Catalogue of solutions and co-benefits

Deliverable D10.2

Version N°2.0

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Abbreviations and acronyms

Acronym	Description
BACS	Building Automation Control System
BECCS	Bioenergy for Energy with Carbon Capture and Storage
BEMS	Building Energy Management System
BIM	Building Information Modelling
BIPV	Building Integrated Photovoltaics
BIST	Building Integrated Solar Thermal
BRP	Building Renovation Passport
CCAM	Cooperative, Connected and Automated Mobility
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CDR	Carbon Dioxide Removal
CEO	Chief Executive Officer
CHP	Combined Heat and Power
CHCP	Combined Heat, Cooling and Power
CIM	City Information Modelling
DACCS	Direct Air Carbon Capture and Storage
DH	District Heating
DHN	District Heating Network
DH&C	District Heating and Cooling
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
ETC	Evacuated Tube Collectors
EV	Electrical Vehicle
FPC	Flat Plate Collector
GESI	Global Enabling Sustainability Initiative
GHG	Greenhouse Gas
GI	Green Infrastructure
HP	Heat Pump
IEA	International Energy Agency
IoT	Internet of Things
ITS	Intelligent Transport System
JRC	Joint Research Centre
LCC	Life Cycle Cost
MSW	Municipal Solid Waste
NBS	Nature-based Solutions
NZEB	Nearly Zero-Energy Buildings/ Blocks

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NZED	Nearly Zero-Energy Districts
PV	Photovoltaic
PVT	Photovoltaic Thermal
RES	Renewable Energy Sources
SECAP	Sustainable Energy and Climate Action Plan
SME	Small and Medium Enterprise
SRI	Smart Readiness Indicator
SUD	Sustainable Urban Drainage
SUMP	Sustainable Urban Mobility Plan
WP	Work Package
WWTP	Wastewater Treatment Plant

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Summary

Addressing emission sources in cities is central to the challenge of reaching net zero emissions, requiring transformational change in all sectors. This deliverable defines a **wide set of solutions** (technologies and innovative solutions) **to address the reduction in emissions across all sectors** (or emission domains) in cities. It is developed in the form of catalogue of solutions to support climate neutral cities development, and currently contains around **180 solutions,** accessible through the Knowledge Repository within the Portal.

Such solutions are organised in **eight Thematic Areas**, although they are **cross-sectoral**, four relevant sectors in climate neutrality transition, which are stationary energy (buildings), energy generation, mobility and transport, and green industry; and four enabling fields for circular economy, nature-based solutions, digital solutions and enabling instruments. The taxonomy and classification of solutions was validated and agreed with the JRC.

Such solutions are described in the form of "**factsheets**" for single solutions and in the form of "Articles" for the thematic areas, each one with their own link to be accessed through the NZC Portal (Knowledge Repository: https://netzerocities.app/knowledge). The latter ones act as "nodes" that connect all solutions defined within them.

Each solution factsheet contains a **detailed description** of the solution, the involved thematic areas and other related tags, co-benefits, the relationship with other solutions (keywords), visuals (images, graphs…), **external links** (which include references for the solution description and examples or case studies of the solution deployed in real environment). In the next deliverable (D10.3 Design environment of solutions), additional information will be added to each solution, related to instruments, pre-conditions and enabling conditions, constraints or barriers for implementation, drawbacks or adverse impacts of the solutions, as well as impacts.

Since cities need to link local actions for climate neutrality with their indirect positive impacts on other areas and sectors, an exhaustive identification of co-benefits was performed, to then be mapped for each solution. Such co-benefits are classified into **climate resilience** (including both climate adaptation and mitigation, **health** (including environment and well-being), **social** (including inclusion and education), **economy** (including local and global connection and entrepreneurship and innovation), **resource efficiency** (which includes waste, water and food efficiency, as well as land use), and **biodiversity** (referred to a greater biodiversity).

The present document delves also in **mapping incubators and accelerators in cities in all sectors**, to help cities to know their possibilities for engagement and for setting up specific programmes towards climate neutrality, since it should not be forgotten the importance of the local challenges, business models and conditions/ context.

Keywords

Thematic Areas; Co-benefits; Technical Innovation; Solution Factsheet; Stationary Energy, Energy Generation; Mobility and Transport; Green Industry; Circular Economy; Nature-based Solutions; Digital Solutions; Enabling Instruments, incubators and accelerators.

Structure of the document

The document is structured into the following main sections:

- **Section 1** introduces the document, highlighting why technical innovation is important to achieve climate neutrality, and main sources of greenhouse gas emissions in cities.
- **Section 2** delves into the **state-of-the-art solutions to address GHG emissions**. It starts with the presentation of the **thematic areas** in which the set of solutions have been structured. It contains then a section devoted for each thematic area, explaining it with examples, and adding a table at the end of each section with the set of solutions included in the NetZeroCities Portal (links to each solution):
    - **Section 2.1** for Stationary Energy;
    - **Section 2.2** for Energy Generation;
    - **Section 2.3** for Mobility and Transport;
    - **Section 2.4** for Green Industry;
    - **Section 2.5** for Circular Economy;
    - **Section 2.6** for Nature-based Solutions and Carbon Sinks;
    - **Section 2.7** for Digital Solutions;
    - **Section 2.8** for Enabling Instruments;
- **Section 3** delves into the **co-benefits** that solutions may have, including its classification for the NZC project.
- **Section 4** includes the explanation of the process for the **Solution Factsheet** development.
- **Section 5** provides a **map of incubators and accelerators** in cities in all sectors.
- **Section 6** includes the next steps within the task 10.3; with an especial focus on solution bundles development.
- A section of **Conclusions** is added at the end of the report, as well as a **References** section, which consolidates the references added as footnotes across the report.
- Finally, it includes an **ANNEX** in **section 7**, with a deeper **circular economy analysis**.

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1 Introduction

Technical innovation for climate-neutrality

- **Quick Reads: https://netzerocities.app/QR-Technological**

For all cities to reach net zero emissions, transformational change in all sectors will be required. Addressing emission sources will be central to this challenge. Fortunately, there are a range of technologies and innovative solutions that can be implemented and deployed to drastically cut these emissions. These technologies and solutions need to cover all main emissions domains, which includes buildings, industry and transport, waste treatment (both solid waste and wastewater), agriculture and forestry, and, of course, energy from fossil fuels (whether from the power grid energy supply or district heating networks, or other).

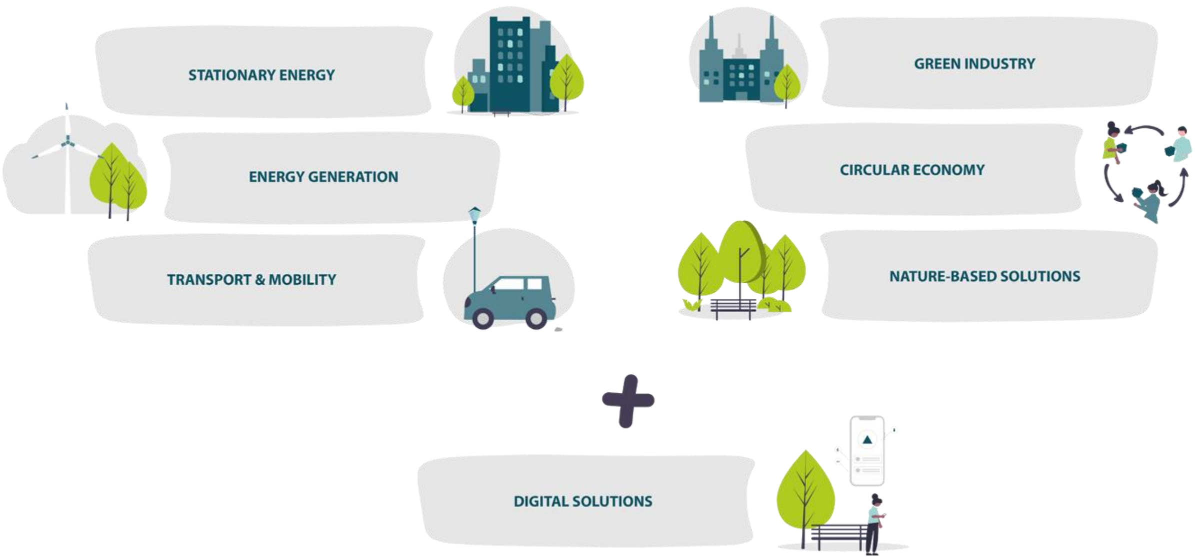

Figure 1: NZC Thematic Areas for technical innovation

The purpose of this document is to provide the overview of **solutions included in the Knowledge Repository** of the Mission Platform (https://netzerocities.app/knowledge) in the first stage, as well as to define its associated **co-benefits**. It provides deep and useful information on each **Thematic Area** where solutions are included, as well as connection between solutions, general descriptions, visuals and external links to further useful information (both to references and to examples of the implemented solution or case studies).

Greenhouse gas emissions in cities

There are different types of CO_2 emissions, and these are often split into **three "scopes"**, as defined by the Greenhouse Gas Protocol, the most widely used international accounting tool to quantify and understand greenhouse gas emissions. **Scope 1** emissions are so-called direct emissions that occur within a city's boundaries and include tailpipe emissions from combustion cars, among others. **Scope 2** emissions are indirect emissions from the generation of heat and electricity used within a city's boundaries, regardless of where it is generated. **Scope 3** emissions are value-chain emissions such as the upstream emissions from the production of cement used in a city's infrastructure or the downstream emissions resulting from municipal waste processing. Indeed, cities generate a wide range of direct and indirect CO_2-emissions across all three scopes, as illustrated by Figure 2. The 'average' European city of 100,000 inhabitants emits around 400 thousand tonnes of Scope 1 and 2 energy-related CO_2 emissions per year (see Figure 3), of which 24% comes from transport, 35% from buildings (stationary energy generation), and 42% from the electricity consumption.

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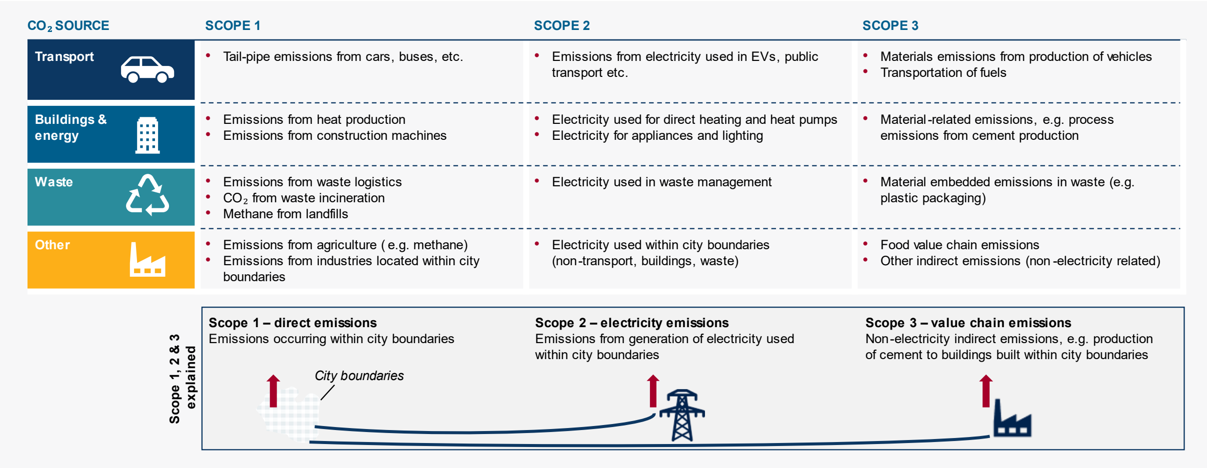

Figure 2: Cities generate a wide range of direct and indirect CO_2 emissions (three scopes and main sources[1])

Although all CO_2-emissions are equally important in the context of climate change, a city's ability to influence its emissions varies significantly across scopes. Compared to scope 1 and scope 2 emissions, scope 3 emissions are much more difficult for cities to influence. For example, cities can incentivise electric vehicles or ban combustion engines altogether to avoid scope 1 emissions. Still, they can do much less to ensure that all vehicles driving its streets are made from low-carbon materials.

Cities need to start focusing on the most addressable areas with the highest impact (scope 1 and 2) whilst acknowledging the importance of scope 3 emissions for full decarbonisation. In the wide list of solutions analysed and characterised in this report, potential solutions addressing emissions from energy use are included, as well as circular solutions directed at value-chain emissions from the production of food and building materials.

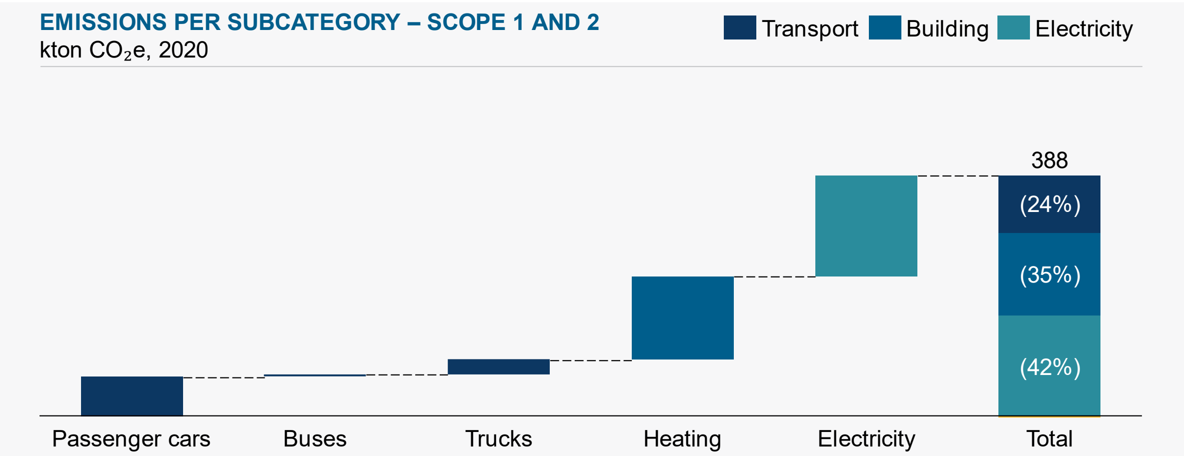

Figure 3: The 'average' city of 100,000 inhabitants emits around 400 thousand tonnes of energy-related CO_2 emissions per year[2]

The International Energy Agency (IEA) developed a report analysing the solutions that could lead to reaching net zero by 2050. The selected pathway (NZC = Net Zero by 2050: A roadmap for the global

[1] The categorisation of emission sources varies throughout the report as a result of it being a synthesis of previous work with varying foci.
[2] The average per 100,000 inhabitants is based on Material Economics' previous city studies. Actual emissions vary between cities. Solution categories and specific solution definitions vary as this report is a synthesis of material used in different context. *Source: Material Economics analysis*.

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energy system) is the one that is most technically feasible, cost-effective and socially acceptable. To adhere to the pathway, governments must put in place step-by-step plans and long-term policy frameworks. They key milestones identified in the report are shown in Figure 4.

