https://www.glasgow.gov.uk/CHttpHandler.ashx?id=19234&p=0

[123] https://www.glasgow.gov.uk/CHttpHandler.ashx?id=45064&p=0

[124] https://www.glasgow.gov.uk/transportstrategy

[125] https://www.glasgow.gov.uk/councillorsandcommittees/viewSelectedDocument.asp?c=P62AFQDNDX2UT1NTNT#:~:text=This%20Circular%20Economy%20Route%20Map%20sets%20out%20a%20framework%20to,for%20environmental%20and%20social%20regeneration

[126] https://www.mobiliteit.lu/en/tickets/free-transport/

[127] https://www.glasgow.gov.uk/CHttpHandler.ashx?id=45064&p=0

[128] https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01

[129] https://glasgow.gov.uk/article/24595/Charge-Place-Glasgow-Frequently-Asked-Questions

[130] https://www.eltis.org/resources/case-studies/oslo-promoting-active-transport-modes

[131] https://www.glasgow.gov.uk/index.aspx?articleid=18620

While most of Glasgow's railway network has already been electrified, there are still a few Intercity diesel trains and minor unelectrified lines that need to be decarbonized as a priority in the coming years. Further steps are required to electrify private transportation. Currently, less than 1% of private vehicles in the city are electric[128]. Glasgow City Council plans to facilitate growth in EVs by adding 60-70 new public charging points a year[129]. This could be further stimulated through an evolution of the low-emissions zone to phase out all non-electric vehicles, or by introducing a road pricing scheme to disincentivize driving in the city center, following the example of Oslo[130].

Glasgow already has several options for mobility sharing, including the Co-Wheels car sharing scheme and OVO electric and standard bike hire[131]. The City Council has reserved priority parking spaces for shared cars. There is an opportunity to introduce other shared mobility services such as electric scooters, which have become popular in other cities, although it is important to ensure that shared mobility vehicles use circular manufacturing principles and have long lifespans in order to reduce their overall impact. A 20% reduction in vehicle use is projected for Scotland by 2030; as a dense and environmentally ambitious city, greater transitions could be possible in Glasgow, with a 30% reduction being suggested by city experts.

There is an 8.4% emission reduction potential in Scope 1 emissions thanks to the modal shift, which could reduce demand for private car use within the city, and to the electrification of the private and public vehicle fleets (even though this would increase Scope 2 emissions).

Reducing vehicle manufacturing materials (mostly steel and plastics) for vehicles purchased in Glasgow would result in a reduction in indirect Scope 3 emissions (0.4%).

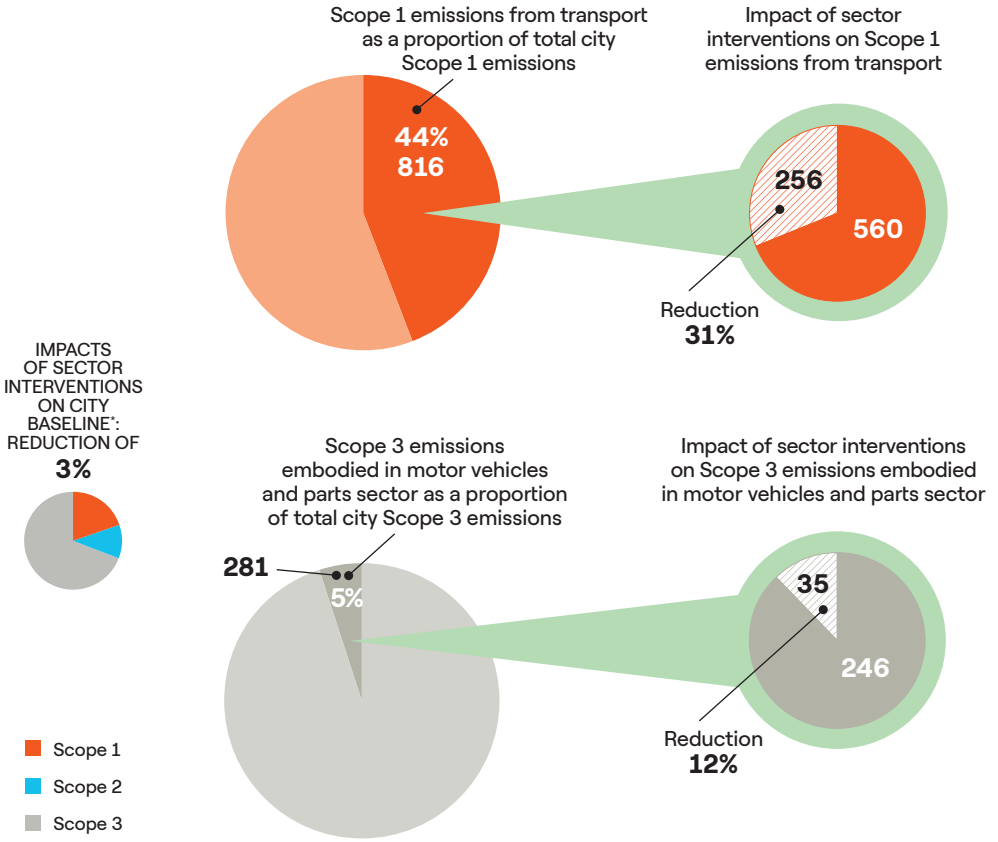
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

Modal shift: (Scope 1) reduction in CO_2 emissions due to a 30% reduction of private vehicle use, replaced by sustainable transportation modes (local public transit, active mobility, shared mobility and micro-mobility); (Scope 3) decrease in indirect emissions along the fuel supply chain
Vehicle sharing and pooling: (Scope 3) 4% reduction in household expenditures on private vehicles
Electrification of transport: (Scope 1) 100% reduction in tailpipe CO_2 emissions of substituted vehicles due to electrification; (Scope 2) increase in indirect Scope 2 emissions due to higher electricity consumption from EVs; (Scope 3) change in indirect Scope 3 emissions due to variations in demand for EVs, electricity and fuel use
Circular vehicle manufacturing design: 50% reduction in materials consumption (steel and plastics) due to more efficient design

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from mobility interventions of 288 $ktCO_2e$	(3.3%)
Scope 1 decrease of 256 $ktCO_2e$	(13.9%)
Scope 2 increase of 35 $ktCO_2e$	(4.9%)
Scope 3 decrease of 67 $ktCO_2e$	(1.1%)

GLASGOW IMPACT OF INTERVENTIONS IN THE MOBILITY SECTOR ($ktCO_2e$)



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Milan

According to Milan's Air and Climate Plan, transportation is responsible for 18% of total GHG emissions in the city area (based on 2017 data), therefore interventions to decarbonise the transport sector are crucial to the city's overall environmental agenda.

In Milan, 72% of public transit passengers use electric subways, trams, trolleys, buses and suburban trains, and 28% use diesel buses[132]. The Municipality of Milan's commitments to create a sustainable and circular city, with specific measures to create green and healthy streets, are based on measures included in the C40 Fossil Fuel Free Streets Declaration[133] it signed in 2017, its Sustainable Mobility Urban Plan (SUMP)[134], which was approved in December 2018, and its Sustainable Energy Action Plan[135] of 2018.

Some of its more ambitious stated goals concern connectivity and accessibility, expressing a desire to reduce dependence on private vehicles and halve road traffic, replacing these with more available and accessible public transit modes as well as active mobility.

The city's Air and Climate Plan estimates that mode shift is the most important route to decarbonizing the city's transport sector. These measures will be reinforced by the electrification of transportation and, in particular, by the Full Electric Plan for Milan public transportation operator ATM[136], which aims to provide the city with a fully electric public transit fleet by 2030. This will cut 75 $ktCO_2e$ a year, 460 tons nitrogen oxide emissions, three tons of PM10 and 0.8 tons of elemental carbon.

The impact on Scope 2 emissions from the electrification of public transit in Milan is set at 0, because ATM has been purchasing electricity from 100% renewable sources since 2017.

The promotion of sustainable transit modes is also supported by traffic restrictions in urban areas: Milan is the first municipality in Europe that has forbidden downtown access to diesel cars, up to and including Euro 4 models in an urban area (Area C). These restrictions also incentivize the purchase of low and zero-emission vehicles and the use of sharing and micro-mobility. Milan public transit is reinforced by a wide spectrum of sharing services: bikes and cars as well as innovative means of transportation such as segways, hoverboards, skateboards, push scooters and one-wheeled vehicles.

Within this study, circular vehicle manufacturing design was modeled by considering a 50% reduction in the amount of steel and plastic used. In Milan, this measure would yield a reduction of Scope 3 emissions of 57 $ktCO_2e$.