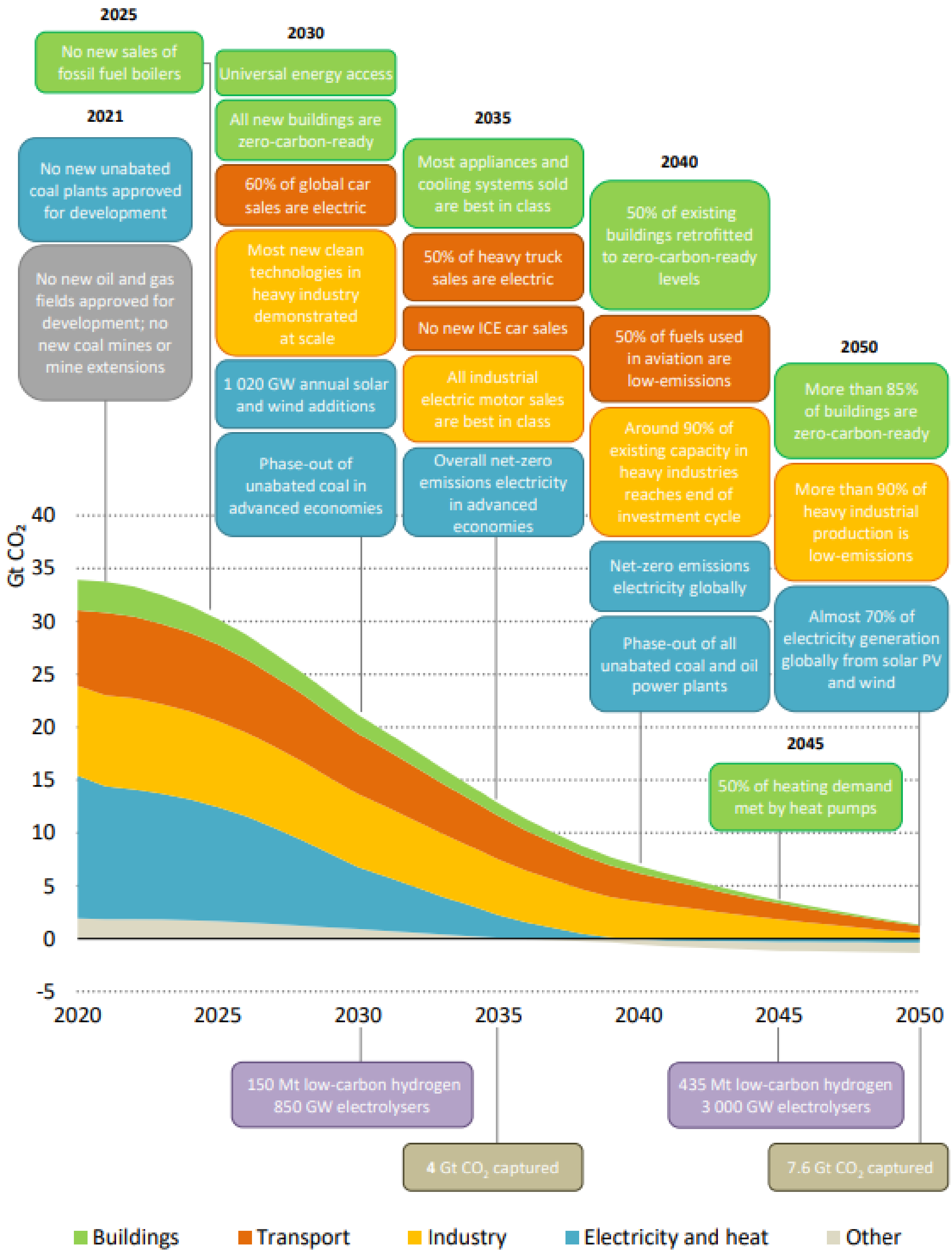

Figure 4: Key milestones in the pathway to net zero[3]

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These key milestones identified at global level are also in line with the road to climate neutral economy by 2050 of the European Commission, which sets as strategic priorities the following[3]:

- Industrial modernisation at the centre of a fully circular economy
- Embracing clean, safe and connected mobility
- Fully decarbonising Europe's energy supply
- Maximising benefits from energy efficiency
- Developing smart network infrastructure and interconnections
- Reaping the full benefits of bio-economy and creating essential carbon sinks
- Tackling remaining CO_2 emissions with carbon capture and storage

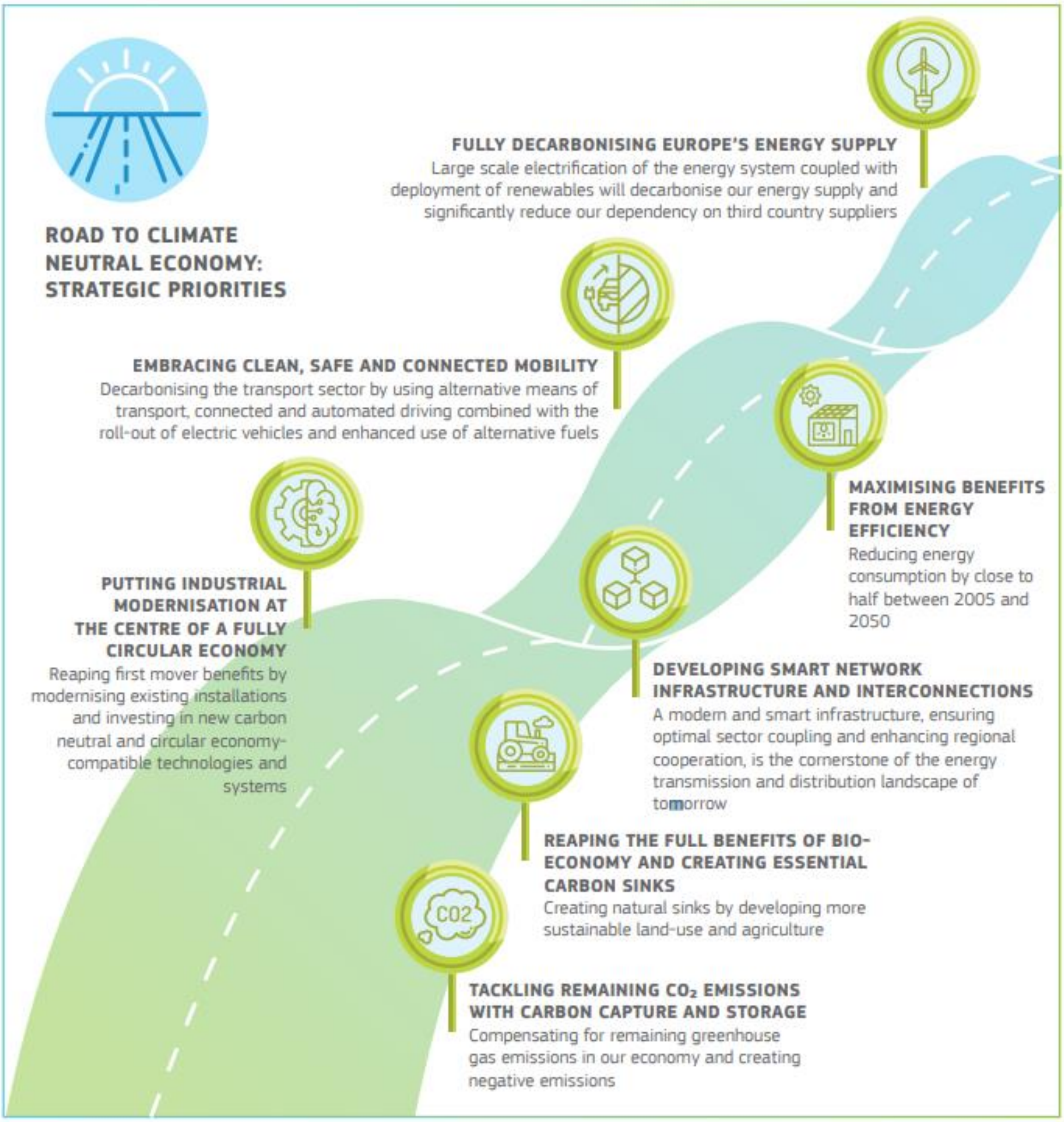

Figure 5: Key strategies for the road to climate neutral economy by 2050 of the European Commission

[3] https://ec.europa.eu/clima/system/files/2018-11/vision_1_emissions_en.pdf

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2 Solutions to address GHG emissions

Thematic Areas

NetZeroCities consortium have distinguished around **180 solutions** addressing emissions from buildings, industry, transport, waste treatment (both solid waste and wastewater), agriculture and forestry, and, of course, energy from fossil fuels (whether from the power grid energy supply or district heating networks, or other). The solutions were classified in different thematic areas related to such emission domains or sources, according to the consortium expertise (see Figure 6). In addition, the taxonomy was submitted to revision with experts from Joint Research Centre (JRC), resulting in a new list of emission domain **thematic areas** (see Figure 7), which is aligned with the Info Kit for Mission Cities[4] (see also Figure 8 for the alignment with the emission sources identified in it).

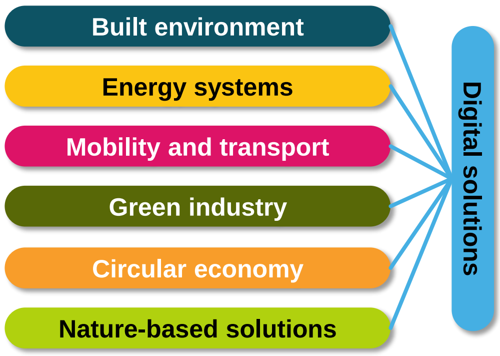

Figure 6: NZC initial Thematic Areas (from D10.1 Taxonomy)

Figure 7: NZC (final) Thematic Areas

For each of the domain areas, individual relevant solutions for essentially all cities addressing their climate impact were identified.

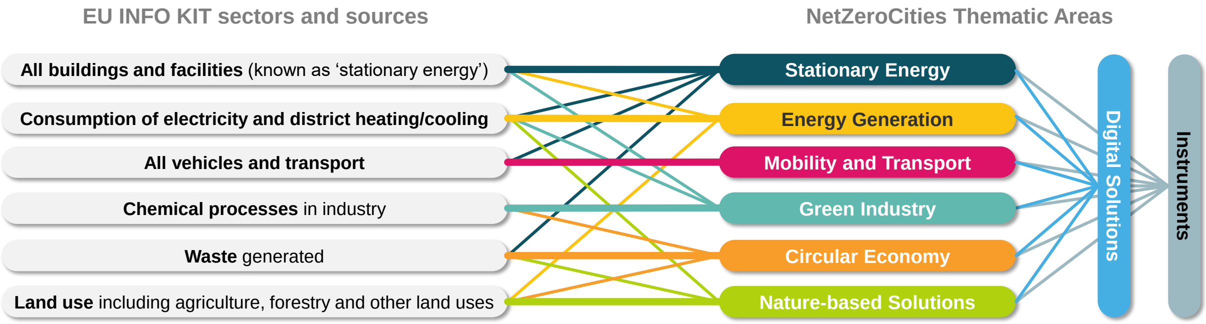

Figure 8: NZC Thematic Areas alignment with the emission sectors and sources identified in the EU Info Kit for Mission Cities

Solutions have different characteristics based on economics (investments, energy savings, and co-benefits) and the type of measure needed to make a change effectively, as illustrated in following Figure 9.

Please note, these ratings are indicative and actual impacts may vary depending on the specific conditions of the city trying to implement the solution/s.

4 https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_eu-mission-climate-neutral-cities-infokit.pdf

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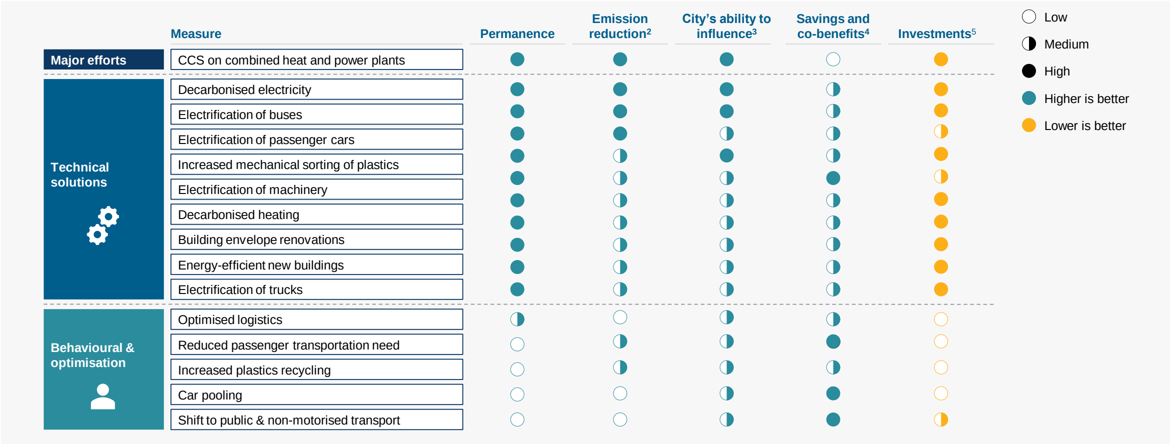

Figure 9: Example of solutions' different characteristics (related to permanence, emission reduction, city's ability to influence, savings and co-benefits, and investments)[5]

- **Permanence** is the duration of the benefits of a solution – the longer they last, the better. The permanence is, in this context, defined as low if the measure's effect is volatile and high if the effects are more permanent.
- **Emissions reduction** (or abatement potential) is the solution's impact on CO_2 emissions – the greater the reduction, the better.
- **Cities' ability to influence** is the extent to which cities have control over a measure. Material Economics defines the influence as significant if the city has direct control over the action, medium if it has an indirect ability to impact the outcome, and low if it cannot impact the outcome.
- **Savings and co-benefits** are defined as the monetary returns for investing in a measure. In this context, savings pertain to decreased costs as a direct consequence of the investment, whereas co-benefits represent the value of beneficial side effects such as better health.
- **Investments** are the upfront expenses involved in influencing a solution beyond what would otherwise be done for other reasons. For several behavioural-based solutions, investments can be close to zero.

Technical solutions generate emissions reductions without any significant behavioural changes needed once specific technical systems or equipment are in place. For example, emissions and noise will decrease independently of driver behaviour and travel routes once buses are electrified. Technical solutions have high permanence, resulting in high to medium-sized emission reductions. Cities may have a high level of control over measures within the city's responsibility (e.g. buses), while other solutions can be indirectly affected through various initiatives. Technical solutions have medium-sized savings, primarily from reduced energy consumption (e.g. energy-efficient buildings and electrification). Investments are relatively high as new technology needs to be purchased or built.

Behavioural- and optimisation-based solutions require changes in human behaviour to reap their benefits. For example, 'optimisation of logistics' largely depends on companies' choices and planning routines, which can change with or without new technical solutions. Behavioural measures are characterised by high benefits/savings as well as low investments, which makes the financial case strong. However, the measures offer little permanence and have a limited impact on emissions. A city may influence behavioural changes indirectly but does not have a high level of control over these measures.

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[5] Solution categories and specific solution definitions vary as this report is a synthesis of material used in different contexts. The categorisation is an estimation by Material Economics based on previous projects.

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Cities generally have a high influence over CCS as a solution if they own or co-own a combined heat and power plant for district heating. Such investments are large but also yield significant CO_2 emissions reductions over a long period. However, there may not be any co-benefits.

Co-benefits are worth emphasising because they often add significant value by helping to solve some of the most pressing issues for mayors in addition to the CO_2 emissions, see Figure 10. Although some are difficult or perhaps even impossible to quantify, it is clear that almost all solutions improve some aspect(s) of economic growth, health, and inclusivity. For example, investments into the geographical coverage of public transportation may increase property value, electrification of vehicles leads to improved air quality and reduced noise pollution, a shift towards non-motorised transportation improves physical health etc.

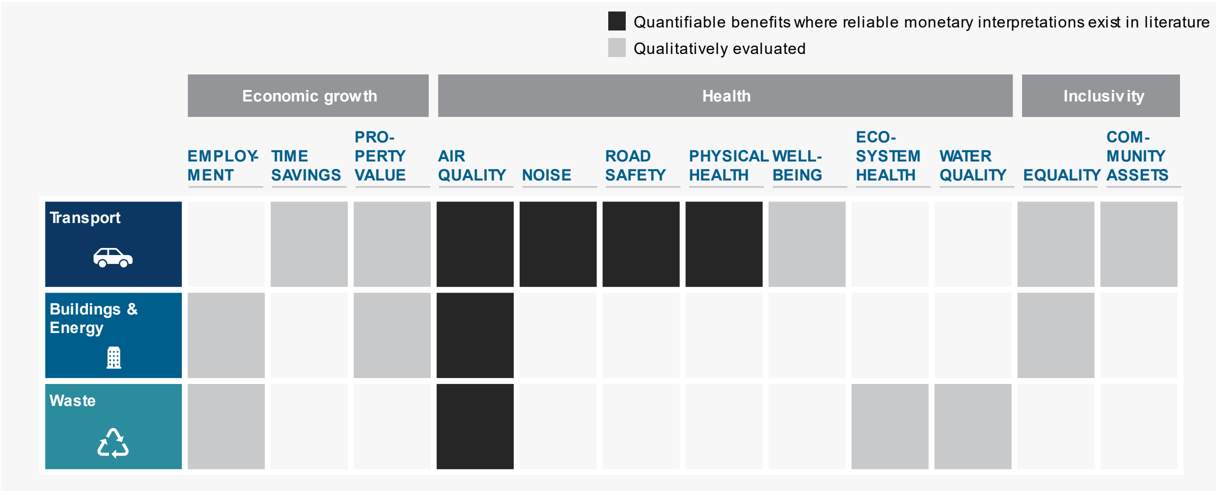

Figure 10: Climate solutions, and their co-benefits, address mayor most pressing issues[6]

In the next sections, each Thematic Area considered in the NZC taxonomy is depicted, including their related categories and the list of solutions that has been characterised by the group of experts.

[6] Solution categories and specific solution definitions vary as this report is a synthesis of material used in different contexts.