[132] https://www.atm.it/it/Pagine/default.aspx

[133] www.c40knowledgehub.org/s/article/Green-and-Healthy-Streets-The-C40-Fossil-Fuel-Free-Streets-Declaration?language=en_US

[134] http://www.trt.it/en/PROGETTI/supervision-sump-of-milano/

[135] https://www.comune.milano.it/aree-tematiche/ambiente/energia/paes-piano-di-azione-per-l-energia-sostenibile

[136] https://www.atm.it/it/AtmNews/Comunicati/Pagine/ATMDAL2030FULLELECTRIC.aspx

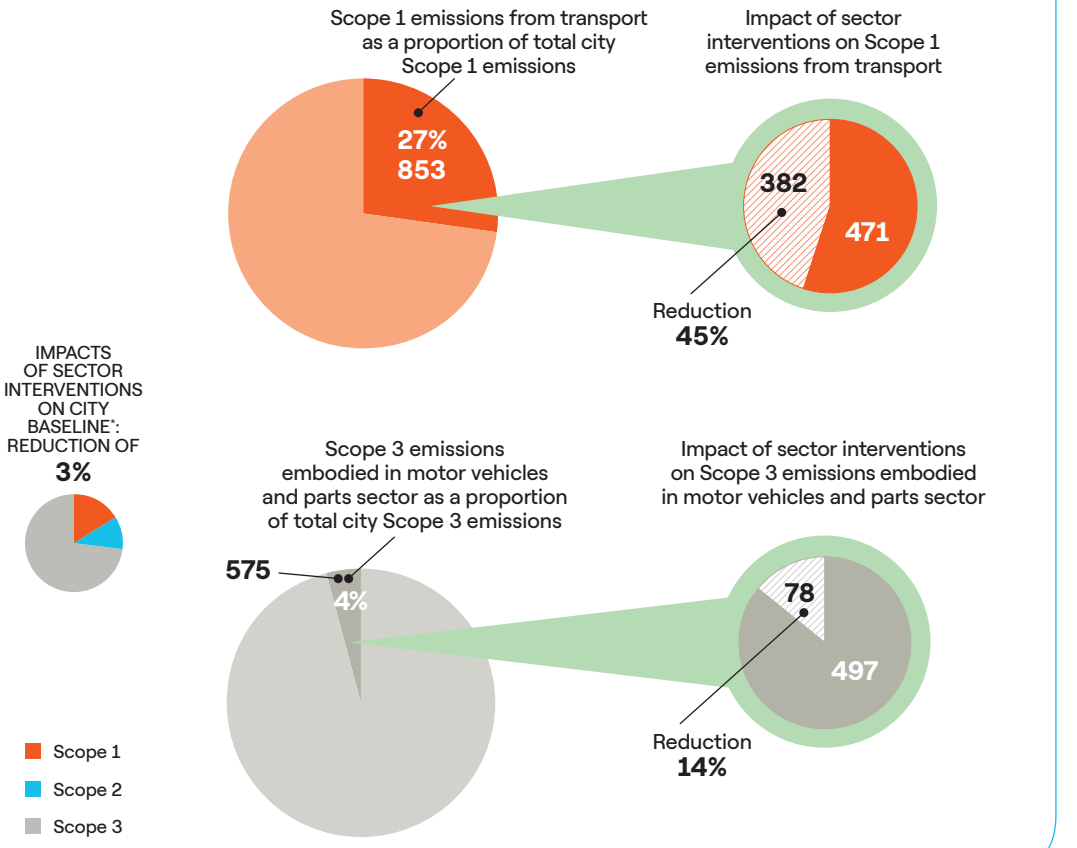
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

Modal shift: (Scope 1) reduction in CO_2 emissions due to the reduction of private vehicle use, replaced by sustainable transit modes (local public transit, active mobility, shared mobility and micro-mobility); (Scope 3) decrease indirect emissions along the fuel supply chain
Vehicle sharing and pooling: (Scope 3) 4% reduction in household expenditures on private vehicles
Electrification of transport: (Scope 1) 100% reduction in tailpipe CO_2 emissions of substituted vehicles due to electrification; (Scope 2) increase indirect Scope 2 emissions due to higher electricity consumption from EVs (cars only, as in public transit the purchased electricity is 100% renewable; (Scope 3) change in indirect Scope 3 emissions due to variations in demand for EVs, electricity and fuel use)
Circular vehicle manufacturing design: 50% reduction in materials consumption (steel and plastics) due to more efficient design

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from mobility interventions of 635 $ktCO_2e$	(3.3%)
Scope 1 decrease of 382 $ktCO_2e$	(12.2%)
Scope 2 increase of 11 $ktCO_2e$	(0.5%)
Scope 3 decrease of 264 $ktCO_2e$	(1.9%)

MILAN IMPACT OF INTERVENTIONS IN THE MOBILITY SECTOR ($ktCO_2e$)



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Sustainable energy systems

VISION

Electricity is a fundamental enabler of all urban activities, and therefore cities are the environment in which this transition will manifest the fastest. To allow renewable energy to reach its full potential, it is essential to shift final consumption from fossil fuels to electricity. The topics of clean energy and energy efficiency are central to the environmental transition goals set by municipalities. The actions planned concern the decarbonization of energy production through the development of renewable sources in urban areas, the increase in purchasing energy from renewable sources, and the adoption of digital solutions to improve and optimize activities and energy consumption.

The main innovative technologies for this transition are first and foremost distributed renewable plants. They have transformed the previous top-down energy distribution paradigm into a model where the consumer can be a producer at the same time. Relevant contribution to the transition comes also from electric technologies for final use (e.g. mobility, heating and cooling, etc.). This transition must be accompanied by an evolution of the network towards the "smart grid" concept, with strong innovation in terms of metering, digitization and artificial intelligence to allow the network to be operated according to the highest security, performance and efficiency standards.

Big data, connectivity and digital technologies are additional key pillars of city evolution thanks to wide networks of sensors, data analysis and processing that enable the real time monitoring and operation of physical assets (e.g. roads, railway lines, water mains, electricity grids) and the flows that run along them (e.g. cars, trains, water, energy, materials, waste)[137]. This allows cities to optimize operations and also to better plan and carry out further interventions. Widespread connectivity also allows residents access to fast and easy services, and to work remotely.

[137] https://www.iea.org/reports/empowering-cities-for-a-net-zero-future

CASE STUDY	SUMMARY
The West Orange project in Amsterdam (the Netherlands)[138]	More than 400 homes in Amsterdam have been fitted with an energy management system as part of the "West Orange" project, which aims to raise citizen awareness of private energy consumption through a display linked to digital gas and electricity meters. The technology, which allows users to monitor specific electrical appliances as well as the entire home, has resulted in a reduction in energy use and emissions per home of up to 14%.
Urban Futurability® Sao Paulo, Bogotá (Brazil and Colombia)[139]	Urban Futurability® is the Enel project that aims to build a new model for the energy grid of the future, based on digitalization, automation and innovation: elements that are key to improving asset efficiency and resilience, but also users' quality of life, by making the grid more flexible. At the same time, the new platform model would help to make the city more sustainable and provide new grid-based services to its residents. Thanks to Network Digital Twin technology, a 3D model that replicates the local electrical infrastructure through sensors installed on the grid, information will be communicated in real time to both distributors and local stakeholders. In terms of the assets, it will be possible to provide a real-time understanding of the asset situation and predictive maintenance/consequent environmental risk mitigation; in terms of end users, this technology will also create a greater awareness of energy use, efficiency and savings.
Open Data Tools: Enel X's "Circular City Index" and "15-Minute Index"	If properly collected, processed and published, open data is a valuable resource with which to monitor indicators that allow administrations to implement a circular economy transition, by supporting existing tools and policies and introducing new ones. With this in mind, Enel X and its academic partners developed the Circular City Index[140]: a score, based entirely on Open Data at a national level, that supports municipalities' transition and that has already been implemented for all Italian cities and will soon be extended to other countries. The Index systematizes urban "circular variables" in four main areas (digitalization, climate and resources, sustainable transport and mobility, waste and materials) in order to foster the digital, ecological and energy transition of cities by highlighting their strengths and weaknesses in these areas. Moreover, by using data analytics and focusing on a work of open data discovery, collection and processing – unique in the smart city sector – Enel X is also developing the "15-Minute Index", a digital solution that supports cities in their sustainability transition by promoting urban planning based on proximity. The index shows the geographical distribution of services (e.g., transport, hospitals, schools, etc.) that are easily reachable on foot by citizens, in order to see which areas are underserved compared to the population density and to redesign the urban environment using the first pragmatic and scientifically validated tool to build a "15-Minute City".

[138] https://www.urenio.org/2010/01/10/2320/

[139] https://www.enelamericas.com/en/stories/a201912-success-of-a-sustainable-model.html

[140] https://www.enelx.com/it/it/istituzioni/sostenibilita/circular-city-index

CURRENT PRACTICES

CASE STUDY	SUMMARY
MIND - Milano Innovation District, Milan (Italy)[141]	As the energy partner providing energy services for the realization of the MIND - Milano Innovation District project – the future center of innovation that will be established in the area that hosted Expo Milano 2015 – Enel X will plan, build and manage the system of production, distribution and sale of electricity through the construction of photovoltaic systems, electrical storage systems, intelligent lighting systems, a multifunctional Smart Pole able to provide value-added services such as video analysis, Wi-Fi access and environmental monitoring, as well as photovoltaic shelters and charging stations for electric vehicles connected to the grid (Vehicle to Grid). The final aim of these solutions is to create an integrated ecosystem that manages the entire grid in an integrated and flexible way, according to "Demand Response" principles.
Green Open Meter, Genoa (Italy)[142]	In line with the national plan to replace 32 million first generation smart meters in Italy and in agreement with the Genoa public administration, Enel has begun installing around 20,000 new meters made of 100% recycled plastic from old meters for users in the city, including small and medium-sized enterprises. Combining technology, innovation and sustainability, the Green Open Meter is the latest-generation meter built using material coming from disposed meters. The regeneration of the 20,000 new meters has made it possible to reduce waste during production by 2.4 tons and to save 16 tons of virgin plastic. This has resulted in an estimated reduction of 140 tons of CO_2 compared to the traditional process.