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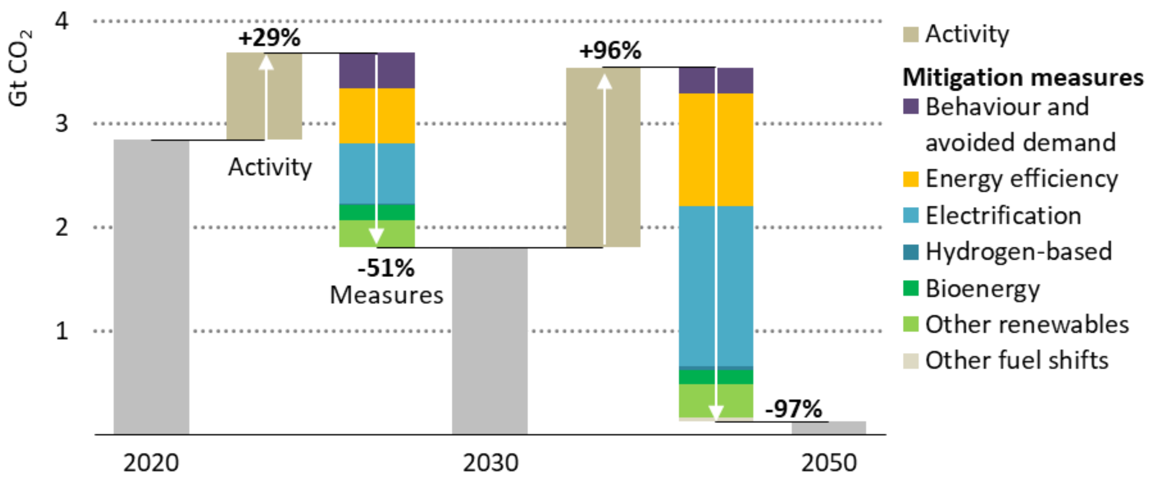
2.1 Stationary Energy (buildings)

- **Knowledge Repository: Stationary Energy (Buildings):** https://netzerocities.app/resource-327

Lead	**Tecnalia**
Contributors	CARTIF, Cerema, Resilient Cities Network, TNO, REGEA, Energy Cities, METABOLIC, AIT, Fraunhofer, POLIMI, VTT

Stationary energy is related to the **energy use and supply in buildings**. Buildings account for 40% of energy consumption in cities. Hence, a significant switch to renewable energy in all buildings and facilities is vital. **Implement energy efficient measures to reduce energy demand and improve energy efficiency.** For 75% of the EU's existing building stock, energy performance is poor and the buildings were constructed before current energy requirements were in place. Only 11% of the EU's existing building stock is being renovated each year, and focus more on energy consumption, rather than the renovation of the building envelope. But actually, according to the IEA, energy efficiency and electrification are the two main drivers of decarbonisation of the buildings sector. So, both renovations should be considered: **addressing buildings' energy performance and buildings' systems.** In this sense, there are **instruments** available in different fields to facilitate the implementation of these kind of renovations, such as **modelling tools** (i.e.: urban energy modelling and future scenarios), **methodological schemes** (i.e.: Sustainable Energy and Climate Action Plans), **financial schemes** (i.e.: blended finance, soft loans), etc.



	2030	**2050**	**Total emissions reduced from 2020 to 2050 (Gton CO_{2eq})**
Behaviour and avoided demand	6.4%	4.7%	0.59
Energy Efficiency	10.1%	20.5%	1.63
Hydrogen	0.2%	0.7%	0.05
Bioenergy	2.9%	2.5%	0.29
Other renewables	4.7%	6.1%	0.57
Electrification	10.9%	29.2%	2.13
Other fuel shifts	0.1%	0.8%	0.05
CCUS	0.0%	0.0%	0.00

Figure 11: Global direct CO_2 emissions reductions by mitigation measure in buildings in the Net-Zero Emissions by 2050 Scenario[7]

[7] International Energy Agency (2021), Net Zero by 2050, IEA, Paris: Net Zero by 2050 Scenario - Data product - IEA.

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Building envelope solutions

Building envelope renovations help deal with the significant emissions of CO_2 and air pollution in cities by reducing the large amount of energy needed for heating. With this solution, the heat demand for space heating and domestic hot water is reduced for the existing building stock by addressing heat losses (excluding heat supply) via extensive heating renovations (e.g., windows, insulation, etc.). The aggregated CO_2 reduction potential of envelope renovations is great as Europe has many old and poorly insulated buildings. Still, it can also be very costly, with some renovation cases much more expensive than others. **Envelope insulation** can be done in several ways. In Cityfied project 31 buildings in Torrelago district (close to Valladolid) were renovated using ETICS (External Thermal insulation composite system). To convince the owners was important to involve them in the decision-making process (e.g. they created new clothesline for them, they were involved to choose the colours of the façades, etc.). Nevertheless, the users now complain that the external walls (which were painted in white colour) are getting dirty due to the exposure to surrounding roads and industries. They would have preferred another coating/final layer. Anyway, the project and savings motivated the owners to continue renovating their buildings (e.g. windows, roof, or ground insulation) to reduce their energy bill. Plus, the company selling the windows renovation, offer to the district a special discount price to increase the sales. Other projects with retrofitting actions are Ile de Nantes, France, with multi-owner buildings retrofitting (insulating attics, walls, and installing thermostats and new energy systems) or Bergedorf-Süd retrofitting project in Hamburg, Germany, where roofs, façades and windows were renovated. Regarding the windows, when they are renovated their design can be improve to avoid solar radiation (with shading devices), or with the right selection of joinery (**joinery for low-energy houses or passive houses**), considering materials, transmission of heat, low-emissive glazing, etc., to dress the openings and reduce energy needs. Other possibility is the integration of nature-based solutions such as **green roofs**, **green walls and green façades**. Furthermore, renovation has multiple co-benefits that are not being considered, such as: creation of jobs and local supply chains, increase of comfort indoors leading to a better quality of life, reduction of GHG emissions and energy poverty (the less energy needs, the more affordable it gets to live in that building which can lead to more costs savings to non-energy purposes)[8], a decrease in future maintenance costs, the energy-efficiency raise awareness among residents, etc.

The truth is, deep renovation is not always achievable in one go. Thus, the Renovation Wave highlights the importance of instruments such as **building renovation passports (BRP),** which can underpin renovations. The BRP is a document outlining a long-term (up to 15-20 years) step-by-step renovation roadmap to achieve deep renovation for a specific building. In Ireland a consultation process of BRP was performed to co-design it (which parts should be included and how), as well as to promote it, and decide the roles (who can edit a BRP, who can have access to it, etc.). Another example is the **Smart Readiness indicator (SRI)**, a common EU scheme for rating the smart readiness of buildings, which has been applied in multiple cases, such as in the renovation of Mediterranean buildings. Furthermore, bureaucracy facilitators such as the one-stop-shop schemes (**one-stop-shop for building renovation**) or the turnkey retrofitting services (**Turnkey retrofit service**) are also a good choice to speed up building renovation processes.

Passive building solutions

Energy-efficient new buildings are costlier than their counterpart but offer meaningful energy savings over a long period. New buildings already have to align with the minimum building standards (available in building codes per country). Still, improvements that raise the energy performance to higher standards than required can come with many benefits in cost savings and CO_2 emissions reduction over time. With this solution, the heat demand for space heating and domestic hot water is reduced in new buildings, thus reducing associated fossil-fuel or electricity consumption. **EPBD** has play an important role in promotion **NZEB** and passive standards, specially forcing the renting market to have a certificate to be able to do their business (e.g. France, Spain[9]).

[8] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC120683/untapping_multiple_benefits_-_hidden_values_in_environmental_and_building_policies.pdf

[9] More examples in https://ec.europa.eu/energy/sites/default/files/swd-on-national-long-term-renovation-strategies.pdf

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Passive building design strategies such as building orientation, passive heating and cooling or natural ventilation should be considered, when possible, to be able to introduce nearly zero energy buildings in cities. Singapore's university designed a high-comfort net-zero energy building with the integration of green inside and outside the building, over-sailing roofs, shades, and renewable energy production with a high-tech control system with adaptive comfort techniques. Passive standards can be used as a promotion of the building efficiency improvement, such as BREEAM, LEED, WELL or Passive House.

In addition, energy performance certificates (EPCs) describe how efficient a building is, giving it a rate, which allows to increase transparency of the performance of the building stock, and helps municipalities to tailor policies and plans towards those non-efficient areas. In Greece and Cyprus, to raise people's awareness of EPCs, financial incentives have been linked to the issuing of EPCs; examples include the Greek 'saving at home' and the Cypriot 'save & upgrade' programme. In Milan, an Environmental Decision Support System Tool (EDSS) that fees with information from the EPCs Italian database (**Urban-scale environmental decision support system based on EPC databases**), allowing to propose solutions for building retrofitting and development of district heating networks. The tool can be potentially be calibrated with real time monitor data, becoming this way a digital twin. Other tools are available, like in Portugal, where the energy certificate has become an "aggregator of information" interconnecting the energy certificate with supply and demand platforms (of the 'one stop shop' type[10]), such as, for example, the casA + Portal.

There are other **integrated solutions** as innovative buildings adapted to climate change conditions, such as **Climate-smart greenhouses**, using nature-based solutions to do so.

Low-carbon and sustainable building materials

Furthermore, materials either for renovation or new buildings, have **embedded emissions** that should be considered. **Circularity** in the built environment and the use of **bio-based materials** (bricks from compressed earth, woods, hemp, straw, cellulose wadding, or recycled textiles) can play a significant role in reducing cities' carbon emissions.

RES and energy-harvesting solutions

Fossil-free electricity, heating and cooling is, in many cases, one of the most critical steps to reduce a city's emissions since the aggregated energy demand and the associated emissions can be substantial. Heating in cities is often produced through a mix of fossil fuels, electricity (e.g. **heat pumps**), and bio-based fuels. The heating can either be produced locally or centralised as district heating. Eliminating fossil fuels from the heating system is a solution with high CO_2 abatement potential, which also positively impacts air quality if generation shifts to, e.g. **heat pumps** with low-CO_2 electricity. The following example show different options for decarbonising the building sector:

- **Photovoltaics (PV)** are the main technology for decarbonising the electricity supply. PV can be installed in many ways: solar canopies, solar ponds, solar parking lots (like in Florida or Zaragoza), and also as a way to provide shading in cities (through organic photovoltaics in Tel Aviv, structures like in Madrid, solar trees in Germany). To promote its installation different incentives can be used, such as reduction of municipal taxes for collective self-consumption installations (like in Sant Cugat), through funding schemes (e.g. Finland), public-private partnership (like in Energy Smart Aland), etc. When there is no space solar parks outside city boundaries can be installed (e.g. the community-funded solar park in Oxfordshire or the brownfields solar fields in New York City, Philadelphia or Chicago), but even heritage cities like Evora are making strong efforts to integrate photovoltaic systems in their protected buildings, using transparent or ceramic innovative photovoltaics to produce electricity inside the city.

- **Solar thermal panels** can also be used for producing heating, either at building scale or large scale (integrated with district heating networks like in Silkeborg or Okotoks). The EPB in each country has been the most supportive scheme to the uptake of solar thermal panels in buildings (especially new buildings), although now solar thermal competes with heat pumps. But a combination of both can be deployed, like in Madrid where the public building company (EMVS)

[10] https://enr-network.org/wp-content/uploads/EnR-Round-Table_Portal-casA_AB-160222.pdf

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renovated a social housing building and then, through an EU project, installed **hybrid photovoltaic-thermal (PVT) panels** coupled with a water-water **heat pump** in a to produce heating, domestic hot water, electricity and cooling. Germany has been supporting 45% of the cost of replacing boilers with solar-assisted heating. Additionally, solar thermal systems can be **Evacuated Tube Collectors (ETC)**, in which the absorber plate and heat pipe are located in vacuum-sealed glass tubes to improve solar radiation absorption, thus reducing heat transfer losses and achieving a greater performance ratio.

- When sun is not available, **sustainable biogas or biomass technologies** can be used. In Lund's nearly zero energy district, a biomass-fired combined heat and power plant was used to produce both district heating and electricity. The biomass resource is mostly from pulp and forest industries and to reduce transport emissions, the source comes from a 200 km radius.

- **Geothermal** is also common for heating and cooling. When temperature is high (200 ºC), like in Montieri, the geothermal source can be used directly for electricity production and heating the houses. When temperature is not enough, heat pumps can be used, like in Bolzano.

- Lastly, but least common, **fuel cells** can also be used. In Japan 120000 fuel cells has been installed in buildings, saving around 50 to 57% of CO_2 emissions. A public-private partnership was used to speed up the process.

Smart solutions

The **RES sources applied to a building** should be linked with digital or smart solutions, such as demand management to be able to adapt demand to prices (implicit **demand response**) or to necessity of the grid (explicit **demand response** controlling heat pumps in large markets to avoid grid congestion), by varying set points of the buildings, running or stopping controllable loads (heat pumps, appliances, etc.) or providing feedback to users through apps to undertake a specific action in a period of time. Demand response has been widely applied in EU projects, such as Helsinki lighthouse demonstrator. Lastly, **Building Automation and Control Systems (BACS)** & Building Energy Management Systems (BEMS). They enable the energy efficient and cost-effective integration of local renewable energy supply technologies, as well as the management of energy storages and flexibilities to optimally balance energy demand and supply in the operation of building energy systems. Examples can be found in Seestadt Aspern Vienna, Barcelona or Cologne. Additionally, aspects of building maintenance can be integrated in building automation systems, which allows for maintenance demand predictions that enable the cost-effective operation of buildings.

Heat recovery solutions

For improving the **efficiency of heating systems**, heat recovery from showers can be used to recover up to 80% of heat, although only few Member States (e.g. Portugal, France, Germany and The Netherlands) are considering the benefit of waste water heat recovery within their energy performance of buildings calculation method[11]. As well as **air-to-air heat recovery systems** (in passive house, 75% needs to be recovered[12]).

It is also worth mentioning the **sewage heat recovery via pump system** as a way to withdraw heat from warm wastewater.

Sustainable and energy-efficient active solutions

Efficient lighting and appliances are both important as old units use much more energy on average than the latest efficiency standards, are relatively easy to upgrade and even have negative abatement costs in many cases. Instead, the challenge for cities lies in identifying how the costs and benefits can be appropriately redistributed, as citizens now bear the cost but stand little to gain from spending extra money on lighting and appliance efficiency. Additionally, efficient appliances can underpinned connections to grids: for example, to power grids through the use of controllable loads and smart IoT,

[11] https://copperalliance.org/wp-content/uploads/2022/03/EuroWWHR-position-paper-on-EPBD-recast-FINAL.pdf
[12] https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm

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or to district heating networks, through heating water circuits appliances that consume from the network instead of producing heat through electric resistance. Cities can for sure tackle efficiency in their own administrations and city's infrastructure. For example, efficient street lighting plays a huge role and it has been tackle in many smart city EU projects. For example, in Hamburg **Smart street lighting or Humble Lamppost** was installed and it included not only modern LED lighting, but also an adaptive lighting (e.g. according to people detection, light levels variation and an optimisation of the communication between light poles), a bicycle counter and Wi-Fi at selected places, allowing the device to become smart. Furthermore, other possible additional services for public lighting can be included in the lamppost, such traffic sensors (Bikes/ Pedestrians/ Cars), e-charging stations, environmental Sensors to measure air pollutants, noise pollution or weather information, among others. In New York, Smart traffic signal systems are connected with buses (that are geo-located) to reduce commute times and improve public transport.

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Table 1: Stationary Energy (buildings) solutions

Stationary Energy (buildings)		https://netzerocities.app/resource-327
Building envelope solutions	Envelope insulation	https://netzerocities.app/resource-154
	Green roof	https://netzerocities.app/resource-164
	Green walls and green façades	https://netzerocities.app/resource-174
	Joinery for low-energy houses or passive houses	https://netzerocities.app/resource-184
Passive building solutions	Passive building design strategies: building orientation, passive heating and cooling	https://netzerocities.app/resource-194
	Natural ventilation (incl. Wind catchers)	https://netzerocities.app/resource-246
Integrated solutions	Climate-smart greenhouses	https://netzerocities.app/resource-276
Low-carbon and sustainable building materials	Reducing embedded emissions of buildings	https://netzerocities.app/resource-286
RES and energy-harvesting solutions	Photovoltaics	https://netzerocities.app/resource-388
	Solar thermal panels	https://netzerocities.app/resource-438
	Solar thermal systems with Evacuated Tube Collectors (ETC)	https://netzerocities.app/resource-458
	Hybrid systems (PVT, PV+HP, ...)	https://netzerocities.app/resource-648
	Geothermal energy for H&C	https://netzerocities.app/resource-668
	Sustainable biomass and biogas technologies	https://netzerocities.app/resource-678
Smart solutions	Building Automation and Control Systems (BACS)	https://netzerocities.app/resource-758
	Demand management	https://netzerocities.app/resource-91
Heat recovery solutions	Freecooling opportunities (Air-to-air heat exchangers)	https://netzerocities.app/resource-728
	Sewage heat recovery via pump system	https://netzerocities.app/resource-738
Sustainable and energy-efficient active solutions	Smart street lighting – Humble Lamppost	https://netzerocities.app/resource-266
	Low-GWP heat pumps	https://netzerocities.app/resource-748

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2.2 Energy Generation

- **Knowledge Repository: Energy Generation:** https://netzerocities.app/resource-338

Lead	**CARTIF**
Contributors	REGEA, METABOLIC, POLIMI, Fraunhofer, Tecnalia, TNO

Replace carbon intensive electricity, heating and cooling with a low carbon energy production. A range of **sustainable energy systems**, which enable low-carbon energy production, development of renewable energy solutions and the efficient use of electricity are necessary to fully decarbonise the energy supply.

RES electricity and thermal energy generation

Decarbonised electricity is a powerful solution for reducing energy-related emissions and a key enabler for emissions reductions in other sectors as they electrify over time. This solution includes various demand-side measures that decrease the scope-2 emissions from electricity use, including increased adoption of distributed renewable generation (such as solar PV or **geothermal energy**) and increased purchasing of certified green electricity from utility-scale wind/solar-PV farms. For some cities, electricity use stands for 50% or more of their total greenhouse gas emissions. The following solutions can be used:

- **Photovoltaics**: which are mentioned in **Stationary Energy area**. Besides the ones above-mentioned, other deployments can be done in agriculture (what is also called as agrivoltaics), off-shore solar floating structures (like in the Netherlands) or energy communities (Freiburg, Crevillent or Hunziker in Switzerland). For the future, photovoltaics could also reach the space.

- **Distributed wind** consists of wind turbines connected to the distribution level of the electric grid, to serve either on-site loads or local loads in the same grid. Use cases are utility (community owned, like Konkanmäki wind farm, or public owned like in USA), industrial (Brande pilot), residential, institutional, governmental, commercial or agricultural. Most common grid applications are grid-connected **microgrids**, isolated grids and remote off-grid. Small wind turbines can also be used, like in Aland.

- Cities are a framework where the **water-energy nexus** is becoming critical due to demographic movements, economic growth, climate hazards (draughts, floods, etc.) and the inexorable increase in the demand. Urban water networks can be considered as a source of renewable energy as they usually hold untapped energy deriving from abundant pressure (water head) or kinetic energy (water flow). **Micro-hydropower plants** can be installed for generating electricity using specially designed in-pipe turbines. Case studies can be found in a river, Grobweil, or in water networks (using pump-as-a turbine), Dwr Uisce. **LIFE NEXUS Project** has carried out the 1st European inventory of micro-hydroenergy recovery potential in the water industry. This catalogue has **101 energy recovery locations** (68 potential and 33 existing installations) from 10 different European Countries. **Waste heat recovery in district heating networks**. The sites with excess of energy are located in existing storage/service reservoirs, wastewater systems (collection or discharge stages) or in devices already installed to alleviate the excess of energy as pressure reducing values or Break pressure tanks.

- Cities can also use **bioenergy**, like in Innsbruck where biogas from waste, the accruing sludge of the waste water plant, solid biomass wood chips and different types of waste heat are used as a primary energy source for to generate heat, electricity, activated carbon and dried sewage sludge, which can be used as a substitute fuel. **Co-generation** can be used to simultaneously produce heating and electricity. Biogas ca also be produced from the collection of organic waste.

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Infrastructure

Decarbonisation of heating and cooling can be done through the technologies mentioned in Stationary Energy area and also, through the integration or **renovation of District heating (DHN) and cooling (DCN) networks**. DHN and DCN a district heating system transports warm or cold water from an external heat source to several buildings for space heating or cooling and, tap water heating. If the district heating already exists and operates at high temperature (above 90ºC), which are considered as 1st, 2nd or 3rd generation of DHN[13]. **The 4G (**from 40 to 70ºC) **and 5G** (<40ºC) **DHCN** have reduced temperatures so as to reduce losses and to allow the usage of low temperature heating sources (e.g. solar thermal) and waste heat (from industries, data centers, showers from buildings, etc.). The heat source can be diverse (water from rivers, sea or ponds; ground, or even waste heat) and of varying degrees of sustainability, providing the opportunity to reduce greenhouse gas emissions. 5G provides the primary heat source for **decentralized heat pumps**. **4G and 5G DHCN** are usually connected to highly efficient buildings (due to temperature level), unless heat pumps are available at substations (booster heat pumps for DHW like in REWARDHEAT project). Furthermore, for new buildings, DHCN can also supply the needs of dishwashers and washing machines like in COOLDH project. Cooling can be also provided through DCN, like in Herleen. **Renovation** can be performed in existing **DHCN** to upgrade them, but to this first the buildings need to be refurbished, which allows the inclusion of RES in the DHCN (like in Stockholm). New European Bauhaus principles can be considered when deploying DHCN like sustainability, together (where the DHN is community owned), and beautiful (through multicultural buildings like in Herleen, Copenhill or Hamburg).

Energy communities can be, in fact, a good **instrument** to uptake most of the above-mentioned technologies. For instance, Ollersdorf municipality invest themselves in photovoltaics and e-mobility, so as to set a good example and promote the citizen investments. For those roof owners who could not participate economically they also have the opportunity to offer their roof and still benefit from the PV production. In the north, instead of installing PV, off-shore wind is also promoted and shared among neighbours (see Windcentrale).

Energy and E-fuel storage

Heat/cold produced at times of peak supply of renewable electricity can be used to meet demand even when the sun is not shining and the wind is not blowing, if storage is used. In fact, electricity and heat supply and demand deal with a **seasonal** mismatch; year-round supply (e.g. from geothermal systems, industrial waste heat) or if supply particularly in summertime (e.g. solar energy) does not match the low heat demand in summer and high demand in winter. **Underground thermal energy storage (UTES)** offers the possibility to store large volumes of excess heat (warm water) in the summer, to be back produced in the winter. Various **seasonal storages** have been studied and tested in field labs and pilots, such as Aquifer Thermal Energy Storage (ATES), Borehole Thermal Energy Storage (BTES), Pit Thermal Energy Storage (PTES), Mine Thermal Energy Storage (MTES) and Tank Thermal Energy Storage (TTES). These seasonal heat storage technologies allow heat delivery to residential areas by thermal heat networks to make much better use of regional sustainable heat sources, thereby reducing the need for fossil fuels for peak demand (Like in the solar community of Okotoks in Canada, or Vojens in Denmark). **Short term energy storage** can also be used when there is no possibility or space to integrate seasonal storage, such as hot or cold-water tanks (like in Lund), or ice storage (DHC in Paris).

Energy flexibility can also be offered by the city through thermal and **electric storage** and smart solutions. Electric storage can be deployed at large scale or community scale. SYMPHONY project uses distributed energy sources (DER) like rooftop solar, batteries and selected household appliances and it is orchestrated as a Virtual Power Plant (VPP) to decarbonise the power system at the same time it lowers electricity bills.

[13] DHN are classified according to temperature level and technologies integrated. See more in https://5gdhc.eu/different-generations-of-dhc/

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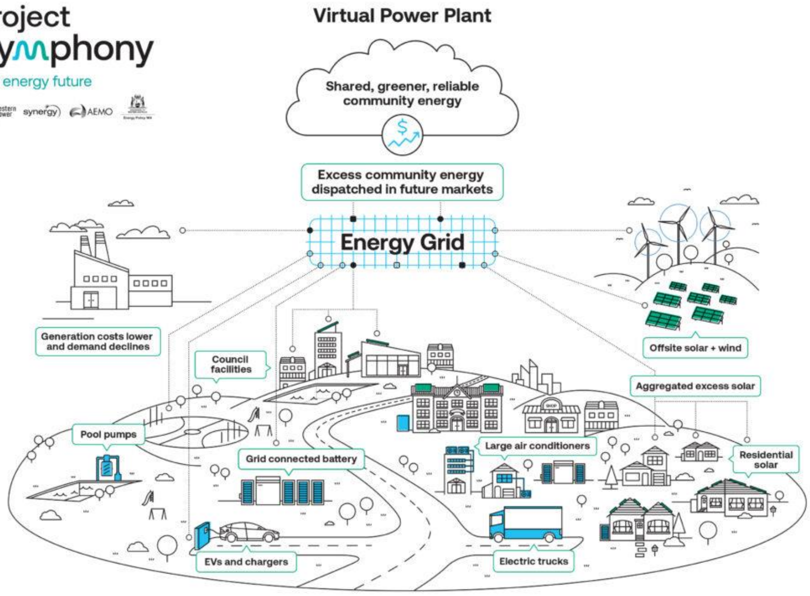

Figure 12: Virtual power plant of SYMPHONY project

Chemical storage (like hydrogen storage or biogas holders, etc.) can also be deployed such as in the "Climate-neutral urban quarter – New Weststadt Esslingen", in Germany that produces and stores green hydrogen on-site. Low-carbon electricity can be used to produce hydrogen (with electrolysers), store it (H2 storage), and use the hydrogen for power generation again (with **fuel cells**).

Energy management techniques (**smart solutions**) such as load balancing (like in Florence), can help to use the storage efficiently.

The combination of solutions can be done through different **concepts**, such as Positive Energy Districts (PEDs), micro-grids, Nearly Zero Energy Districts (NZED) or green neighbourhoods. In PEDs is important to reduce energy needs as much as possible through the improvement of the building façade and building design, so as to then install as much as possible of renewable energy technologies to produce more energy than what is needed on-site. Examples of PEDs will be available soon in the EU PED-database.

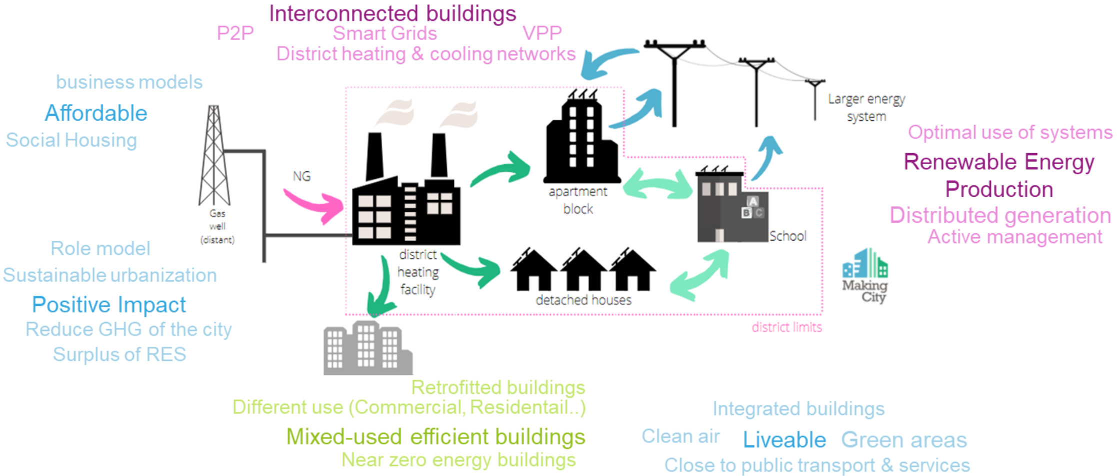

Figure 13: Positive Energy district concept (MAKING-CITY project)

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Table 2: Energy Generation solutions

Energy Generation		**https://netzerocities.app/resource-338**
RES electricity and thermal energy generation	Distributed wind	https://netzerocities.app/resource-768
	Micro-hydropower generation in urban water networks	https://netzerocities.app/resource-778
	Geothermal energy	https://netzerocities.app/resource-788
	Co-generation systems	https://netzerocities.app/resource-798
	Sustainable biomass and biogas power	https://netzerocities.app/resource-808
	Fuel cells	https://netzerocities.app/resource-818
Energy recovery	Waste heat recovery in district heating networks	https://netzerocities.app/resource-858
Energy and E-fuel storage	Electricity storage: Chemical storage	https://netzerocities.app/resource-868
	Thermal Energy Storage	https://netzerocities.app/resource-828
	Seasonal storage (pits, dwells, etc.)	https://netzerocities.app/resource-848
Infrastructure	From 3G to 5G District Heating and Cooling networks (generation to substations)	https://netzerocities.app/resource-878
	Renovation of DH&CN (1G and 2G)	https://netzerocities.app/resource-838
	Microgrids	https://netzerocities.app/resource-888
Smart solutions	Energy management techniques	https://netzerocities.app/resource-898

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2.3 Mobility and Transport

- **Knowledge Repository: Mobility and Transport:** https://netzerocities.app/resource-2488

Lead	**VTT**
Contributors	EIT Urban Mobility, Rupprecht, UITP, South Pole, CEREMA, TNO

The *Mobility and Transport thematic area* aims to phase out all fossil fuel-based modes of transport within the boundaries of the city, or ideally, the Functional Urban Area, and, simultaneously, facilitate the use of alternative, cleaner and more sustainable transport modes. To do so, the goal is on the one hand to prioritise **walking**, **cycling**, public transport and other mobility services (**car sharing**, **micromobility**) in order to reduce private car use, and on the other hand, to make use of the technological innovations such as electrification, **Cooperative Intelligent Transport Systems (C-ITS)** and **Cooperative, connected and automated mobility (CCAM)**. The ultimate goal is that all transport needs are being met without generating carbon emissions.

In the following, the solutions, instruments and strategies to reduce emissions from road transport are presented following the A-S-I scheme: ***Avoid*** (i.e. reduce the need to travel or avoid travel by motorised modes), ***Shift*** (i.e. shift to more environmentally friendly modes) and ***Improve*** (i.e. improve the energy efficiency of vehicles technologies and transport modes.

Instruments: a comprehensive planning framework

The starting point for any public administration to adapt its mobility system should be an overarching planning framework such as a **Sustainable Urban Mobility Plans (SUMP)**, a concept strongly promoted by the European Commission. A SUMP is one of the main instruments used worldwide to plan mobility systems in an integrated way, looking at environmental and climate change aspects. An excellent package of guiding documents is available from http://www.eltis.org and is constantly being adapted and aligned to wider EU policies (Green Deal, Urban Mobility Framework, Efficient and Green Mobility Package). A SUMP combines technical planning with the social-political dimension and builds on relevant sector plans, e.g. urban development plan or climate plan. This comprehensive and overarching type of process and document is thus laying the foundation for future and green investments in the mobility sector in the city and/ or Functional Urban Area. A SUMP should include a common vision, strategic objectives, and an integrated set of short-, medium- and long-term measures from different policy areas, including regulation, promotion, financing, technology and infrastructure.

Reduced passenger transportation needs decrease also CO_2 emissions and externalities (air pollution, accidents, noise) from passenger transport (cars and public transport). This primarily occurs through urban planning activities but also through digitalisation of work and meetings to ensure that the key social and commercial services and infrastructure exist close to residential areas and that, for example, co-working spaces do not only exist in the city centre. This will reduce the need for white-collar workers to travel for work. The integration of **land use planning and urban space management with mobility planning** is a central strategy to reduce and avoid vehicle miles travelled and to shift motorised trips to zero or low carbon modes of travel.

Gender diversity considerations in urban mobility should be also taken into account for any mobility or transport planning.

Vehicle solutions

Electrification of passenger transport through electrified vehicles (EVs) is one of the most promising solutions in the long term. Electrification eliminates 100% of the tailpipe emissions (CO_2, NOx, and PM) that come from the combustion of fossil fuels. It is, therefore, a solution with enormous co-benefits. However, the total abatement potential also depends on the carbon intensity of the electricity used and the carbon footprint of producing the vehicle (mainly the battery). Taking these factors into consideration is essential when evaluating electrification as a decarbonisation solution.

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- **Zero emission electric cars** can provide an opportunity to reduce global GHG emissions (UN Habitat, 2014) and increase air quality, if powered by renewable energy sources. Plus, the use of second life batteries and improved battery performance may in the future further reduce the need of raw materials and the related environmental impact. However, the adoption of EV depends on several factors, faces a lot of challenges (high capital costs, lack of charging infrastructure, grid impact, etc.) and the collaboration from various stakeholders. Some of these challenges can be overcome by using new solutions such as **smart and flexible charging** (schedule charging based on power constraints, price and priority, selling unused power back to the grid), **smart energy management**[14] (Improving EV and stationary load management, reducing the risk of grid overload), **bi-directional EV charging** (like in Amsterdam or Switzerland), or **portable electric vehicle chargers** (solving the lack of charging infrastructure in cities[15]).

- **Zero emission buses** eliminate 100% of the tail-pipe emissions and come with comparable benefits to passenger cars. Some co-benefits may even be higher per tonne of CO_2 abated, for example, PM emissions and noise. Electrified buses have experienced the fastest increase and, according to Interact Analysis, it is expected that in 2025 around 40% of new city buses registered in Europe will be battery electric buses. It has the potential of a significantly higher impact than the electrification of cars since buses have more operating hours per day and a higher annual fuel consumption (ELIPTIC Policy Recommendations, 2018). According to ELIPTIC project, "it takes 100 electric cars to achieve the impacts of one electric bus (but there is not 100 times the funding for electric buses)". To ensure the service of BEB, rapid charging infrastructures are sometimes needed in (See Figure 14, in Rotterdam). In Stockholm a scientific study was made to decide which stops needed charging infrastructure and which ones not (only 10-25% of the stations will require charging infrastructure). In Rotterdam the optimisation of the charging scheduling was studied.

Figure 14: Rotterdam rapid charging infrastructure

- **Electrified trucks** could reduce most of the externalities associated with freight transport. Similar to the electrification of cars and buses, this solution eliminates tailpipe emissions when trucks shift from internal combustion engines to electric engines and batteries.