[141] https://corporate.enel.it/it/comunicatiregionali/press/d/2020/08/mind-milano-innovation-district-enel-x-vince-con-linnovazione-ed-e-partner-energetico-di-mind-

[142] https://www.e-distribuzione.it/archivio-news/2020/12/il-green-open-meter-per-l-ambiente.html

INTERVENTIONS

A series of interventions for the energy sector were tested that could be applied in the city context. Reduction of emissions in this sector is achieved through interventions that have an impact on the indirect GHG emissions through the use of renewable energy instead of fossil fuels and the indirect emissions associated with the supply chain of installed assets:

- **A decarbonized and electrified city:** the growth of renewable energy production is the most important way to avoid emissions related to fuel consumption. Nonetheless, many fuel related emissions in cities are related to final energy uses that currently do not rely on electricity. To extend the reach of renewable energy, it is therefore necessary for mobility, heating and cooking to shift to electricity, in order to fuel them with renewable energy. This general paradigm based on renewable energy, smart grids and final electrical use could potentially produce zero emissions.

  Cities can support the development of renewable energy sources within their city limits, as many cities are already doing. Although there are many possible renewable technologies, the one that is most widespread in the city limits is **the installation of PVs on the roofs** of public and private buildings, thanks to its modularity, lower visual impact and the availability of solar radiation in many latitudes.

  The effect of this intervention can vary considerably depending on the amount of usable space available to install solar panels, limitations due to the historical and artistic constraints of certain buildings, the amount of potential solar radiation, and rooftop installation characteristics. This intervention aims to reduce the use of fossil fuels in the production of electricity, taking into consideration the different aspects of the cities due to their geographic location and the arrangement of the buildings in the environment.

  Renewable production can be achieved using new generation solutions within the city limits, and **buying energy from renewable plants** outside the city limits, for example by entering into a Power Purchase Agreement (PPA). This is an agreement where the administration could commit to buying energy from a specific renewable project over a long-term period. This takes into account the construction of wind plants able to satisfy all the electricity needs of the municipality,[143] including buildings owned by local administration, public lighting, electric transport and residential buildings.

[143] For the four cities in the study, municipality electricity consumption is reported in the following documents: Genoa: SECAP Genoa; Milan: Piano Aria Clima di Milano; Glasgow: UK local authority and regional carbon dioxide emissions national statistics: 2005-2019; Bogotá: balance energético, potencial energético de generación en la región central

- **Digitalization of services – smart city** is another important lever for the city transition, as it makes it possible to reap the full potential of big data, connectivity and artificial intelligence. It impacts many aspects of urban life, such as the use of smart meters that can help citizens to become more aware of their consumption and optimize their consumption patterns, bringing both economic and environmental benefits and leading to a reduction of Scope 2 and Scope 3 emissions[144]. Although not included in the assessment, other useful interventions that should be taken into consideration include:

  - The real-time monitoring of various urban parameters (e.g. passenger flow, traffic patterns, parking space vacancies, etc.) to optimize operations and have a solid statistical base from which to define new interventions;
  - Connectivity: the development of a reliable digital infrastructure for all cities to enable them to benefit from remote services such as e-government, e-health, and remote working
  - Platforms and tools that allow citizens to access information, make proposals, discuss and actively participate in city life.

Another useful intervention, which is beyond the scope of this study, is technology related to **home automation**, which includes the implementation of domestic solutions that monitor and manage home appliances and aim at reducing the energy needs of any building, especially in terms of winter heating, summer cooling and lighting. The continuous and real-time monitoring of some parameters (temperature, energy consumption, etc.) can make it possible to optimize energy use and quickly detect any anomalies.

[144] A. Bagnasco, A. Vinci, F. Silvestro, G. Mosaico, Soluzioni innovative per il risparmio energetico negli edifici del terziario (Innovative solutions for energy savings in service sector buildings), Gestione Energia-FIRE, no. 1, 2020 and "Reducing household electricity demand through smart metering: The role of improved information about energy saving", James Carroll, Seán Lyons, Eleanor Denny.

Benefits of these interventions

The transition to a circular economy should not neglect the citizens' quality of life, and the energy sector can play a crucial role in this. The development of smart grid and smart meters, for instance, and the spread of digitalization facilitate a more efficient use of energy by reducing energy waste and consequently reducing costs to the citizens, thanks to the availability of resources and the competitiveness of new technologies. Citizens can even become producers of electricity, with the possibility of selling surplus energy back to the grid and reaping economic benefits as a result. Switching to renewable energy sources and electrifying consumption significantly benefit the quality of life in cities by reducing emissions, thereby improving air quality and citizens' health.

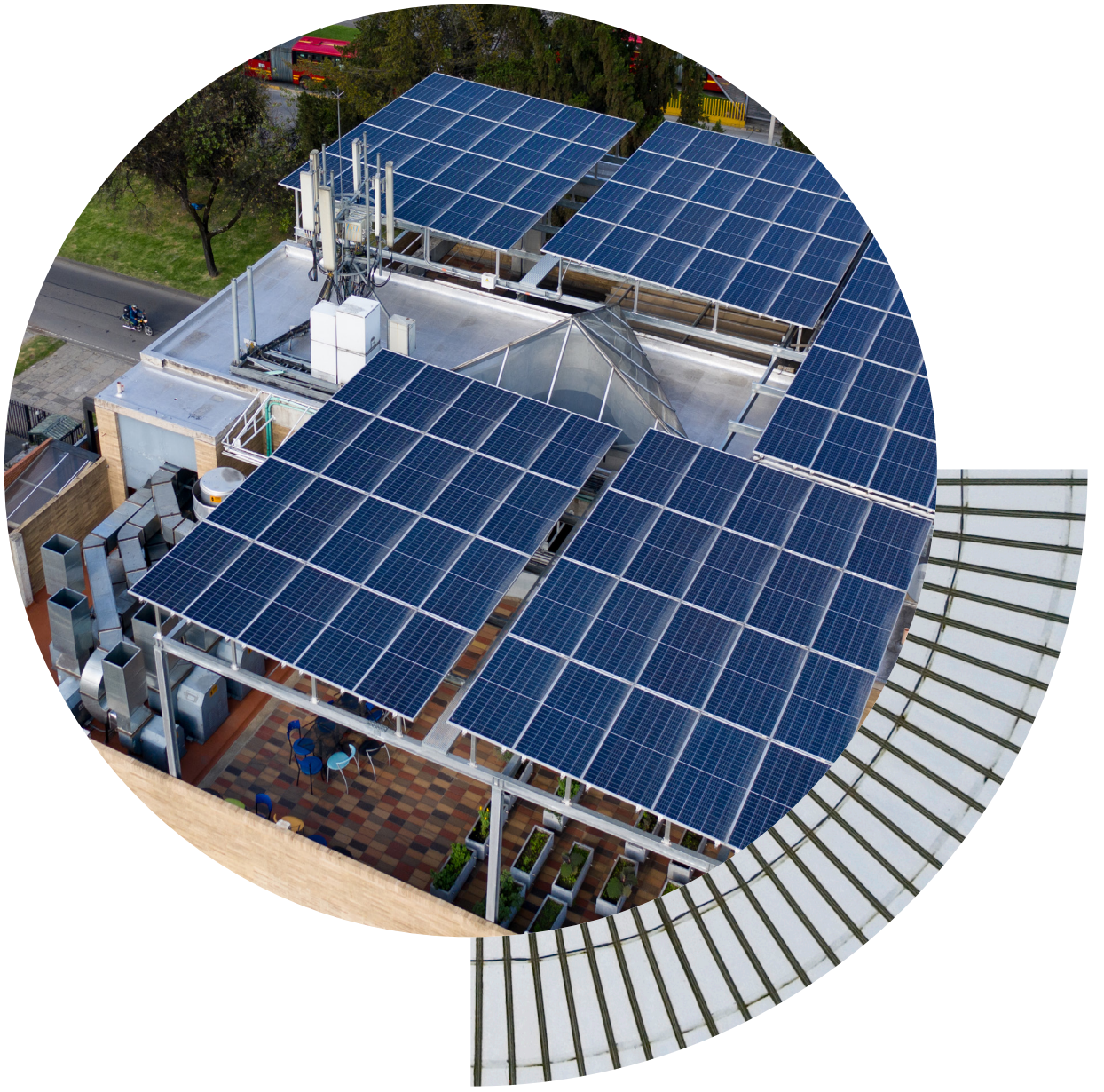
The benefits, however, are not limited to this dimension. The use of electrical technology (e.g. induction cooking surfaces), eliminates indoor emissions and safety risks. All-digital solutions also help reduce the time and resources needed to carry out certain activities and can offer services to the most vulnerable for example, e-health, e-government, etc. With regard to resilience, the use of renewable sources and the evolution towards more intelligent and flexible grids can help reduce the risk of energy supply problems such as interruptions related to extreme weather events, etc.

Focus on cities and results

The four case study cities' sustainable energy systems, their readiness to adopt digitalization, the level of intervention tested by quantitative analysis, and the resulting magnitude of opportunity given by the circular economy initiatives advocated in the report are detailed in the sections below.

The interventions applied to different urban contexts have been chosen for their replicability and according to the indications of the different stakeholders. These are innovative and challenging interventions that aim to drastically reduce the consumption of fossil fuels for energy production by exploiting local production through renewable sources (sun and wind) and the reduction of consumption.

These are high-level values that try to capture the potential decarbonization opportunity presented by each city's ambitious initiatives as they move toward a more circular system.



Bogotá

The city of Bogotá is very open to the most innovative technologies, and this is certainly a strength for the energy sector. In line with this, photovoltaic panels have been installed in parking lots and on the roofs of the city's bus rapid transit system Transmilenio's offices, producing energy to be consumed on site.

Looking at the private sector, El Dorado Airport installed more than 10,000 solar panels in 2019, accounting for 12% of its total consumption (3,800,000 kWh per year). The adoption of this project prevents 1,375 tCO_2 from being released into the atmosphere. This is one example where stakeholders believe that, in the city of Bogotá DC, decarbonization is primarily a concern of the business sector, which aims at enhancing their manufacturing processes, cutting costs, and therefore contributing to low greenhouse gas emissions. This can facilitate and encourage the widespread installation of energy production systems, making them ever more accessible.

The city is also committed to the efficiency of consumption, starting from initiatives related to public lighting.

The most relevant intervention in terms of reduction of Scope 2 emissions is the purchase of energy from renewable plants outside the city limits which account for 53%. In comparison, a minimal 0.21% increase in Scope 3 emissions can refer to the whole lifecycle of the onshore wind farm. Smart metering could be another important key intervention: smart meters can reduce domestic electricity consumption up to 8%.

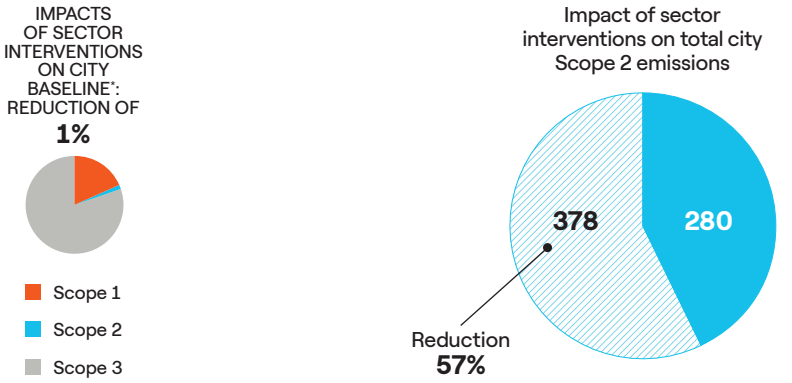
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

5%	(Scope 2) reduction in emissions associated with the use of fossil fuels for electricity production due to the installation of PV panels on rooftops
53%	(Scope 2) reduction in the intensity of electricity emissions due to purchase of energy produced outside the city limits by renewable plants
8%	(Scope 2) reduction in residential electricity consumption due to the implementation of one smart meter per household

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from energy interventions of 270 $ktCO_2e$	(0.6%)
Scope 2 decrease of 378 $ktCO_2e$	(57.4%)
Scope 3 increase of 108 $ktCO_2e$	(0.3%)

BOGOTÁ IMPACT OF INTERVENTIONS IN THE SUSTAINABLE ENERGY SYSTEMS SECTOR ($ktCO_2e$)



*See page 16 of Chapter 2

Genoa

Within the goal of reducing CO_2 emissions in the energy sector, the city of Genoa could implement actions aimed at increasing overall energy efficiency, renewable energy production, the level of digitalization and a dedicated plan for the port DEASP[145] (Documento di pianificazione Energetico Ambientale del Sistema Portuale del mar ligure occidentale, or Energy and Environmental Planning Document of the Western Ligurian Sea Port System) in which the concept of dock electrification is included. Moreover, the city of Genoa supports the creation of Energy Communities by encouraging the production and shared consumption of electricity from renewable sources by citizens and SMEs.

The reduction of a city's electricity consumption also entails the monitoring of its consumption. From this point of view, the use of "smart metering" enables the study and implementation of energy efficiency strategies, based on more accurate consumption readings. The intelligent metering of consumption is essential not only for utility companies but also for consumers, in order to increase their awareness and consequently allow them to adjust their consumption habits. Finally, a shift toward a renewable electricity mix is essential for the decarbonization of the city.

One of the most effective intervention in terms of reduction of Scope 2 emissions is the installation of PV panels on the roofs of buildings: this intervention would be particularly effective due to the solar exposure of the city of Genoa due to its geographic location. The installation of PV panels on just 15% of the roofs in Genoa would allow for a reduction in Scope 2 emissions of 97 kCO_2e, which is significant. In addition, this intervention would have minor effects on Scope 3 reduction, as all the embodied emissions of the fossil fuels for electricity production supply chain would be impacted.

[145] https://www.portsofgenoa.com/components/com_publiccompetitions/includes/download.php?id=1235:deasp-2020.pdf

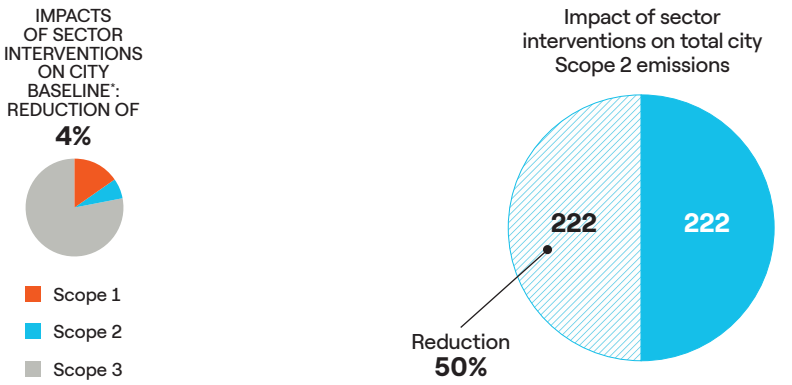
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

22%	(Scope 2) reduction in emissions associated with the use of fossil fuels for electricity production due to the installation of PV panels on rooftops
33%	(Scope 2) reduction in the intensity of electricity emissions due to purchase of energy produced outside the city limits by renewable plants
8%	(Scope 2) reduction in residential electricity consumption due to the implementation of one smart meter per household

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from energy interventions of 233 $ktCO_2e$	(3.6%)
Scope 2 decrease of 222 $ktCO_2e$	(50%)
Scope 3 decrease of 11 $ktCO_2e$	(0.2%)

GENOA IMPACT OF INTERVENTIONS IN THE SUSTAINABLE ENERGY SYSTEMS SECTOR ($ktCO_2e$)



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GENOA PORT

In a city like Genoa which lives in close contact with its port, it is essential to act on port infrastructure in order to obtain meaningful results in terms of reducing emissions.

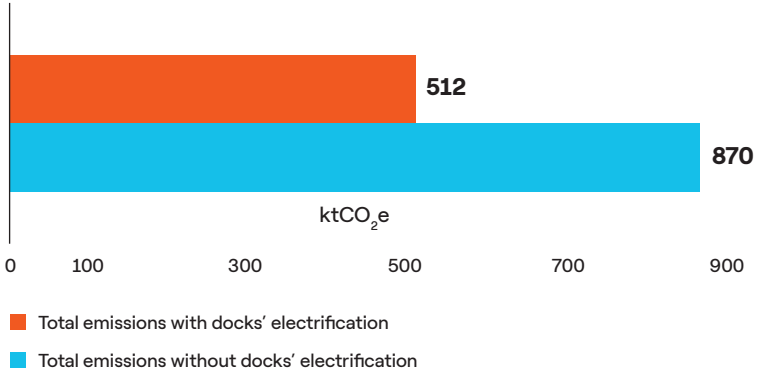
In this vision of sustainability and circularity, the port plays a fundamental role: the most significant results are obtainable through cold ironing[146], as shown in the case study of the port of Los Angeles in California[147], which began moving towards zero emissions in 2007 and today is the most advanced port in terms of electrified docks.

The electrification of the port of Genoa has been a recurrent topic for several years. This is an important step towards environmental sustainability, since a ship being loaded or unloaded in 10 hours generates CO_2 emissions equal to what 25 cars emit in a year[148]. In addition to CO_2, many other agents are also emitted into the atmosphere (such as NOx, SOx, VOC, PM10 and PM2.5) and equally as important is the noise pollution produced by thermal generators which, in a city like Genoa that is very close to the port, can be disturbing.

Data from the Italian Energy Services Manager[149] indicated an energy mix for 2017 that consisted of 36% of electricity from renewable sources (hydraulic, solar, biomass, wind, geothermal), 42% from natural gas, and only less than 1% of electricity produced using petroleum-derived fuels (naphtha). Meanwhile, 100% of the electricity produced by ships for their own consumption comes from the burning of heavy fuel oil (OCD).

The lower emission factor from the electricity consumption of the ships, is the result of the electrification of the docks compared to that of energy production through the thermal engines placed on board leads to a dramatic reduction in pollutant emissions into the atmosphere. In addition, associating the emissions of the moored ships to the electricity mix allows a progressive reduction over time because of the increasing share of electricity from renewable energy sources. With a hypothetical 100% renewable electricity mix, the moored ships would not produce delocalized polluting emissions. This is crucial for the objective of cutting emissions by 2030 and decarbonization by 2050.

The complete electrification of the docks at the port of Genoa (cargo, ferries and cruises) would reduce the annual emissions of almost 360 $ktCO_2e$, equal to approximately 41% of the emissions coming from the harbor system[150] (standing and operating ships, port operators and light and heavy vehicles in transit in the port).