- **Hydrogen Fuel Cell Electric Vehicles (FCEVs)** could be also an option when electrification is not possible. FCEVs are complementary to full EVs, as FCEVs offer fast refuelling (3-5 minutes) and long driving range (500km+ on a single tank), which exceed the corresponding characteristics of BEVs. In the urban context, there are two vehicle groups, in which BEVs have

[14] Promising practices for integrating electric vehicles into the grid: Start with smart
[15] Check the guide: EV_charging_guide, of the International Council on clean transportation

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challenges and FCEVs show great promise: garbage trucks and taxi fleets. Also, hydrogen busses have been deployed in some European Cities. Similar to the challenges of EVs, hydrogen needs the deployment of infrastructure, specially of "Hydrogen refuelling stations" which can be challenging (needs green hydrogen local production, compressors at different pressure levels[16], etc.) but interesting for industrial cities (to create an industrial-urban symbiosis). The project Zefer deployed 180 FCEVs in Paris, London and Brussels for the demonstrations of viable business cases. Lifengrabhy developed and demonstrated the use of 2 garbage trucks on hydrogen in Veldhoven and Eindhoven.

Cooperative, Connected and Automated Mobility (CCAM) refers to the exploitation of automated driving functionalities and connectivity capabilities towards the establishment of a cooperative and integrated transport system. In this way, CCAM is expected to transform the way we travel and has the potential to increase traffic safety and performance, reduce environmental impacts, and enhance the inclusiveness and resilience of mobility services. However, the envisaged benefits that CCAM might bring can only be fulfilled when local authorities have the capability of making structured and informed decisions to shape CCAM deployment to societal needs. Proactive planning approaches are required to ensure a positive roll-out of CCAM and its alignment with local policy goals. One CCAM solution is autonomous bus, tested e.g. in AVENUE project in Copenhagen, Geneva, Luxemburg and Lyon.

Infrastructure solutions

Cities can implement different measures to speed up electrified vehicles (EV) adoption, such as **urban Vehicle Access Regulations**), providing **free or preferential parking for EV** and **priority lane access** to car-sharing and ride-pooling companies using EV, introducing **low or zero-emission zones** (like for example in Brussels and Bergen), **electrifying the municipal vehicle fleets**, **simplifying administrative processes to build charging points**, establishing **congestion pricing in transport**, providing **local subsidies for EV purchase or tax write-offs for companies or citizens** willing to install charging points.

Furthermore, urban freight delivery can be also electrified, and logistics can be improved. **Optimised logistics** is one of the solutions that can reduce the negative impacts of freight transport in cities. By improving the utilisation of trucks (tonnes transported goods per truck) and optimising their routes, it is possible to greatly reduce the total vehicle kilometres and thereby the CO_2 emissions, air pollution and noise. Plus, **last-mile logistic points** such as the one in **Vienna** could help.

Additionally, **fostering walking** is important. A walkable city requires consideration at different levels: 1) at the city-wide level: pedestrian axes, reduction of urban cuts and hierarchies of road; 2) at the neighbourhood level: traffic calming, parking management and reduction of motor vehicle through traffic; 3) at the street/square level: allocation of public space, reduction of speed, access for people with reduced mobility, quality and safety of sidewalks and intersections. Examples of walking interventions include: exploratory walks, citizen involvement in the design and management of public spaces, temporary or small-scale measures (e.g. car-free areas in front of schools, tourist streets, seasonal furniture and parklets), narrowed crossings (widened sidewalks, kerb bulges, mid-crossing refuge islands). Vitoria has created urban pathways for pedestrians linking the centre with the north of the city, tackling cultural change and a communication campaign. Rotterdam has developed more comfortable and safe green spaces investing in active frontages lighting and seating as well as connecting neighbourhoods with road crossings and promoting policies to reduce cars (by reducing parking spaces, and building outskirts of the city garages).

Another development path is the **modal shift from car transport to public and active transport.** Favouring public transport, walking, or **cycling** can significantly decrease travel emissions. Cities may achieve this by enhancing the appeal of alternative means of travel, for example, by improving roads and routes for bicyclists and pedestrians as well as the availability, quality and cost of public transportation options. The former tends to be a very cost-effective solution for society as it, like the previous one, reduces both CO_2 emissions and externalities (air pollution, accidents, noise) and thereby generates significant health benefits, especially when switching to active mobility (walking/cycling).

[16] Hydrogen needs to be compressed to 700 bar for passenger vehicles, and 300-350 bar for trucks and buses.

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The IEA[17] has introduced **behavioural change** (e.g. by switching regional flights to high-speed rail, reduce the use of cars in cities, etc.) as one of the key issues in cutting emissions from the mobility sector. Furthermore, changing patterns in mobility will also lead to implications in materials demand. **Cycling** has a large potential to replace car journeys up to 5-8 km in urban areas. For journeys up to 15 km, for cities with hills and for cities with high temperatures, pedelecs (bicycles that provide electric support while pedalling) are an option. Cycling (whether electrically supported or not) also offers more flexibility than public transport for trip chaining (a practice more common for women than men). Another area with great potential is the use of cargo bikes (or a bike with a trailer), like in Vienna and many other European cities, both for private use to transport children or bulky items or in large-scale use for last-mile urban logistics. In some cities, even electric cargo bikes are now available to rent. In the same line, Amsterdam is carrying out a long-term pilot to promote shared bikes (normal and cargo). Of course, if cycling is increased, this will lead to emissions associated with the construction of cycle lanes, but it is estimated that these emissions would be less than 5% of the emissions avoided by lower car use. The transformation will require the reallocation of space from car facilities (parking, traffic lane) to cycling, the reduction of speeds, the limiting of motorised traffic and the creation of more secure parking facilities for bicycles. Furthermore, there is also potential to increase social inclusion by enabling more people cycling (older people or those with physical disabilities), like in UK, and to encourage people to cycle more (e.g. winter cycling in Gävle or Turku).

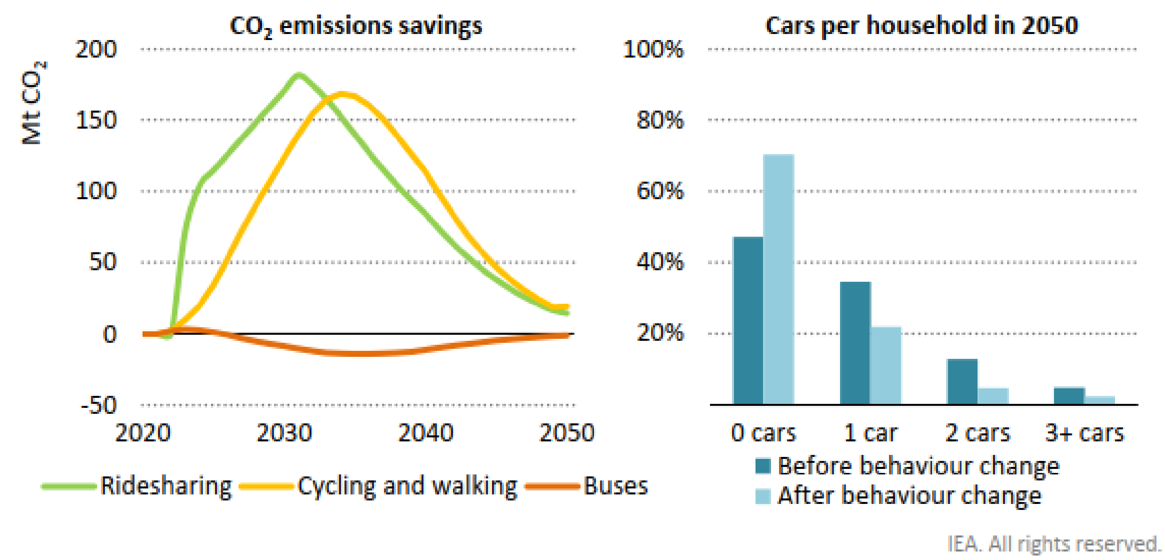

Figure 15: Global CO_2 emission savings and car ownership change due to behavioural change in in the Net-Zero Emissions by 2050 Scenario[18]

Congestion pricing is a transport demand management measure adopted to reduce the impacts of traffic congestion on cities, by implementing tolling systems to influence short-term demand choices, forcing travellers to switch to low impact road routes and sustainable transport modes.

Service solutions

Car sharing systems and **collective passenger transport** provide access to a car for users who might not own a car, because they do not need it for daily journeys or cannot afford a private vehicle. Car sharing models present a reliable, flexible, and cost-efficient alternative to car ownership that supplements the sustainable modes of walking, cycling and public transport. Though they are generally not run by the city in which they operate, the municipality can set up a supportive infrastructure, and

[17] International Energy Agency: https://www.iea.org/
[18] International Energy Agency (2021), Net Zero by 2050, IEA, Paris: Net Zero by 2050 Scenario - Data product - IEA.

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

establish appropriate policy and legislation to integrate car sharing into the city fabric and with public transport.[19] Different forms of car sharing are station based and free-floating systems.

Increased carpooling (*a group of people travelling together in a car)* can increase the utilisation of cars (average number of passengers per car) independent of the transportation need and thus reduce the overall vehicle kilometres and the associated emissions and negative externalities. In addition to the benefits to society, carpooling reduces the up-front investment need for car users on average, as more people share the same cars. **Carpooling** has been used, for example in the University of Cracow[20], by creating an on-line carpooling system data base that allowed the students to look for travel companions. In Bremen, an action plan to provide support for the **car-sharing** development was established, allowing to substitute more than 6000 cars. Furthermore, in the main Bremen website there is information available of the different type of models for sharing cars available and a map with the station spots. Together with carpooling, also **micromobility** vehicles (bicycles, scooters, etc.; which can be electric or not) can be shared in a city. Shared micromobility sometimes needs special infrastructure (e.g., available parking places to leave the devices) across the city. However, shared micromobility poses some challenges to cities, e.g., the invasion into public space and unregulated parking, vandalism and short lifecycle of devices, emissions from shared vehicle transport for repositioning or recharging, user safety or the use of data generated by shared micromobility. To tackle these challenges, cities might consider to regulate speed limits, individual protection equipment, and minimum age (like in Romania), parking, technical features, or data exchange. New technology, such as swappable batteries (like in Paris), may help to optimize the logistics of collecting electric vehicles for charging. Micromobility can be integrated with public transport through the use of APPs, smart cards, integrated ticketing systems and multi-modal marketing campaigns.

While the new services are growing in popularity, they ought not to replace but rather complement public transport systems and active modes. In that way, multi-modal, integrated, and robust public transport systems that function as the backbone of mobility is central to sustainable mobility systems. There are three important drivers that can increase the viability of **multimodal transport**. The first is multimodal digital platforms, the second is multimodal ticketing and the third is mobility hubs.

- **Multimodal digital platforms** allow for a variety of mobility services made available to users via an app. These apps usually include functions such as route planning and navigation as well as ticketing. The means of transport that can be accessed through these platforms should be as wide as possible (such as public transport, ride-sharing, car-sharing, bike-sharing, scooter-sharing, taxi, ride-hailing etc.) and include also private mobility providers. An advanced version of this is **"Mobility as a Service (MaaS)"**. For example, Helsinki, Vienna, Antwerp and Birmingham have MaaS offering available through Whimapp, but also other service providers can be used (see https://maas-alliance.eu/homepage/what-is-maas/).

- **Electronic ticketing, Multimodal ticketing and smart cards** (combining multiple operators) can facilitate boarding and transaction but also the integration of different modes under one card or system (such as MaaS). The electronic ticketing can either be a contactless ticket card, a bank card, a multi-application card or an NFC (Near Field Communication)-enabled mobile device or online remote loading. Multimodal ticketing requires a strong cooperation between the different operators. London in the U.K and Tallinn in Estonia have been the forerunners in electronic, multimodal ticketing (**smart cards**).

- **Mobility hubs** are a means to seamlessly link various modes of transport in order to enable inter-modal trip chains as an alternative to the private car (e.g. in Dresden). Mobility hubs link the use of traditional means of transport such as bicycles or cars with public transport (e.g. Bike & Ride or Park & Ride at train stations). Nowadays, mobility hubs also allow easy access to new forms of mobility or shared transport due to the widespread use of digital or smartphone-based information and mobility services.

[19] Implementing a large car sharing scheme.pdf
[20] Example: page 123 of U-MOB catalogue (https://u-mob.eu/wp-content/uploads/2019/01/best_practices_EN-v2.pdf)

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Cooperative Intelligent Transport Systems and Services (C-ITS) constitutes an effective instrument for existing over-burdened traffic systems to implement innovative, sustainable visions tackling traffic movements and at the same time visualizing, monitoring and constantly evaluating traffic situations. As exchange of data and information are made possible through C-ITS, facilitating a more harmonized intermodal traffic infrastructure, services like dynamic lane changing, alternative route choice, improved traffic signalization, could be established. C-ITS capabilities can significantly improve road safety, through the cooperation of the different road users and the implementation of support functionalities to minimise human-errors resulting in traffic accidents. Another way to improve logistics is the **Drone delivery system**, but it has not been widely adopted, although it has been tested in Dublin.

Also, other policies, services and instruments can be considered to complement urban mobility planning. Examples of these are digital services like **smart parking**, **Urban Vehicle Access Regulations (UVARs)** and **Mobility Management**. **Smart parking** can be planned with the help of modelling and simulations, where optimization, e.g., of potential parking locations, can be applied to urban design decisions. Furthermore, there are tools available for the **parking policies, management and fees** such as apps (PaaS), IoT/sensor technology, the use of real-time data for parking availability, etc. They can contribute to behavioural change through emission-based parking fees, as an incentive to use lower or zero-emission vehicles, more efficient mobility planning leading to shorter journeys and thus easing congestion of traffic, as less people are circulating to look for parking. The above-mentioned apps can connect to digital twinning platforms to deliver additional data. Furthermore, simulations in the digital twin can be used to quickly evaluate scenarios e.g. for the assessment of multiple parking policies, such as an app that can choose suitable parking fees to achieve the desired behavioural change. **Urban Vehicle Access Regulations** (UVARs) are means to reduce the number of vehicles entering a given geographical area, by means of regulatory measures (e.g., low-emission zone, like in Stockholm, Milano, Madrid, etc.), financial measures (e.g., congestion charge, like in London) or spatial measures (e.g. creation of a superblock or reallocation of road space to create a pedestrian zone, like in Barcelona). Low emissions zones are generally introduced in stages, meaning that they become gradually stricter over the course of several years. This allows citizens and businesses time to adapt to the changes by purchasing lower-emitting vehicles, retrofitting existing vehicles where possible or finding alternative modes of transport within the LEZ area (e.g., walking, cycling, public transport, e-scooters). **Mobility Management** refers to the promotion of sustainable transport and managing the demand for car use by offering services with the final objective of changing travellers' attitudes and mobility behaviour. At the core of mobility management are "soft" measures such as information and marketing campaigns (like in Romania), awareness raising (e.g., personal cards in Lahti), mobility education, mobility info points, and school and company travel plans. "Soft" measures most often enhance the effectiveness of "hard" measures within urban transport (e.g., new tram lines, new bike lanes or charging infrastructure). Compared to "hard" measures, mobility management measures do not necessarily require large financial investments and may have a high cost-benefit ratio in a short time frame. Some examples can be found in https://www.eltis.org/resources/case-studies/mobility-management-insights-and-examples-successful-implementation.

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Table 3: Mobility and Transport solutions

Mobility and Transport		**https://netzerocities.app/resource-2488**
Vehicle solutions	Zero emission buses	https://netzerocities.app/resource-398
	Zero emission electric cars	https://netzerocities.app/resource-408
	Hydrogen Fuel Cell Electric Vehicles (FCEVs) in urban transport	https://netzerocities.app/resource-508
	Cooperative, connected and automated mobility (CCAM)	https://netzerocities.app/resource-418
Infrastructure solutions	Bi-directional EV charging (V2X)	https://netzerocities.app/resource-428
	Public charging system for EVs	https://netzerocities.app/resource-448
	Fostering cycling	https://netzerocities.app/resource-468
	Fostering walking	https://netzerocities.app/resource-478
	Mobility hubs	https://netzerocities.app/resource-488
Service solutions	Goods delivery with Drones	https://netzerocities.app/resource-518
	Electrified urban freight delivery/ Last mile delivery	https://netzerocities.app/resource-528
	Fleet decarbonisation	https://netzerocities.app/resource-538
	Car sharing	https://netzerocities.app/resource-558
	Shared micromobility	https://netzerocities.app/resource-578
	Collective passenger transport	https://netzerocities.app/resource-608
	Mobility as a Service (MaaS)	https://netzerocities.app/resource-628
	Cooperative Intelligent Transport Systems and Services (C-ITS)	https://netzerocities.app/resource-498
	Parking policies, management and fees, smart parking	https://netzerocities.app/resource-638
	Smart cards	https://netzerocities.app/resource-658
	Multimodal ticketing and smart cards	https://netzerocities.app/resource-688
	Multimodality	https://netzerocities.app/resource-698

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2.4 Green Industry

- **Knowledge Repository: Green Industry:** https://netzerocities.app/resource-2643

Lead	**Tecnalia**
Contributors	CARTIF, REGEA, POLIMI, TNO

Industry is the second-largest global resource of energy sector CO_2 emissions. In Europe the total final energy demand in the industry accounted for 2950 TWh/yr in 2020, 66% of which came from process heating. The main fuel source for fulfilling this demand is gas (36%), followed by coal (20%) and oil (8%). In Europe, EU paper production plants represented 20.5% of the world pulp production in 2018, still relying on fossil fuels for the 40% of its energy use. A vast majority of these plants, self-produced more than 50% their electricity thanks to own CHP units. In addition, the food and drink industry are the EU's biggest manufacturing sector in terms of jobs and value added.