[146] https://reader.elsevier.com/reader/sd/pii/S0965856418303264?token=A8002A7870CF2E43A1882756DADE62D1963EBAA9B46D490030C852A384BAB3FC06C49E9939B965ED32D01B82ED2D3F9E&originRegion=eu-west-1&originCreation=20211028143542

[147] https://www.portoflosangeles.org/environment/air-quality/alternative-maritime-power-(amp)

[148] L'elettrificazione delle banchine dei porti del Mar Ligure Occidentale" - Ports of Genoa https://www.portsofgenoa.com/it/green-port/iniziative-green.html

[149] GSE, "Fonti rinnovabili in Italia e in Europa. Verso gli obiettivi del 2020", Febbraio 2018

[150] Elaboration of the University of Genoa on data contained in the DEASP (Documento Energetico Ambientale Sistema Portuale del Mar Ligure Occidentale)

Glasgow

Glasgow's energy consumption in buildings and infrastructure is dominated by gas (65%) and electricity (35%)[151] that is supplied almost entirely from national grid energy distribution and transmission systems. However, the city has plenty of local renewable energy resources, including wind, solar, biomass and geothermal, that can facilitate the transition to a low carbon electric city with a decentralized energy supply system.

In recent years, Glasgow has increased its local renewable energy generation capacity. Wind resources have been harnessed through a wind farm at Cathkin Bank, as well as smaller wind turbines operating at schools and at the Clyde Tunnel. The city is also supporting green hydrogen and energy storage with a variety of projects, including the construction of the UK's largest electrolyzer adjacent to the Whitelee onshore windfarm[152]. Further renewable capacity is supplied by solar photovoltaic panels on council owned buildings, schools and social housing across the city[153].

The potential use of geothermal energy in the city has been demonstrated by a small program using mine water to heat 17 homes in Shettleston[154]. The UK's first water-source heat pump project to supply district heating to existing buildings is also being developed on the Clyde[155].

Despite these new programs and proposals, further expansion of Glasgow's renewable energy system is needed to meet the city's peak energy demand, while challenges also exist around the seasonality of energy sources and temporal differences between supply and demand (intermittency) with wind energy power generation highest the winter and solar power generation highest in the summer.

Waste energy can also provide power and heating to nearby homes and businesses. Glasgow's Recycling and Renewable Energy Centre (GRREC) produces enough energy to power 22,000 homes[156]. Further waste heat could also be harnessed from Glasgow's wastewater systems and industrial premises such as city-center breweries. Waste heat and other renewable energy generation can be supplied to buildings using local district energy networks such as the program at the Glasgow 2014 Commonwealth Games Athletes Village[157] and the University of Glasgow's district heating and power network[158]. Glasgow City Council's local heat and energy efficiency plan is also exploring the opportunity for further district energy networks throughout the city in order to localize the energy supply and reduce fuel poverty[159].

However, it is important for any transition of the energy system in Glasgow to incorporate circular principles such as reusing equipment and material from older generations of wind turbines and decommissioned oil and gas platforms. A reduction in Scope 2 emissions has been registered thanks to the purchase of energy produced outside the city limits by renewable plants, which is also associated with a small Scope 3 reduction related to the construction of the new asset.

[151] Proportion of consumption excluding petroleum products used for transport. https://www.understandingglasgow.com/indicators/environment/energy_consumption

[152] https://www.scottishpower.com/news/pages/green_hydrogen_for_glasgow.aspx

[153] https://glasgow.gov.uk/article/19516/Glasgows-new-solar-schools-show-great-dividend

[154] https://www.gov.scot/publications/study-potential-deep-geothermal-energy-scotland-volume-2/pages/13/

[155] http://www.scottishenergynews.com/uks-first-water-source-heat-pump-project-for-district-heating-to-be-launched-on-the-clyde/

[156] https://www.glasgow.gov.uk/article/24081/Glasgow-Recycling-and-Renewable-Energy-Centre-Fully-Operational

[157] https://www.vitalenergi.co.uk/our-work/commonwealth-games-athletes-village-operation-maintenance/#:~:text=We%20designed%20%26%20built%20the%20low,a%20120%20bed%20care%20home

[158] https://www.gov.scot/publications/local-heat-energy-efficiency-strategies-phase-1-pilots-technical-evaluation-report/pages/3/

[159] https://www.gov.scot/publications/local-heat-energy-efficiency-strategies-phase-1-pilots-technical-evaluation-report/pages/3/

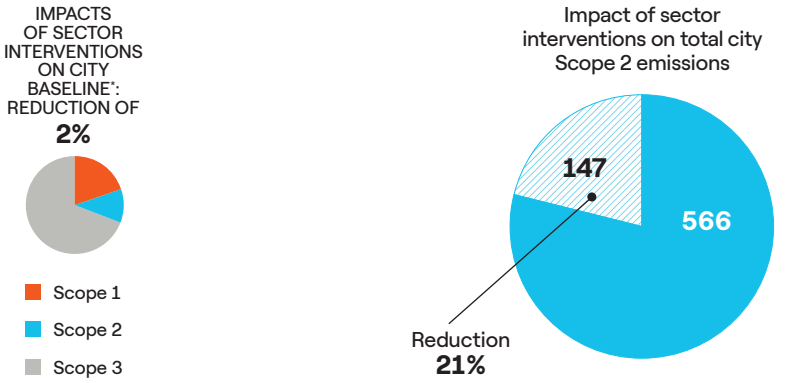
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

5%	(Scope 2) reduction in emissions associated with the use of fossil fuels for electricity production due to the installation of PV panels on rooftops
14%	(Scope 2) reduction in the intensity of electricity emissions due to purchase of energy produced outside the city limits by renewable plants
8%	(Scope 2) reduction in residential electricity consumption due to the implementation of one smart meter per household

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from energy interventions of 151 $ktCO_2e$	(1.7%)
Scope 2 decrease of 147 $ktCO_2e$	(20.6%)
Scope 3 decrease of 4.8 $ktCO_2e$	(0.1%)

GLASGOW IMPACT OF INTERVENTIONS IN THE SUSTAINABLE ENERGY SYSTEMS SECTOR ($ktCO_2e$)



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Milan

The topics of renewable energy and energy efficiency are central to the environmental transition goals set by the Municipality of Milan. Actions planned in this regard concern both the decarbonization of the built environment and of energy production. Within the CO_2 inventories of the city, electricity consumption is the first source contributing up to 50% of overall emissions, 37% of which is attributed to the tertiary and productive sector.

Milan's overall energy consumption across all sectors is due to electricity consumption of 32%. Therefore, decarbonizing electricity production is required to comply with the 45% emission reduction target set for 2030. In line with these objectives, Milan will promote the massive deployment of solar photovoltaic systems to promote local electricity production. Decentralized production will take place mainly through the development of energy communities, the purchase of certified green energy and greater efficiency of energy use in the tertiary and productive sector through the involvement of stakeholders. The municipality will also encourage large private users that cannot be energy independent to join associations and consortia that produce certified green energy from solar, wind and hydroelectric sources.

Heat recovery from wastewater is also considered a strategic renewable source of energy, which can be used to power local networks or integrate the district heating network by means of heat pumps. Sources include wastewater from purification plants and water at aqueduct pumping stations.

The topic of home automation and new technologies for buildings is pivotal for improving energy performances in the cities of the future, and Milan is no exception to this. New smart neighborhoods could provide innovative solutions, such as monitoring and optimization of energy consumption in housing units, monitoring consumption of electrical appliances, optimized district heating and lighting efficiency, smart meters and smart grids, water and heating consumption.

Thanks to its geographical position, one of the most effective intervention in terms of reduction of Scope 2 emissions is the installation of PV panels on the roofs of buildings. A minimal increase for Scope 3 was recorded due to embodied emissions of PVs life cycle. Considering the effect of reduction on Scope 2 emissions, in comparison with the increase in Scope 3 emissions, the intervention is still very efficient.

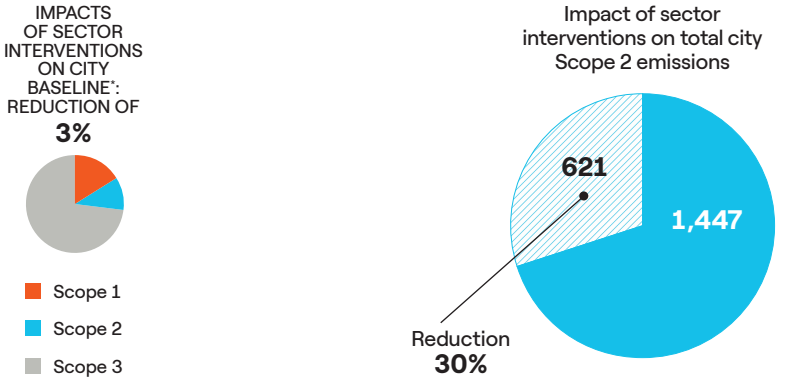
SUMMARY OF INTERVENTIONS AND POTENTIAL IMPACT ON CO_2

10%	(Scope 2) reduction in emissions associated with the use of fossil fuels for electricity production due to the installation of PV panels on rooftops
21%	(Scope 2) reduction in the intensity of electricity emissions due to purchase of energy produced outside the city limits by renewable plants
8%	(Scope 2) reduction in residential electricity consumption due to the implementation of one smart meter per household

HEADLINE RESULTS

Total decrease in the city's consumption-based emissions from energy interventions of 627 $ktCO_2e$	(3.3%)
Scope 2 decrease of 621 $ktCO_2e$	(30%)
Scope 3 decrease of 6 $ktCO_2e$	(0%)

MILAN IMPACT OF INTERVENTIONS IN THE SUSTAINABLE ENERGY SYSTEMS SECTOR ($ktCO_2e$)



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Main evidence

In this section we have created an evidence base for city leaders and main decision-makers that illustrates how interventions based on circular economy principles are needed to achieve net zero targets. We focussed on three important sectors and created total carbon baselines for the year 2017 that provide a consumption-based emissions perspective for each city. We then tested the impacts of interventions that we believe could be implemented by 2030 against the 2017 baseline to understand the impacts on Scope 1, 2 and 3 emissions.