According to the IEA[21], in heavy industry the **key solutions** in the pathway to net zero will be:

- **Carbon capture, utilisation and storage (CCUS)**[22]: which will tackle the majority of emission reduction, with 35%.
- **Material efficiency**: which can help to reduce 19% of the global emissions.
- **Electrification of processes**, to reduce 12% of global emissions. Electrified machinery releases no CO_2 and no air pollutants at the site but relies on access to electricity with a low CO_2 footprint to bring down emissions. It is a solution that is most relevant for industry-heavy cities. When electrification is not possible, hydrogen from low-carbon sources, can help to reduce 10% of the global emissions.
- **Other solutions** such as: Other **fuel shifts** (9%), **Bioenergy**[23] (5%), **Energy efficiency** (4%) or **other renewables** (1%).

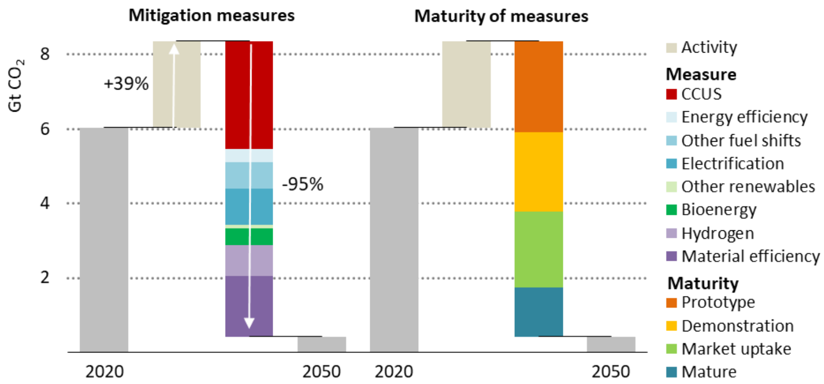

Figure 16: Global CO_2 emissions in heavy industry and reductions by mitigation measure and technology maturity category in the Net-Zero Emissions by 2050 Scenario[24]

Industrial clusters will play a major role in the uptake of CCUS, which will require an investment in infrastructure (for transport and storage). Other **technologies** will be: low-emissions ammonia-fuelled

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[21] International Energy Agency (2021), Net Zero by 2050, IEA, Paris: Net Zero by 2050 Scenario - Data product – IEA: https://www.iea.org/reports/net-zero-by-2050
[22] CCUS: The process of capturing CO_2 emissions from fuel combustion, industrial processes or directly from the atmosphere. Captured CO_2 emissions can be stored in underground geological formations, onshore or offshore or used as an input or feedstock to create products.
[23] Bioenergy: Energy content in solid, liquid and gaseous products derived from biomass feedstocks and biogas. It includes solid biomass, liquid biofuels and biogases.
[24] International Energy Agency (2021), Net Zero by 2050, IEA, Paris: Net Zero by 2050 Scenario - Data product - IEA.

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ships, hydrogen-based steel production, direct air capture, solid state refrigerant-free cooling or solid-state batteries. To uptake these solutions, among others, will need of[25]:

- Higher **education and funding** R&D helping companies innovate
- Create **networks** for **knowledge** exchange
- Using **public procurement** to boost **investment**
- Setting right **regulatory frameworks** for markets and finance
- Investing in enabling **infrastructure**
- **Certification and standardization**, as well as creating of **Carbon Dioxide Removal (CDR)** programmes, to fund and certify the emission trading mechanisms to offset emissions.

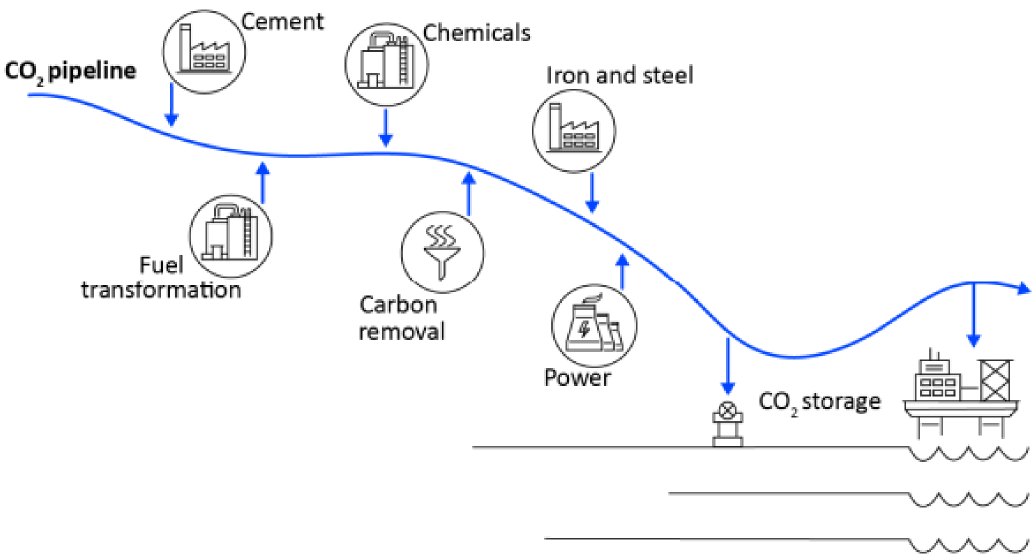

Figure 17: CO_2 pipeline in an industrial cluster

Energy Efficiency in Industrial Processes

In NZC Green Industry solutions are covered and described to inform cities and to give them advices on **how a city can promote the use of these solutions with its industry stakeholders**. For example, for **improving energy efficiency in industrial processes**, **heat recovery and revalorisation** is described. This is particularly relevant for sector-coupling, especially if the city owns a DHN or can promote the revalorisation of the waste heat into DHN. REUSEHEAT EU project, waste heat is revalorised with a heat pump and injected into district heating networks. The source of waste heat comes from data centres (from the heat released to cool down the servers), hospital (from the cooling of surgery room and the areas with special air requirements), or metro (recovering heat from the tunnels). From the project, the main barrier encountered was that regulation and financial support is mostly missing in EU and therefore, it does not boost the promotion of waste heat investment. Plus, a contractual agreement is needed between the waste heat supplier and the district heating operator, which is not standardized and it needs one-to-one cooperation, which can hander the process[26]. Other example is PITAGORAS project, which focuses on the efficient integration of city districts with industrial parks through smart thermal grids. Technologies and concepts for medium temperature waste heat recovery,

25 https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
26 https://www.reuseheat.eu/wp-content/uploads/2022/04/ReUseHeat-Handbook-For-Increased-Recovery-of-Urban-Excess-Heat.pdf

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considering as well integration with renewable energy sources, and heat (and power) supply to cities is developed and demonstrated.

For improving energy efficiency, digital solutions are also widely used, such as smart **energy management systems** or **monitoring systems**, which allow to integrate distributed energy sources (storage, RES generation), new market actors (prosumers, aggregators, etc.), the application of the integration of intelligence (artificial intelligence, algorithms, data mining, blockchain, etc.) to allow security, privacy, adaptation and automation.

Lastly, **replacement of equipment** not necessarily due to failures or existent damage, but to increase efficiency is also important. A successful example is the case of electric motors and variable speed drives which, depending the kind of industry, may represent up to 70% of the energy consumed.

Renewable Generation for Industrial Processes

For **on-site generation**, the industry can invest in local RES (for electricity production see energy generation thematic area), but also specific **Solar Thermal**, **Geothermal**, **High Temperature Heat Pumps**, and **Green Hydrogen Technologies**, for its use in industrial processes.

Solar Thermal with the advanced solar process heat technologies, could potentially meet almost 50% of head demand in the industrial sector[27]. Heat in the lower temperature range (<80°C) can be provided with commercially available systems, such as flat plate collectors (FPC) and evacuated tube collectors (ETC). For medium-temperature processes, ultra-high vacuum FPC or ETC with concentrators can generate temperatures of up to 200°C. **Solar concentrators** like parabolic dish collectors, parabolic trough collectors, and Linear Fresnel collectors can generate compressed steam with temperatures of up to 400°C. Additionally, solar thermal-driven technologies can be used for cooling or air-conditioning purposes, like **absorption or adsorption heat pumps**.

Geothermal energy can be also used for electricity or industrial processes (ultra-deep geothermal energy, from around 4km depth, which could produce more than 120ºC heat). The possibility to produce geothermal heat depends on many surface factors that can vary locally.

Industrial Heat Pumps technologies, i.e. mainly vapour compression[28,29], absorption[30], and chemical[31] heat pump technologies, are necessary and effective to improve energy efficiency and reduce greenhouse gas emissions. Furthermore, the application of **heat pump technologies** opens new options for sector coupling of electricity, heating, and cooling and provides flexibility, e.g. through heat storage in industrial plants. Moreover, according to a recent comprehensive study by Marina et al.[32], in the temperature range of 90 to 160 ºC the highest thermal demand is found in the paper sector (83.03 TWh/yr), followed by chemical (53.96 TWh/yr), refinery (35.14 TWh/yr) and food and beverage (18.96 TWh/yr). These temperature range is particularly important for high temperature heat pumps (which can upgrade waste heat from 30 to 160ºC) for applications in the **food, paper, and chemical/pharma industries**, in particular in drying processes, as well as in pasteurizing, sterilizing, evaporation, and distillation.

[27] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_ETSAP_Tech_Brief_E21_Solar_Heat_Industrial_2015.pdf

[28] Arpagaus et al. (2018): High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. Energy, https://doi.org/10.1016/j.energy.2018.03.166

[29] De Boer et al. (2020): Strengthening Industrial Heat Pump Innovation, Decarbonizing Industrial Heat, White Paper, https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/ies/projekte/projekte_tes/91_sccer-eip/2020-07-10_whitepaper_ihp_-a4_small.pdf

[30] Xu and Wang (2017): Absorption heat pump for waste heat reuse: current states and future development. Front Energy, https://doi.org/10.1007/s11708-017-0507-1

[31] Ducheyne et al. (2017): New industrial chemical heat pump from Qpinch. 12th IEA Heat Pump Conference 2017, http://hpc2017.org/wp-content/uploads/2017/05/O.3.9.2-New-industrial-chemical-heat-pump-from-Qpinch.pdf

[32] Marina, A. et al. (2021). An estimation of the European industrial heat pump market potential. Renew. & Sust. Energy Reviews, 139, 110545.

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Hydrogen can be produced from electrolysis of waster (powered by electricity coming from RES), the reforming of biogas (instead of natural gas) or biochemical conversion of biomass[33], if in compliance with sustainability requirements. **Green hydrogen** can be injected in iron metal production, ammonia production (Armijo & Philibert, 2020) and, other chemicals production, to decarbonise the process. The project HYBRIT reduced in 98% the CO_2 emissions production per tonne of crude steel, thanks to the use of hydrogen in the process. **Hydrogen valleys** (also known as hydrogen clusters) can help on the rapid update of hydrogen and create synergies between different companies. The most famous hydrogen valleys are Northern Netherlands Hydrogen Valley and Orkney Islands (in Scotland).

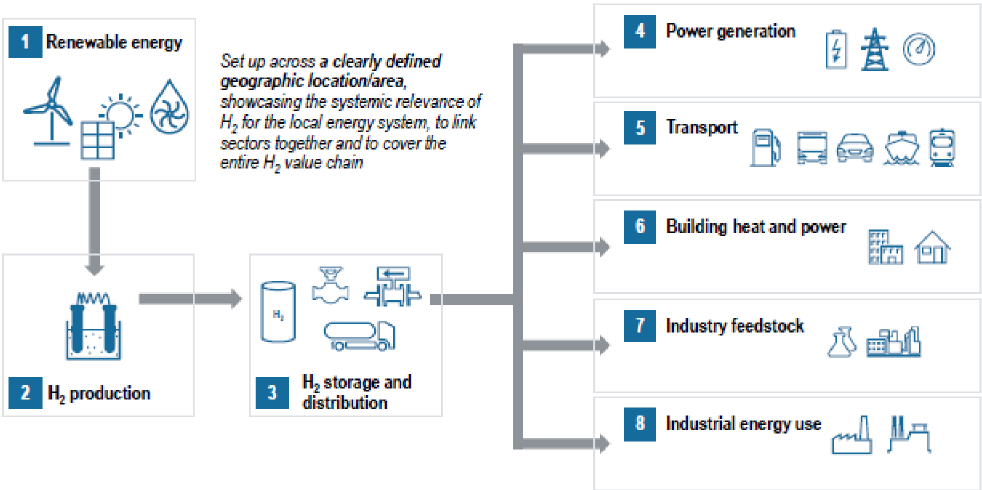

Figure 18: Conceptual overview of an H_2 valley

[33] Ongoing Commission assessment of the EU and global biomass supply and demand and related sustainability and a planned study announced in the EU Biodiversity Strategy (COM(2020) 380 final) on sustainability of the use of forest biomass for energy production.

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Table 4: Green Industry solutions

Green Industry		https://netzerocities.app/resource-2643
Energy Efficiency in Industrial Processes	Heat Recovery & Valorisation	https://netzerocities.app/resource-1398
	Energy Management Systems	https://netzerocities.app/resource-1408
	Monitoring Systems	https://netzerocities.app/resource-1418
	Replacement of equipment	https://netzerocities.app/resource-1428
Renewable Generation for Industrial Processes	Solar Thermal in industries	https://netzerocities.app/resource-1438
	Geothermal heat source solution in industries	https://netzerocities.app/resource-1448
	High Temperature Heat Pumps	https://netzerocities.app/resource-1458
	Green Hydrogen Technologies in green industry	https://netzerocities.app/resource-1468

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2.5 Circular economy

- **Knowledge Repository: Circular Economy:** https://netzerocities.app/resource-2615

Lead	**CARTIF**
Contributors	LGI, METABOLIC, Tecnalia, VTT, Climate KIC, TNO

A 2°C economy must be circular and cities will play a central role in the transition as motors of the global economy. In the coming decades, cities will be increasingly important due to the expected greater urbanisation rates and the significant infrastructure investments and developments needed. Cities are aggregators of materials and nutrients, accounting for 75% of natural resource consumption, 50% of global waste production, and 60- 80% of greenhouse gas emissions[34].

The linear 'take-make-dispose' model is leading to economic losses as a result of structure waste and negative environmental impacts. In response to a linear economy, the circular approach aims to decouple growth from finite resource consumption and is **restorative and regenerative** by design.

In European cities, a major challenge is to **expand circularity** beyond traditional resource recovery in waste and water sectors and to provide **systemic solutions able to be demonstrated and replicated effectively elsewhere**. Yet, circular economy requires a different way of thinking and investing resources in the traceability of materials and products and for this reason, it is not easy to mainstream this approach in the daily practice and management of cities. There are key specific features to be considered when addressing circular transitions in cities[35]:

- When focus on a specific value chain, it is necessary to support the **entire ecosystem** and not only the production itself, including activities like storage, distribution, retail activities, etc. This represents a significant burden for local authorities as cities have a very limited control and influence along the process and the chain to product design. This **value-chain perspective** is especially relevant when addressing food or materials consumed in cities, as most of the emissions arise outside the city, such as from farmlands or industrial areas. Surprisingly, cities climate targets generally do not include emissions from materials, calling for urgent solutions to address these emissions effectively.

- It requires availability of **data** and constant **traceability** of products, materials, stocks, flows and impacts.

- **Financing** the transition often relies on **public funding** because the initial investment is too high or because many associated activities are not profitable yet or at all. For example, to treat municipal solid waste (MSW), cities do not have the adequate infrastructure and are relying on obsolete treatment plants. In some cases, the technology already exists but it is either not available yet to local authorities at commercial scale or competing standards make it difficult to choose the right solution.

- There are also **regulatory barriers**, often linked to the size of local industries. Large industries might require approval from the national government (taking lot of time) while SMEs might not have enough capacity to take such initiatives.

- **Stakeholder engagement** and **behavioural change**: engaging with multiple stakeholders is key for the circulation transition, including citizens and "triple helix" stakeholders. Especially at the start of a new initiative campaigning and incentives are needed, to align individual agendas.

- **Governance**: the circular transition requires social and organisational innovations.

[34] UNEP, Resource Efficiency as Key Issue in the New Urban Agenda, http://www.unep.org/ietc/sites/unep.org.ietc/files/Key%20messages%20RE%20Habitat%20III_en.pdf
[35] NetZeroCities: Deliverable 13.1: Report on city needs, drivers and barriers towards climate neutrality.

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On the other hand, there are a number of factors that uniquely position cities to drive the global transition towards the circular economy and greatly benefit from the outcomes of such a transition[36]:

- **Proximity of people and materials in the urban environment**: *Reverse logistics* and *material collection cycles* can be more efficient due to the geographical proximity of users and producers and can create new business models. The proximity and concentration of people enables also sharing and reuse models.

- **Sufficient scale** for effective markets due to the presence of both a large and varied *supply* of materials, and a high potential market *demand* for the goods and services derived from them.

- The ability of city governments to shape **urban planning and policy.** Local governments have a large and direct influence on urban planning, the design of mobility systems, urban infrastructure, local business development, municipal taxation, and the local job market. Furthermore, it is expected that on a global scale, 60% of the buildings that will exist in 2050 are yet to be built[37]. Since these investments will largely need to be made in cities, it presents a massive opportunity for local governments to use their influence to apply circular economy principles.

- **Digital revolution** with technologies like *asset tagging*, *geo-spatial information*, *big data management*, or *widespread connectivity.* Digital technology has the potential to identify the challenges of material flows in cities, outline the key areas of structural waste, and inform more effective decision-making on how to address these challenges and provide systemic solutions.

NetZeroCities has mapped a total of **32 Circular Economy solutions**, encompassing **24 technical solutions** (described in this section) and **8 instruments** (described in Section 2.8).Technical solutions have been grouped in different categories and sub-categories depending on the **type of resource**. Thus, **four main categories** have been defined (**Waste, Water, Energy** and **Food**), together with different sub-categories to cover the wide range of resources related to the circular economy:

Waste

There are three main elements for the **integrated and sustainable waste management** in a city:

- **Waste collection**, usually driven by a commitment of authorities to protect and improve public health and environment conditions,

- **Waste disposal**, driven by the need to decrease the adverse environmental impacts of solid waste management; and

- **Waste prevention**, reuse, recycling and recovery of valuable resources from organic wastes, driven by both the resource value of waste and by wider considerations of sustainable resource management.

Successful interventions, represented by the previous three physical elements, need to be supported by **governance** in terms of inclusivity (both for users and providers), financial sustainability and proactive policies. Next, the different waste subcategories are described, including specific strategies and solutions for their efficient management.

Municipal solid waste (MSW) is one of the key areas of municipal environmental policy and is also the item on which town councils spend most resources. In fact, **European cities are mostly promoting circular economy in this sector of solid waste and recycling**. Among the measures available, it can be cited the **Municipal Solid Waste (MSW) separation at source** within district level that can be implemented for example by means of the pay-as-you-throw (PAYT) solution. PAYT system is an economic instrument based on incentives which enable the real production of waste in each home or business to be calculated, and the tax is determined by the amount and type of waste that is thrown

[36] Ellen MacArthur Foundation 2017. Cities in the Circular Economy: an initial exploration.
[37] NRDC-ASCI, Constructing Change (2012)

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away. Thus, pay-as-you- throw systems promote waste prevention and recycling and enable the 'polluter pays' principle to be applied. In Europe, the most common model is pay-per-bin, followed by the chamber system especially in densely populated areas. This scheme is common in German cities, such as Dresden, Heidelberg, Hamburg, Berlin, Freiburg and Düsseldorf.

On the other hand, the **anaerobic digestion** of the organic fraction of MSW (and the co-digestion with other organic waste fractions) is a **common process implemented throughout the world** as it offers a sustainable source of biogas while valorising municipal waste. Anaerobic digestion also produces digestate, a nutrient-dense mixture that can be used by farmers as a high-quality fertilizer:

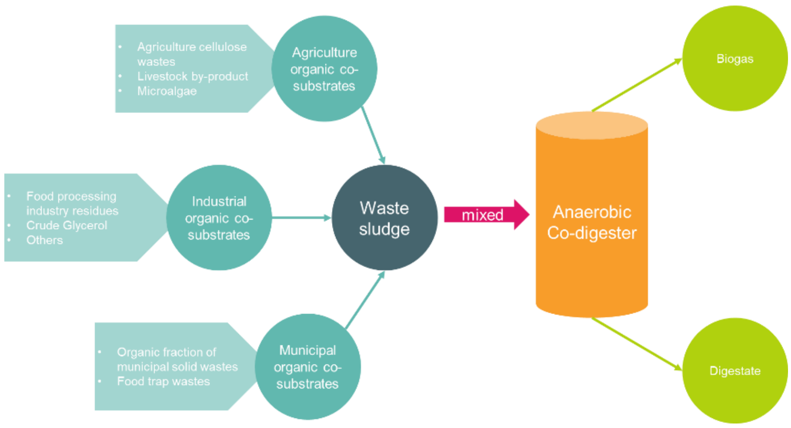

Figure 19: Conceptual view of the anaerobic digestion of the organic fraction of the MSW[38]

Textiles are one of the key circular sectors in Europe. For this waste, different measures based on urban recovery and processing techniques, or waste to feedstock optimization can promote circular textiles in cities. For example, the **Amsterdam Pilot**, which is being implemented within the Reflow Project will increase the recycling percentage of home textiles, through redesigning diverse methods for collection with citizens, while providing feedstock for the recycling industries. Another example is city of Jätehuolto (LSJH), which is planning a processing plant for all of Finland's post-consumer waste textiles in the Topinpuisto circular economy centre. The facility will enable the recycling of post-consumer textiles, converting them into recycle fibre.

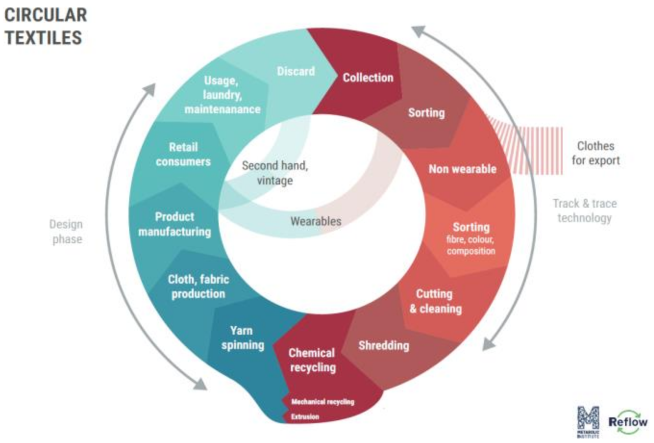

Figure 20: Circular textiles conceptual view

A variety of new technologies are being developed in response to European legislation and market forces that aim to recover **critical raw materials (CRM) from end-of-life appliances**. These diverse resource recovery processes are often regrouped under the concept of "**urban mining**", which considers cities' waste streams as economically important reserves of metals needed for digital and low-carbon technologies. At European level, The Urban Mine Platform displays all readily available data on products put on the market, stocks, composition and waste flows for (1) **waste electrical and electronic**

[38] Yang, Qi & Wu, *et. al*. (2019). Biogas production from anaerobic co-digestion of waste activated sludge: co-substrates and influencing parameters. *Reviews in Environmental Science and Bio/Technology*. 18. 10.1007/s11157-019-09515-y

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equipment (WEEE) and (2) **vehicles and batteries**, for all EU 28 Member States plus Switzerland and Norway.

- Recycling **WEEE** has been gaining increasing attention as a potentially economically important source of critical elements. Recycling WEEE avoids the environmental impact of landfilling hazardous materials while also reducing the need for primary extraction of critical materials, and the significant environmental damage extraction causes. Moreover, the EU is currently dependent on imports to supply much of its required CRM and harvesting from waste stocks, thus helps mitigate the risk that supply could be disrupted.

- On the other hand, the transition to a low-carbon economy will lead to an exponential increase in the demand for **batteries and related raw materials** (such as lithium, cobalt, nickel and manganese). From a circular point of view, recycling and recovery of battery raw materials are not enough, and innovations based on materials substitution, materials and products redesign can change materials requirements substantially. The Digital Battery passport is a digital twin of a physical battery and basically will be a sustainability certificate that contains all applicable information on environmental, social, governance, and life-cycle requirements involving all actors in the battery value chain.

Plastics are among the key sectors identified in the EU Circular Economy Action Plan. The need for solutions that promote circularity in this sector will be increasing as their consumption is expected to double in the coming 20 years[39]. **Plastic Waste Management**, which refers to the prevention, reuse, recycle, recovery and disposal of plastics, is crucial to achieve circular plastics in Europe. Another alternative measure to promote circularity is **expanding the use of bio-based and compostable materials**. Current recycling rates in Europe are only about 10% as current practice is not set up to facilitate the production of *secondary plastics*[40]. An influx of new materials is required to replace plastics that are lost and to compensate for downgrading of quality.

Figure 21: Plastics life cycle[41]

Mixing and downgrading effects are causing serious problems, making a large share of used plastics literally worthless. Although current plastic recycling is very low, recent studies have shown that **56% of plastics could be mechanically recycled**.

Packaging is the main value chain in European plastic industry and represents 40% of the total plastic uses. In order to reduce the demand of (over)packaging waste and promote circularity, several measures can be implemented: (1) Production of materials from renewable raw materials that can be used as packaging materials, (2) Decrease the material amount, for example by using thinner multilayer structures, (3) Replace multilayer structures by mono-materials, (4) Recycling of packages and packaging materials, which is affected by package design and the materials used in the packaging and which is widely linked to waste management and collection systems and (5) use the recycled packaging materials in the production new materials. The final target would be fully recyclable packaging, which is based on renewable raw materials.

[39] https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf
[40] Material Economics, 2018, “The Circular Economy - A Powerful Force for Climate Mitigation.”
[41] Woldemar d’Ambrières, « Plastics recycling worldwide: current overview and desirable changes », Field Actions Science Reports, Special Issue 19 | 2019, 12-21.

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The construction sector is responsible for over **35% of the EU's total waste generation**[42]. Material use for buildings can decrease by 30% by means of more efficient measures including:

- **Material efficiency building designs**: Eliminating waste from building designs may appear trivial yet entails the massive potential for emissions reductions as construction projects often use more materials than is needed. For example, it is often possible to achieve the same structural strength using only 50–60% of the cement currently being used. **Urban mining model** to assess circular construction opportunities and optimize resource use and exchange and **Circular Life Cycle Cost (C-LCC)** for deep renovation can be two solutions to promote material efficiency.

- **Reduce construction waste**. Up to 40% of urban solid waste is construction and demolition waste, and Europe currently landfills 54% of this waste. The use of the **Residual Value Calculator** for construction parts/material (as part of business model/value chain) can reduce material demand and waste generation.

- **Recycled building materials**. This is perhaps the most well-known way to decrease the emissions from new material production. However, to scale materials recycling, it is necessary to design materials and products for disassembly and high-value recycling already from the start. This is vital to ensure that they can be used as inputs for new products when they reach their end-of-life. Among the measures to promote the recycling of building materials it can be cited: (1) the **optimal management of waste at the end of building life cycle**, (2) the **reuse of local building waste (e.g. local waste material bank)**, (3) **Online register with building and infrastructure material/parts/products for reuse/circular use** or (4) the **Building material passport** (defined within the Instrument category).

- **Sharing business models**. Sharing business models could increase the utilisation of existing buildings and thus reduce the need for new office space to be built. In the circular economy, service-based business models, such as sharing, can increase the utilisation of underused buildings, spaces, and construction components. For example, in London, peer-to-peer renting, better urban planning, office sharing, repurposed buildings, and multi-purposed buildings increase the value of new buildings and can double the utilisation of 20% of the city's buildings in 2036, saving over GBP 600 million annually.

- **Prolonging the lifetime of buildings** is a way to reduce the amount of new material and thereby the associated emissions. A structure built traditionally has an expected technical lifespan of 50–100 years, but usually, after 20–30 years, it is not economically valuable. Demolition is often the go-to solution. In the circular economy, the economic value of a building is maintained by extending its 'functional' lifespan. Cities can stimulate longevity in buildings through modular, flexible, and durable designs. Modular design typically reuses 80% of the components in a building's exterior so that it can stand for 100 years or more, coupling modularity with durability. Such design approaches also ensure a building can be adapted to changing user needs and offer easier maintenance and renovations.

Water

Under a circular economy approach, the full value of the urban water is recognized and captured as a **service**, an **input to processes**, a **source of energy** and a **carrier of nutrients and other materials**. The European Union (EU) is threatened by serious water shortages. One third of EU territory is already experiencing water stress, posing threats to agriculture, the environment and drinking water. Extending the lifecycle of water resources is essential in a time when water shortages and droughts becoming more intense and frequent and affect a greater number of people. Different circular solutions have been identified in function of the location or scale within city boundaries:

[42] Eurostat data for 2016.

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- **Building level**. The housing sector accounts annually for 33% of water consumption. **Water reuse** is the central element of two circular measures demonstrated in the HOUSEFUL Project: On one hand, **greywater can be separated from blackwater** (water from toilets or kitchens) and then treated on-site for direct reuse in toilets recharge or irrigation, providing a reduction of tap-water use. This solution is being implemented during the refurbishment of a residential building in Sabadell (Spain). On the other hand, solid and liquid/solid free waste fractions (un-segregated water) can be separated for further valorisation, as it is being demonstrated in a Community centre located in Fehring (Austria).

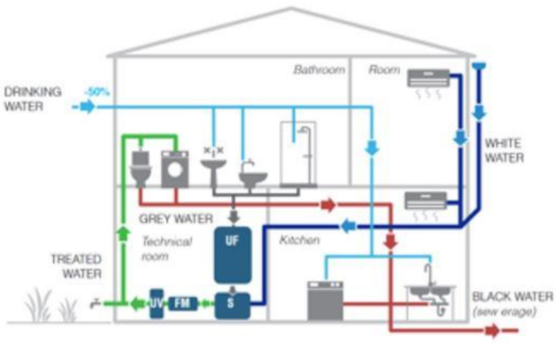

Figure 22: Greywater reuse at building level[43]

- **Urban water cycle.** Circular solutions offer an opportunity to deliver water supply and sanitation services in a more sustainable, inclusive, efficient, and resilient way. Among the solutions available it can be cited the **sustainable drainage systems (SuDS)** described in the Section 2.6 (water interventions within NBS) or the **Micro-hydropower generation in urban water networks**, described in the Section 2.2 (RES electricity and thermal energy generation).

- **Wastewater treatment plant (WWTP).** Circular economy approach can be integrated within the wastewater treatment by means of the "**Biorefinery**" concept. It is centred on the conversion of the organic carbon and nutrients in the wastewater stream to value added products, together with clean or 'fit for use' water as a product. The "Biorefinery" concept is increasingly recognised for its potential to enhance resource productivity and its contribution to the bio-based economy.

Energy

Circularity can be centred on two overarching principles:

- **Energy efficiency** to maximize product use. For example, it can be cited the **industrial symbiosis** for facilitating cross-sectoral energy and material exchange.

- **Energy generation**, including the recovery of by-products and waste. For example, the **production of biofuel based on black liquor from the paper industry**. At building level, bio-waste can be treated for **biogas** production. Finally, the "**Contingent approach**" guarantees the energy saving/production. This solution is based on GIS data of buildings and supports the upscaling of renovation solutions by identifying the specific buildings, within the building stock, where a previously successfully applied solution can be repeated. For municipalities, this can be an instrument to plan and operationalize energy transition plans.

Food

While the food value chain is responsible for significant resource and environmental pressures, an estimated **20% of the total food produced is lost or wasted in the EU**. Therefore, in line with the Sustainable Development Goals and as part of the review of Directive 2008/98/EC38 referred to in section 4.1, the Commission will propose a target on food waste reduction, as a key action under the forthcoming EU Farm-to-Fork Strategy, which will address comprehensively the **food value chain**.

[43] https://redi.eu/greywater-recovery-system/

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To design and implement **circular food cities** it is important to first assess food-related flows going into and leaving the city. **Urban Metabolism Mapping** can help to better understand these flows. Another important step towards circular flows in the food industry is the implementation of regenerative agriculture practices. Also, in order to reduce losses, it is necessary to know how the waste is generated, either food waste or human waste. Valuable nutrients and chemicals can be extracted and then used as fertilizers, plastic, chemical or textile feedstock, food compounds, or for animal feed.

Finally, in order to encompass the full value chain of producing food for human consumption, it is necessary to find and use alternative protein sources. While alternative proteins are studied, the easiest shift in the consumers' diet is to exchange meat with fish intake. Nevertheless, this higher consumption must be done avoiding overfishing and improving the current catching processes: fish by-catch and discards account for approx. 30% of the total world capture fisheries, which translates into approximately 30 M of tons of the available resources, not utilized for human food products.

Besides the listed solutions, Material Economics have further analysed solutions in the food and construction sector. See section 7 ANNEX: Circular economy analysis.