Built environment

Cities face different challenges for decarbonising the built environments, and in all cases, circular principles offer a framework for emissions reductions across the entire lifecycles of buildings. City governments must adopt whole life cycle and systems approaches to understand the baselines of existing buildings and energy infrastructure before developing area-based plans and programmes of projects to decarbonise all buildings. From our analysis we have demonstrated examples of projects that showcase the feasibility of circularity within the built environment. It is now time to scale up these individual examples through progressive, city-wide action, including creating local area energy plans, monitoring vacant building stock, and implementing circular procurement standards and specifications, and digital material passports.

Mobility

Unsurprisingly, a common theme across all cities is the potential to reduce carbon emissions by people shifting to public transport, car sharing and pooling and to walking and cycling. The rate and type of the change varies according to each city's baseline mobility patterns, and geography. The carbon analysis also emphasised mobility's interconnection with the built environment, land-use planning and energy sectors. The electrification of local public transport (e.g. e-bus) and the promotion of private electric mobility thanks to the installation of charging infrastructures and dedicated policies is one of the main city levers to decarbonize the sector, especially if accompanied by the promotion of the use of renewables. Truly cross-sector collaboration is required to promote 15-minute neighborhoods, to reduce the distances citizens need to travel between home, work, education, and leisure locations. The reallocation of space away from private vehicle parking is a necessary step to incorporate efficient lanes for public transport, walking and cycle paths and green infrastructure into our cities.

Energy Systems

Decarbonising the energy vectors for cities is a critical need, cutting across and supporting all sectors to decarbonise from heating in buildings, to mobility and public lighting in cities. To do this cities can support the development of renewable energy sources not only inside their territory (by promoting the PV installation) but also outside the city for example through the mentioned PPA solution with renewable power plants. As well as collaborating with energy generators and network operators, cities can also work with large infrastructure providers nearby to catalyse transformational change. From our analysis, the port of Genoa presents a great example – where electrification of the port could reduce emissions from the harbour system by 41% and catalyse wider decarbonisation across Genoa.

THE EUROPEAN INVESTMENT BANK (EIB)

"Like the EU and Climate Bank, the EIB supports projects with climate action and environmental sustainability impact.

We have a particular focus on supporting the circular transition in cities, recognizing their potential to be both cradles and catalysts for circular change.

The circular city transition involves many different sectors, and promoters and projects of different types, which need different kinds of financial and other support. Clear projects, contexts and objectives are needed to correctly address economic supports. To provide insight into circular city opportunities and the access to financing for related projects, the EIB and the European Investment Advisory Hub have prepared the Circular City Funding Guide. This web platform includes information on the circular city context, information for fund seekers and fund providers and case studies and circular city resources to inspire action and change.

To further support cities in their circular transition, the EIB, with funding support from the European Union through the European Investment Advisory Hub, has recently launched the Circular City Centre and the Circular Economy Technical Assistance Facility."

4. Governance and policies

In Chapter 3 we presented our analysis that demonstrates the impacts of circular interventions across three important sectors for the four cities we have studied. We recognise that the transition to the circular economy will not happen on a sector-by-sector basis – all sectors are inextricably bound together and action to reduce total emissions in all sectors is required. The importance of citywide governance and the impact of municipalities' actions in pursuit of circularity must be neither underestimated nor ignored and, in this Chapter, we set out some city-wide recommendations for leaders and policy makers.

Transitioning from linear to circular economic models at city and national scale will require systemic approaches involving a broad range of stakeholders, since the circular economy spans across all elements of all sectors, both public and private. Cities must adopt new governance models that stimulate new ecosystems in which citizens and all organisations – city leaders, policy makers, industry, NGOs, academia – can collaborate and contribute to accelerating the shift towards an entirely new economic paradigm.

To enhance and facilitate the involvement of civil society, citizens and professionals from different fields should be allowed to contribute their knowledge to the definition of policies that impact the entire economic sector.

Accelerating the shift to an entirely new economic paradigm, implies also the involvement of local initiatives, knowledge institutions, NGOs and residents across sectors.

Secondly, the role of the local government is important in raising **awareness** among citizens on the importance of active participation and in providing them with the tools to ensure that innovation and sustainability are increasingly central to every initiative.

This commitment is particularly relevant in an open governance approach that aims to make decision-making processes increasingly transparent and shared, to foster involvement, and to accelerate the creation of public-private partnerships. Participation, transparency, and accountability are considered essential attributes of open governance as the public sector does not have a monopoly on public value creation, but it does have in most situations the prime role in ensuring that public value is created"[160].

Among the relevant examples of governance redesign to support the transition to the circular economy, the Netherlands[161] is a notable case.

NETHERLANDS CASE

The **Dutch governance approach** towards circularity started by informing and spreading **awareness** among citizens and all stakeholders about the main environmental and socio-economic challenges of the city, in order to convey a sense of urgency. In this context, it is easier to develop and implement a shared vision and plan towards circularity. A second requirement is to focus on **context-specific opportunities**: leveraging the most promising and disruptive innovators can be the key to solving specific local issues, considering city peculiarities and needs in an innovative way. Third, successful implementation requires strong circular **business models**, a transparent division of labor costs and benefits in order to accelerate and scale up the transition.
Amsterdam's vision to be 'a thriving, regenerative and inclusive city for all citizens, while respecting the planetary boundaries'[162] puts citizens at the heart and thus creates an environment in which every resident feels that their contribution matters and is relevant to achieving the vision.

Within cities, new regulatory frameworks, incentives, research funding, information systems, citizen awareness and participation, and international cooperation are the fundamental **governance mechanisms** that facilitate a transition to a circular economy. Some examples are given later in the study.

These mechanisms present critical issues, in particular the fact that policy measures or lines of action might be divided among several departments and therefore lose the incisiveness and extension that they could have. The four cities analyzed in this study (Bogotá, Genoa, Glasgow and Milan) addressed challenges and found solutions to be replicated by other cities for a successful circular economy transition.

[160] Millard, J., (2018), "Open governance systems: Doing more with more", Government Information Quarterly.

[161] https://sloanreview.mit.edu/article/six-lessons-from-amsterdams-smart-city-initiative/

[162] https://www.amsterdam.nl/en/policy/sustainability/circular-economy/

City governance can enhance the circular transition

The main pillars of the circular economy strategies adopted by the cities we have studied, and which have emerged from interviews with stakeholders across multiple sectors (local institutions, private sector companies and NGOs) and from policy analyses, are summarised below. They provide a useful framework for all city leaders and policy makers to consider and adopt.

1. **Set out a citywide vision for the circular economy:** A circular economy requires systems to cope with and nurture new disruptive and circular business models. Therefore, it is important for the local government to have a systemic view and to collaborate and coordinate across all sectors. A traditional approach of executing projects in organisational silos is not conducive to circularity and achieving net zero carbon targets. A citywide vision gives stakeholders the confidence to plan for the long-term.

   The vision should be long-term but subdivided into interim stages with outcomes and targets. Glasgow has created its Circular Economy Route Map for a decade (2020-2030), and Amsterdam has set an ambition for 2050 with intermediate plans[163]. When setting the vision, city governments must highlight potential barriers or unique characteristics of the city that could be an obstacle to circularity. Early identification will help the long-term monitoring of these challenges throughout planning and implementation.

   Zero Waste Scotland recommends taking a place-based approach to city visioning: using other cities' plans as inspiration and adapting them to local issues and priorities[164]. Cities also need to consider the different contexts in different parts of the municipality. Urban centres are dense, whilst peri-urban areas – in-between urban and rural territories – can be particularly vulnerable and prone to developing into 'wastescapes' because they are generally characterised by mixed functions and fragmented by major infrastructure. Therefore, adding a spatial dimension to the city vision that accounts for the challenges and opportunities presented in different areas of the city is an important step in defining an achievable vision.

2. **Circular economy strategies must be part of overall city planning:** cities often adopt separate strategies for decarbonisation, resilience and a circular economy. These strategies and their desired outcomes overlap, and synergies could be achieved by integrating them. For example, circular economy strategies can lead to both decarbonisation and resilience. It is important to consider the effects of these interventions and how they align with broader city goals. For instance, Milan's Air and Climate Plan sets out responses to the challenges of climate change and reducing air pollution, and includes actions specific to the circular economy[165].

   The city's land use or spatial plan should consider the importance of the use of space in the transition to circularity. Now is an optimal time to embed circularity into city plans, as leaders around the world look to revive localism and implement 15-minute neighborhoods. Designing dense cities where buildings are fully utilised, transport distances are minimised, and efficiencies in energy provision are maximised should form the basis for future city planning.

[163] https://www.amsterdam.nl/en/policy/sustainability/circular-economy/

[164] https://www.zerowastescotland.org.uk/circular-economy/cities-and-regions

[165] https://www.comune.milano.it/piano-aria-clima

3. **Set circular targets and metrics:** the circular economy is an economic model that seeks to minimise resource use. It requires its own new sets of indicators to help with tracking material and energy flows, quality of life and resilience, in addition to economic flows. Therefore, it is important to associate overall objectives and specific initiatives to quantitative targets, and to measure performance. Collection and sharing open data such as real-time air quality, public transport performance and availability of EV charging stations and other services for citizens is a critical service and an important information base which, if properly developed, can become a tool for monitoring and continuous improvement, allowing administrations to make decisions and set goals.

4. **Disclosing the circular performance of the city** can be a very effective tool for encouraging the active participation of citizens, developing and communicating proposals, and monitoring their implementation. Some of the clearest examples of this approach are in the Amsterdam and Paris circular strategies. Amsterdam started by calculating the total burden of the raw materials and materials that the city consumes along with total waste produced, to measure the impact on CO_2 emissions and the environmental costs, and then set measurable targets. Paris has already developed two roadmaps with precise indicators and targets to ensure the measurability and monitoring of its progress in circularity[166].

Cities should be open-minded in setting metrics and targets and go beyond GDP and traditional development indicators to those which relate to the circular transition, such as waste quantities, raw material use, building occupancy, recycling and reuse rates, state of habitats and the natural environment; material living conditions; physical and mental health; education; social interactions; economic and energy security; and governance and basic rights.

To ensure circular strategies are embedded into all aspects of the economy, frameworks like the Doughnut Model (as in the City of Amsterdam) have been used to ensure the need of citizens within the city are met, whilst respecting planetary boundaries[167]. This all-encompassing model promotes systems thinking in a way that is more progressive than typical city planning.

If progress towards certain targets is slower, or the necessary change greater, then focus groups could be set up to prioritise action in challenging areas. Outreach and knowledge sharing could also help expedite the transition in these areas.

5. **Use new finance opportunities:** the financial focus on sustainability, and specifically on the circular economy, is rapidly growing. For projects designed in the circular economy framework, various financing opportunities exist, from subsidised finance, such as loans and grants, to equity investments, to more innovative solutions such as crowd funding. Each approach to financing has specific characteristics that suit different types of investments; the Amsterdam Climate & Energy Fund (AKEF) and the Sustainability Fund are two examples of tools adopted to support the New Amsterdam Climate Plan in reducing Amsterdam's emissions[168].

[166] https://cdn.paris.fr/paris/2019/07/24/38de2f4891329bbaf04585ced5fbdf0f.pdf

[167] https://www.amsterdam.nl/en/policy/sustainability/circular-economy/

[168] https://www.amsterdam.nl/en/policy/sustainability/policy-climate-neutrality/

City governments can support businesses with a clear focus on circular principals by formalising their endorsement of circularity through the procurement process. City governments can also work with industry and industry regulators to push circularity metrics into existing frameworks (examples include Task Force on Climate-Related Financial Disclosures, Carbon Disclosure Project, Science Based Targets Initiative). City governments can also encourage national governments to introduce supportive measures including favourable loan and tax rates for repair, refurbishment and retrofit to incentivise these actions over new construction.

Ultimately, the city should focus on creating a market economy that incentivises circular actions. If it remains cheaper to import new materials or goods instead of reusing or repurposing existing assets within the city boundary then companies will continue to choose the most economically viable option.

6. **Have an implementation plan:** circular cities with clear commitments in the long term show the way for the transformation from a linear to a circular economy, but they can experience tensions from stakeholders pushing for immediacy. Public local administrations, while working towards the well articulated development of a circular economy in the long run, have to face many issues regarding effective communication and satisfaction of present needs. Therefore, it is important to define and communicate clear long term plans accompanied by detailed and consistent short-term planning, in order to initiate an effective transformation while at the same time constantly monitoring short-term effects and results.

For example, to transform the productive system in a circular and sustainable way, it is important for the administration to support private sector stakeholder, particularly the small and innovative ones, by removing financial and regulatory obstacles. The renewal of existing management practices, the simplification of authorization procedures, and the definition of incentives to circularity are some of the accompanying measures for the realization of a circular transformation. At the same time, the benefits of decarbonization must be constantly highlighted to citizens and to businesses.

7. **Increase stakeholders' awareness and their inclusion in the achievement of circularity goals:** this is vital for the effective implementation of governance initiatives. This interaction has been seen, for example, in Glasgow as the city council and the University of Glasgow work together to understand the city's baseline in terms of circular economy principles and identify measures to be adopted. The associations that bring businesses together also play an important role in promoting participation. As an example, Bogotá's Secretary of the Environment together with the Chamber of Commerce of Bogotá has arranged working groups that include citizens in the diagnosis of the city's needs[169]. Assolombarda in Milan promotes the organization of workshops, training courses, and other activities to produce content and tools to increase awareness of the circular economy among the associated companies[170]. Assolombarda is a cross-sector entrepreneurial association that promotes members' interests, primarily around sustainable development and using technology for good.

Co-creation encourages citizen involvement – from initial solution design, through to implementation. Providing regular feedback to citizens, through accessible websites or digital dashboards, can help foster a shared sense of responsibility for the circular solutions[171]. This is important for transitioning to a model where citizens sit alongside local government as the decision makers and not just as the beneficiaries of policy interventions.

Another route to engage city stakeholders is through the formation of Urban Living Labs (ULLs)[172] where part of the city is used as an urban experiment to demonstrate circular interventions and generate enthusiasm for similar approaches in the wider city. Stakeholders are engaged in a five-step process of co-exploration, co-design, co-production, co-decision, and co-governance. The Municipality of Turin has opened an ULL, simplifying conditions for circular companies, and turning the city into a test site for circular innovation[173]. Aarhus, London and Santander are all involved in OrganiCiti, where portions of the project budget are set aside for ideas proposed by citizens[174].

8. **Build capacity for implementing the transition to the circular economy:** to achieve the scale of actions required, capacity building activities will be important to ensure the necessary skills, knowledge and awareness exist within the city. Partnerships between local government and educational institutions can provide circular economy learning and training pathways to upskill the local population, disseminate knowledge, and engage local businesses through recruitment pathways.

City governments can also be an advocate for the circular economy beyond the city boundary by analysing supply chains, sharing knowledge and experiences. This requires a culture of openness, where both successes and failures are shared with other city leaders to promote the use of best practice techniques but also prevent the duplication of effort and resources on policies and interventions that have been less successful.

[169] https://efus.eu/about-us/bogota-chamber-of-commerce-ccb/

[170] https://www.assolombarda.it/fs/201178111842_20.pdf

[171] https://www.frontiersin.org/articles/10.3389/frsc.2021.690458/full

[172] https://www.cogitatiopress.com/urbanplanning/issue/viewIssue/132/PDF132

[173] https://journals.sagepub.com/doi/full/10.1177/1460458220987278

[174] https://citymonitor.ai/community/can-co-creation-help-cities-find-new-way-solve-their-problems-1624

Dedicated policies can lead to needed changes

As the Circular Economy implies a systemic change, key interventions should be looked at across all sectors. The city of Amsterdam for instance followed a "Cluster" approach. Clusters represent high impact areas in each city, for instance hotels in which several sectors such as built environment, food and mobility converge. At the same time, there are clear policy action fields per sector, that cities should consider.

Built environment:

1. **Regenerate existing buildings and infrastructure** – the approach to city growth and expansion has to be reconsidered: the 'city expansion through land use' approach is unsustainable not only because of the depletion of environmental resources, but also in terms of the higher costs necessary to provide services for citizens and to build and maintain infrastructures, as well as longer commuting times. Thus, one of the key challenges is to regenerate existing buildings and infrastructure before building new ones. Cities will need to identify key areas and stimulate public and private investments to revitalize those areas. On a building level, before deconstructing or demolishing, developers and architects should prove they have conducted a thorough cost-benefit analysis comparing refurbishment versus new construction. Refurbishments must be prioritized. In accordance with these aims, the Amsterdam circular city strategy allows the realization of new sustainable and circular districts such as Buiksloterham in Amsterdam, which was born from an unused industrial area selected by the Municipality for this purpose[175].

2. **Green public procurement** – cities must leverage GPP policies and use their purchasing power to create a demand for circular and sustainable construction solutions. Current GPP policies in the European Union are focused on computer equipment but should be extended to include the built environment. This should also include requirements related to a whole-life carbon calculation of new construction and refurbishment activities.

3. **Demonstrators and pilot projects** – cities can stimulate the adoption of circular construction activities by developing demonstrators and pilot projects to create trust across the value and supply chain, showing that circular buildings and infrastructure are technically feasible and commercially viable. The city of Lappeenranta, Finland, for example, is clearly committed to that by testing and adapting circular economy technologies as well as business models in collaboration with innovative companies[176].

[175] https://www.amsterdam.nl/projecten/buiksloterham/

[176] https://uia-initiative.eu/en/uia-cities/lappeenranta

Mobility

Mobility is one of the most critical sectors, since in many ways it defines city life: how people and goods move around the city impacts almost every decision that businesses and citizens make. In general, this is the sector where discussion is most advanced[177]. The most relevant policies refer to:

1. **Support micro-mobility:** it is important to recognize that mobility is not limited to cars or public transport; many other solutions exist, such as walking and biking. These are often neglected by citizens because of concerns that include the distance to reach destinations and the continuity, safety and pleasure of the path. To make walking and biking a realistic alternative to cars, it is necessary to create dedicated lanes, connected in extended and connected networks, equipped with bike parking spots and resting places, etc. The role of the municipality is fundamental in making it possible to effect a wide-spread change of habits in the public, thereby promoting a true modal shift. This is what the city of Bogotá has done over time through the enhancement of the Ciclovia de Bogotá, a project that closes some of the cities streets to traffic on certain days, creating a bike and walking path that stretches more than 120 km.[178]

2. **Improve public transport:** public transport is one of the most efficient means of transport and should be the backbone of urban mobility. Thanks to city analytics, it is possible to monitor actual flows of passengers and therefore optimize fleet operations to provide a better service to citizens. Public transport is key for mobility to be sustainable and affordable. To that end, dedicated mobility plans integrating different means of transport and redefining urban mobility are being adopted by many cities, for example the mobility plan in the city of Barcelona, which aims to promote a public transport system that allows different modes of travel to coexist and in which pedestrians and cyclists are prioritized and protected.[179]

3. **Carsharing/Carpooling:** as cars are parked most of the time, large areas of cities are reserved to cars not only as streets but also as parking areas. For this reason, it is necessary to reduce the number of cars and increase their actual use through solutions such as car sharing and carpooling. This also creates more affordable opportunities for citizens. For example, the city of Copenhagen has chosen to co-fund a public bicycle sharing system[180].

4. **Go electric:** the move to electricity is fundamental in order to eliminate emissions locally and, with renewable growth, globally. All of the above recommendations are listed in order of efficiency, and electrification should be a part of previous interventions, such as electric bicycles, electric buses, and electric vehicles. In terms of electric vehicles, adoption should be supported through a broad infrastructure of charging stations, free parking and free access to limited traffic zones. The city of Santiago, for example, created the largest fleet of electric buses outside of China, leveraging innovative financing systems and collaboration with large producers and utilities and a partnership with the Zero Emissions Bus Rapid deployment Accelerator (ZEBRA)[181].

[177] https://emf.thirdlight.com/link/8izw1qhml4ga-404tsz/@/preview/1?

[178] https://www.idrd.gov.co/en/ciclovia-bogotana

[179] https://www.barcelona.cat/mobilitat/en/about-us/urban-mobility-plan

[180] https://bycyklen.dk/en/

[181] https://www.c40.org/what-we-do/scaling-up-climate-action/transportation/zero-emission-rapid-deployment-accelerator-zebra-partnership/

Sustainable energy systems

Decarbonization is a widely discussed topic and many cities are already actively pursuing it[182] leveraging clean electrification and digital technology to harmonize urban energy systems from smart grids to technologies that allow energy efficiency[183]. Potential policy areas are:

- **Electrify energy consumption:** emissions from households (for heating and cooling), from transport, and from harbors are among the main sources of air pollution in cities. All these emissions could be avoided by moving forward with electrical solutions such as heat pumps, electric mobility, cold ironing, etc. The adoption of these technologies must be accelerated in order to achieve decarbonization targets. Municipal interventions can influence consumption behavior, as pointed out by the Mayor of London's Energy Efficiency Fund (MEEF)[184], which supports, among others, energy efficiency and renewable energy generation projects; the investment fund, which is linked to the European Commission, contributes to the city of London's targets on climate change.

- **Grow renewable energy production in cities:** although cities are already connected to reliable energy transmission grids and do not have wide areas dedicated to renewable energy production, there are still reasons for them to support the development of integrated photovoltaics, as it could also provide a good economic opportunity for public and private buildings. Procedures to authorize these installations should be simple and fast, in order to facilitate and support PV adoption. Many cities around the world, like Malmö, Sweden[185], are committed to 100% renewable energy use by 2030; in some cases, they have already succeeded, such as Basel, Switzerland, where 100% of renewable power comes from the city's own energy supply company[186].

- **Focus on data analytics and metrics:** the circular economy is a quantitative approach so it is important to measure and monitor all available key parameters in cities in order to optimize in the short term and to plan and set targets for the medium and long term. Sensors, open data, big data, and analytics are levers to achieve this. One of the characteristics of the city of Amsterdam's circular strategy is an open approach that leverages successful platforms and networks – such as Amsterdam Smart City, New Amsterdam Climate (Nieuw Amsterdams Klimaat) and Circular City (Cirkelstad) – as much as possible. This allows it to take advantage of the constant increase in availability of data to make shared decisions.[187]

- **Digitalize:** despite the fact that many jobs and services cannot be virtualized, some services activation and checks on network can be managed or provided remotely, thereby helping to reduce time and money spent.

[182] https://www.weforum.org/projects/systemic-efficiency

[183] https://www.arup.com/expertise/industry/energy/solar-pv

[184] https://www.london.gov.uk/what-we-do/environment/climate-change/zero-carbon-london/mayor-londons-energy-efficiency-fund

[185] https://malmo.se/Miljo-och-klimat/Energisatsningar/Klimatneutral-avfallsforbranning.html

[186] https://www.cdp.net/en/cities/world-renewable-energy-cities

[187] https://www.amsterdam.nl/en/policy/sustainability/circular-economy/

BANCO INTERAMERICANO DE DESARROLLO (BID)

"Latin America and the Caribbean has been one of the most affected regions by the pandemic. However, this also brings us an opportunity to rebuild better, supporting more resilient, more inclusive and lower carbon economies.

The circular economy plays a key role in the agenda to fight climate change. To reduce greenhouse gas emissions, we need to change how we produce and consume food and goods. In addition, the circular economy promotes economic growth and social inclusion, which are key ingredients for the recovery.

We want to help companies in the region with their strategies in this area and with financial instruments that are adapted. For this, IDB Invest is developing a value proposition composed of innovative financial solutions (that can combine our own capital with concessional financing from donors and mobilize funds from other investors) and advisory services.

We also want to facilitate the development of the right taxonomy that can underpin a consensus around the identification, execution and financing of projects, programs and initiatives on which the adoption and scalability of circular practices can hinge, joining forces with IDB in their work with countries, and with IDB Lab in their quest for innovative solutions."

Conclusion

This study investigated the role of the circular economy as a lever for decarbonizing cities. Our research and analysis remind us that the carbon footprint of a city and the impacts of interventions to decarbonise go beyond direct emissions and encompass those generated outside city boundaries.

Emissions occurring outside a city because of electricity generation and the demand for resources (Scope 2 and Scope 3) are generally far greater than those occurring within city limits (Scope 1): in the cities considered in this study, Scope 2 and Scope 3 emissions accounted for about 80% of total emissions. Although the exact percentage varied widely between the four cities according to their different economic activities, the significance of Scope 2 and 3 emissions demonstrates that they must be considered when designing policies, strategies, and action plans to achieve net zero carbon.

We studied the decarbonisation impacts of a selection of circular interventions for three sectors – built environment, mobility and sustainable energy systems for four cities – Bogotá, Genoa, Glasgow and Milan. The total carbon footprint analysis of each of the four cities demonstrated the importance of action within and across these sectors, and we believe this action needs to be systemic across the whole economy and all sectors. Based on our analysis and a series of interviews with stakeholders from the cities in the study we would make the following recommendations to city leaders:

1. Set out a citywide vision for the circular economy.
2. Integrate disruptive circular economy strategies as part of overall city planning, combining economic, energy and spatial plans.
3. Adopt focussed, multifaceted targets and metrics and actively monitor progress towards circularity.
4. Use new and emerging finance opportunities.
5. Increase stakeholders' awareness and their inclusion in the definition and achievement of circularity goals.
6. Build capacity for the circular transition in the city and beyond through education, upskilling, and knowledge sharing.

The transition of cities to a circular economy is complex but necessary and without this, net zero targets will not be fully met. The circular economy represents the framework within which to realize this transition and achieve different economic, environmental and social targets at the same time. This transition requires an overall redesign of the city in an "all encompassing" process and must explicitly include other key aspects among its targets such as quality of life and resilience, which must be synergic with all adopted initiatives.

A key consideration is that this transition is no longer a technological challenge, but rather will require the removal of barriers in other directions: a strong role of open governance, continuous cross-sectorial collaboration, the growth of public-private partnerships, etc.

These observations further highlight the central role of cities in solving global challenges. They are not only the physical places where impacts occur, but they also have the means and organisations that can take action to mitigate them. Many of the interventions considered in this study will not be carried out by cities alone, but will be implemented by a broad range of urban stakeholders, including businesses, institutions, citizens, universities, etc.

In addition to our recommendations above, our analysis, the interactions with city stakeholders and thinking around the importance of the circular economy in achieving decarbonised cities led to the following conclusions and observations:

- **Cities are global players, and their impact is not limited to city limits:** an emission reduction strategy must assess both production-based and consumption-based emissions.

- **A long-term city circular economy vision requires a wide support base:** in order to be realized, a city's transition requires a long-term perspective that goes far beyond electoral terms. Therefore, the engagement of all stakeholders is fundamental in the definition as well as the implementation phases. It is important that residents are made aware of city targets and performance and how they can contribute, from defining strategies to direct engagement in daily life as citizens and consumers.

- **City re-design is an integrated process with monitored targets:** a transition to a circular economy requires a vision that involves all city sectors and stakeholders. The vision must be as unique as the process to achieve it and must include all the outcomes that are relevant to the city. All outcomes (such as decarbonization, zero waste, resilience, 15-minute city, social inclusion) must be brought together in an integrated strategy, with clear indicators to be monitored, to leverage all synergies for maximum effectiveness. As shown in this study, there is a strong interrelation between the built environment, mobility and energy, and an integrated approach will maximize the benefits.

- **Technology is not the issue:** the technologies we need are available now – they are reliable and economically competitive. Innovation has made huge progress in recent years, in terms of both physical and digital solutions, including renewable energy, new sustainable materials, new construction solutions, electric vehicles, recycling technologies, digitization, big data, and others. The challenge now is to implement them at scale and speed, to achieve overall city decarbonization targets.

- **Collaboration is key to overcoming barriers:** technologies alone cannot guarantee a successful transformation if the overall context does not support them. Cities are complex entities in which different needs co-exist, including economic activities, environmental issues, social challenges, and historical/architectural constraints. Technologies must be placed in such a way as to express their full potential to achieve a city's overall targets. Moving from a linear to a circular model requires changing economies that have operated following the traditions of decades, and addressing aspects such as incentives, policies, norms, habits, etc. Therefore public-private collaboration and involving other relevant stakeholders is fundamental to identifying and removing all barriers.

Contributors

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