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Table 5: Circular Economy solutions

Circular Economy			https://netzerocities.app/resource-2615
WASTE	Municipal solid waste (MSW)	MSW separation at source (district level): Smart waste: pay-as-you-throw	https://netzerocities.app/resource-2169
		MSW treatment: anaerobic digestion for biogas production	https://netzerocities.app/resource-2257
		Urban biodegradable waste for compost	https://netzerocities.app/resource-2291
	Textiles	Urban recovery and processing techniques, waste to feedstock optimization	https://netzerocities.app/resource-2301
	Electronics and ICT	New processes and strategies for the recovery of Critical Raw Materials	https://netzerocities.app/resource-2315
	Batteries and vehicles	System level circular economy (CE) approaches in batteries	https://netzerocities.app/resource-2383
	Plastics	Plastic waste management	https://netzerocities.app/resource-2421
		Expanding the use of bio-based and compostable materials	https://netzerocities.app/resource-2439
	Packaging	Reducing demand for (over)packaging/ packaging waste, improved circular design and strategies that fully replace the need for packaging	https://netzerocities.app/resource-2453
	Construction and Buildings	Optimal management of waste at the end of building life cycle	https://netzerocities.app/resource-2467
		Re-using local building waste (e.g., local waste material bank)	https://netzerocities.app/resource-2477
		Residual Value Calculator for construction parts/material, consumers products etc.	https://netzerocities.app/resource-2487
		Online register with building and infrastructure material/parts/products for reuse/circular use	https://netzerocities.app/resource-2498
		Urban mining model to assess circular construction opportunities and optimize resource use and exchange	https://netzerocities.app/resource-2508
		Circular Life Cycle Cost (C-LCC) for deep renovation	https://netzerocities.app/resource-2518
	Other waste products	Reduction of raw materials, waste and integration of secondary materials	https://netzerocities.app/resource-2532
WATER	Building level	Greywater and rainwater reuse at building level	https://netzerocities.app/resource-2543
		Efficient treatment and reuse of un-segregated water at building level	https://netzerocities.app/resource-2554
ENERGY	Energy Efficiency	Industrial symbiosis assessment and solution pathways for facilitating cross-sectoral energy and material exchange	https://netzerocities.app/resource-2564
	Energy Generation – RES	Energy/ production of biofuel based on black liquor from the paper industry	https://netzerocities.app/resource-2574
		Waste to energy in buildings	https://netzerocities.app/resource-2584
		Guarantee the energy saving/production in buildings: "Contingent approach"	https://netzerocities.app/resource-2594
FOOD		Circularity food cities	https://netzerocities.app/resource-2604
		Encompassing the full value chain of producing food for human consumption - valorisation of low value fish species	https://netzerocities.app/resource-2614

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2.6 Nature-based Solutions and Carbon sinks

- **Knowledge Repository: Nature-based solutions**: https://netzerocities.app/resource-2644

Lead	**CARTIF**
Contributors	South Pole, METABOLIC, Resilient Cities Network, CEREMA, Tecnalia, LGI

As shown in the Net-Zero Emissions by 2050 Scenario[44] of the IEA, to reach climate neutrality by 2050 part of the emissions will need to be offset with **carbon dioxide removal (CDR).** In fact, in the Info Kit for Cities is mentioned that *"If cities have GHG emissions which cannot be fully mitigated by 2030 due to technological or financial constraints, those so-called residual emissions will have to be compensated".* To **deal with residual emissions,** **carbon sinks** are the best option. They consist of remove carbon dioxide emissions through **nature-based solutions** (such as forests and soils), or/and technological solutions, such as **CDR** (carbon dioxide removal). Another option for residual emissions that the Info Kit considers are carbon credits, although it recommends to limit them and it will be subject to certain rules (see the info Kits for more information).

Urban carbon storage and sequestration, and singular green infrastructure

The focus of this thematic area is the carbon sinks and nature-based solutions. The International Union for Conservation of Nature states that **"Nature-based solutions (NBS) could provide around 30% of the cost-effective mitigation needed by 2030 to stabilise warming to below 2ºC"[45].** Furthermore, it can cut emissions from changes in land use (including agriculture, forestry and other land uses[46]) by means of the creation of **natural carbon sinks for carbon storage and sequestration**. NBS can also tackle major **societal challenges** such as the environmental degradation and biodiversity loss, water security, food security, human health, economic and social development, disaster risk reduction, or climate change mitigation and adaptation.

NBS foster coordination among sectors (e.g. infrastructures, transport, energy water, built environment and environment) and can foster cross-sectoral policies. In Helsinki the use of **urban carbon sinks** play a key role in emission compensation for its Carbon-Neutral Helsinki 2035 Action Plan, and related actions such as the **planning and green areas design** (ensuring sufficient green structures in each plot) or the **reforestation and conservation of areas and forests** in the city. Choosing the right nature-based solution to meet the diverse urban challenges will be the main issue[47], such as: **planting trees for cooling** down the streets (like in Lyon), **vertical green infrastructure** (like in Genova), **green resting areas or parks** (like in UK), **shading green structures** (like in Valladolid and Izmir), **floating gardens** (like in Liverpool), community gardens, etc. and the areas could be connected to grey infrastructure (such as **green corridors**, like in Vitoria**).**

Also, NBS can be used for **community composting**, for recycling organic solids (reducing waste diverted to landfills or costs of transport and city waste management), and use the output as fertiliser and for soil amendment in local parks and green spaces within the community area, or sold through municipal buy-back programmes, like in the city of Nitra. The green areas can be used for also **filtering water** (**green filter area,** like in Colombia) or air, through **urban garden bio-filter**, which can reduce PM and pollutants in the air (like in Valladolid).

For the **regeneration of areas that are degraded or contaminated** (like roundabouts, roadsides, etc.), **smart-soils and phytoremediation** can be used, like in Washington DC where plants detoxify a range of pollutants in Spring Valley neighbourhood.

[44] International Energy Agency (2021), Net Zero by 2050, IEA, Paris: Net Zero by 2050 Scenario - Data product - IEA.
[45] https://portals.iucn.org/library/sites/library/files/documents/2020-020-En.pdf
[46] afforestation / reforestation, enhanced weathering, biochar, soil carbon sequestration, blue carbon methods and techniques, ocean alkalinisation, and ocean fertilization.
[47] https://www.sciencedirect.com/science/article/pii/S1618866721003642

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Furthermore, with the right choice of plants and maintenance, pollinators can be increased, e.g. **pollinator verges and spaces**, like in Ohio where an integrated plan to support the 4B's was implemented to protect birds, butterflies, bees and beauty along roadsides, which are **essential to our ecosystems** and to agriculture.

Water interventions

Last but not the least, NBS can be used **for climate adaptation**, especially for **areas** that are **sensitive to droughts and floods**. To tackle this challenges the following solutions can be used:

- **Hard drainage-flood prevention**, **grassed swales and water retention pounds**, serve to slow and convey stormwater runoff promoting infiltration into the ground resulting in cleaner runoff (like in Connecticut, USA).
- **Floodable park**, serving to control flow rates and decrease flood peaks by storing excess floodwater and releasing it slowly once the risk of flooding has passed (like in Alicante, Spain).
- **Green pavements**, which are made out of a porous concrete surface that allow water to filter in the inside and absorbed by the ground (like in Delft, The Netherlands).
- **Sustainable Urban Drainage Systems (SuDS)**, which are designed to manage and use rainwater close to where it falls, on the surface and incorporating vegetation, tend to provide the greatest benefits (like in Buckland House Car Park, Hampshire, UK).
- **Water irrigation and maintenance technologies** to reduce flooding and improve water quality autonomous sensors and valves to create "smart" stormwater systems (like in Ann Arbor, Michigan, USA).
- **Constructed wetlands**, which can treated wastewater and control stormwater runoff (like in Woodcroft Estate, Sydbey, Australia).
- **Rain gardens**, which are shallow basin designed to collect, store, filter and treat runoff water (like in Lyon, France).

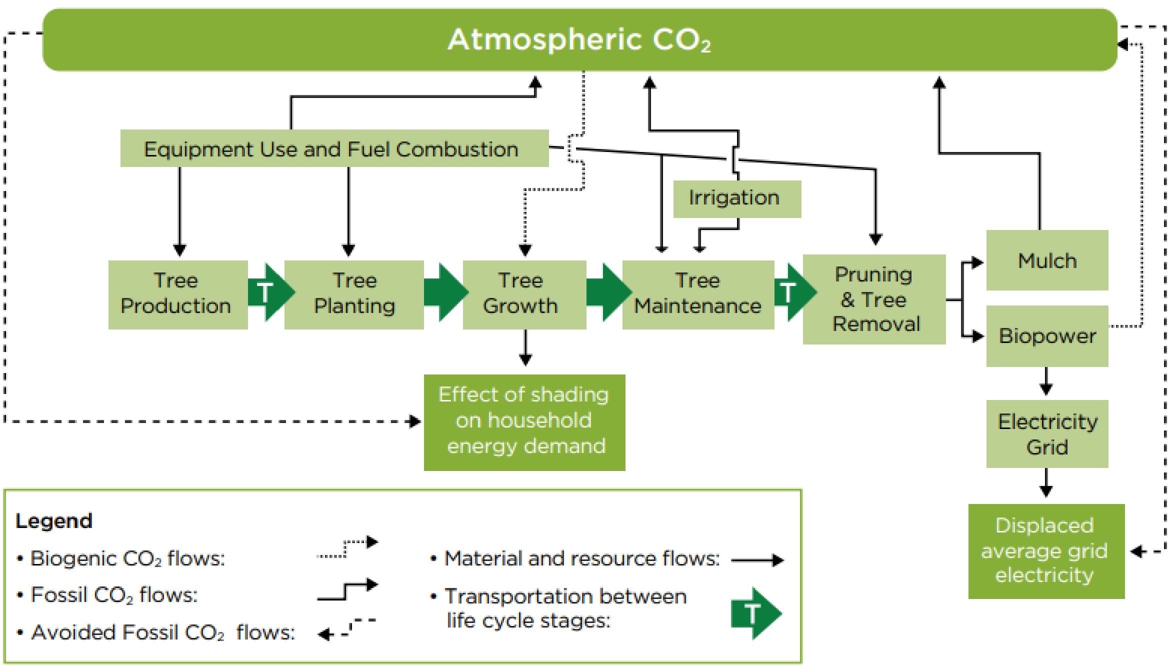

Figure 23: Carbon sequestration through urban carbon sinks (trees, etc.) in Los Angeles

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Table 6: Nature-based Solutions (NBS) solutions

Nature-based Solutions		**https://netzerocities.app/resource-2644**
Urban carbon storage and sequestration, and singular green infrastructure	Urban carbon sink	https://netzerocities.app/resource-1128
	Smart-soils and phytoremediation	https://netzerocities.app/resource-1158
	Pollinator and verges spaces	https://netzerocities.app/resource-1178
	Vertical mobile gardens	https://netzerocities.app/resource-1188
	Green shading structures	https://netzerocities.app/resource-1198
	Floating gardens	https://netzerocities.app/resource-1218
	Green filter area	https://netzerocities.app/resource-1228
	Urban garden bio-filter	https://netzerocities.app/resource-1238
	Green resting areas, parks and urban forests, parklets	https://netzerocities.app/resource-1258
	Cooling trees	https://netzerocities.app/resource-1268
	Green corridors for active and cooler mobility	https://netzerocities.app/resource-1278
	Community composting	https://netzerocities.app/resource-1298
Water interventions	Hard drainage-flood prevention	https://netzerocities.app/resource-1308
	Grassed swales and water retention pounds	https://netzerocities.app/resource-1318
	Floodable park	https://netzerocities.app/resource-1328
	Green pavements: hard drainage pavements; green parking pavements	https://netzerocities.app/resource-1348
	Sustainable Urban Drainage Systems (SuDS)	https://netzerocities.app/resource-1358
	Water irrigation and maintenance technologies	https://netzerocities.app/resource-1368
	Constructed wetland	https://netzerocities.app/resource-1378
	Rain garden	https://netzerocities.app/resource-1388

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2.7 Digital Solutions

- **Knowledge Repository: Digital Solutions:** https://netzerocities.app/resource-2645

Lead	**OASC**
Contributors	TNO, VTT, AIT

Digital Solutions can support advances in many areas of citizens' lives. According to the Global Enabling Sustainability Initiative (GESI)[48], **digitalization can improve**:

- **Healthcare and wellbeing**, by mean of t**elemedicine** (like in Norway), to support the healthcare system via phones, through the **real-time air quality monitoring** (like in the City of Cork), to warn people when the air quality is not good for sports, etc.

- **Economic development** and housing, through the sharing or peer-to-peer accommodation **platforms** (such as spareroom).

- **Engagement** and community for creating connections of **stakeholders, start-ups and citizens** through **platforms**: **citizen participation platforms** (like OpenStad), **city dashboards** (like in London), **open data platforms** (like in Tampere).

- Improve the management and operation of mobility, through **smart traffic signals** (like in Catalonia) or **mobility platforms** (like in the Stuttgart region).

- Efficiency and use of resources such as water (e.g. leakage detection), waste (e.g. **optimization of waste collection routes** (like in Barcelona), and energy (e.g. **smart buildings, smart street lighting,** like in Hamburg).

Digital technologies can have significant impact on many aspects of the move to Net Zero. In fact, as stated in '*Digital Europe - How to spend* it: *a digital investment plan for Europe report',* **digital technologies have the potential to reduce by 20% the global CO_2 emissions by 2030**[49].

The main reason for this is because of the vast amounts of data that is being generated, much of which can be captured in near real time, which allows much greater insight of the impact of human activity and of the most effective ways of reducing its negative impact of the environment. A widely quoted statistic is that 90% of world's data has been produced over the last few years. The challenge is that only 10% of the data that is being generated is being analysed (in the IEA report on ***Digitalisation and Energy***[50]).

According to the latest report of CINEA (***Digitalization in Urban Energy systems***[51]), the main challenges are: data challenges, insufficient coordination and integration, lack of capacity, limited access to finance, and digitalisation risks. Digital tools have been used in past EU projects at different levels (smart buildings, urban data platforms, etc.) but the full potential of those tools is yet to be realised, although they can be potentially disrupting with great potential for energy efficiency and resource efficiency. What can be done at city level in the short term is the following:

- Strengthen support from public authorities for data collection, access, and sharing. At the same time ensure transparency to citizens about the values from sharing data (like in Vienna).

- Focus on the local digitalisation needs (see the focus on local in EU strategies).

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[48] https://www.gesi.org/events/report-launch-digital-solutions-for-climate-action
[49] https://digital-europe-website-v1.s3.fr-par.scw.cloud/uploads/2020/10/DIGITALEUROPE_How-to-spend-it_A-digital-investment-plan-for-Europe.pdf
[50] https://www.iea.org/reports/digitalisation-and-energy
[51] https://op.europa.eu/en/publication-detail/-/publication/864bbbe7-f1d9-11ec-a534-01aa75ed71a1/language-en

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- Strengthen coordination: by helping develop communities of practice, central units for local support, and engagement of stakeholders (like in London).
- Increase investment in capacity building, to empower digitalisation capacity across city departments and across stakeholders (like in Scotland).
- Enable participation of public/private sectors and citizens in those interventions with clear financial benefits.
- Enhance the awareness among citizens of possible financing/ subsidy mechanisms.

The digital solutions cover a wide variety of topics, since they are meant to focus on **exploring opportunities to develop and improve digital connectivity and digital tools**, such as **artificial intelligence**, **IoT**, **BIM**, **Digital Twin**, **predictive modelling**, etc., in order to establish **cross-cutting enablers** for other areas. Digital solutions can provide a basis for progress in urban processes and facilitate decision-making by cities with citizens to drive action.

Analytics modelling solutions

Analytic modelling solutions can effectively support city planning and policy-making, by means of solutions such as **predictive modelling**, a crucial element for both real-time management and long-term planning of many aspects of urban areas (like in Tallinn); **digital twin** for individual buildings and wider at city level: **local digital twin**, (as being used in Helsinki); **scenario-based analysis**, which can cover multiple domains (see for instance on climate action); **Artificial Intelligence (AI) applications** (see, for instance); **GHG monitoring from space** (taking advantage of satellite-based Earth observations), see this World Bank publication; or application of **BIM** (Building Information Modelling), which combines data and 3D geometry modelling, or **CIM** (City Information Modelling), for a broader perspective (see this video).

Urban Digital Platforms

Digital Platforms at city level are another essential tool to be used to support city planning and policy-making. The solutions described in this field are meant to support cities' view and provide relevant information city open data platforms (such as the one in Vienna) on **City Platform Architecture** see the reference architecture description of the Espresso project), **CO2 Emission Trading Platforms** (such as Carbon TradeXchange or, the one developed in CIX Project), **City Dashboards** (like in València), **Predictive Maintenance supporting tools** (like in Leeds), **Advanced Renovation Support** (as part of the BEYOND project in Helsinki), or **Data and Solution Catalogues** (e.g. in Glasgow), as a local data space to share and make useful data.

Other digital solutions: digital infrastructure, disaster and resilience management, e-governance solutions

Edge computing is a type of cloud computing that takes place near to the objects of interest (unlike normal cloud computing, where the processing and storage happens in a remote site). It is specifically relevant where cloud computing meets the **IoT (Internet of Things)**, and can have several applications for a city, such as environmental monitoring.

Vulnerability and risk information systems can be also very helpful for a city disaster and resilience management (see this World Bank document), as well as **satellite and geospatial data**, which works with satellite images and geolocated data and can offer to city planners and governments to take informed decision by quantitative analysis and even predictions based on these technologies.

Citizen participation platforms are also essential in the communication and involving, collaboration and empowering of citizens. They allow citizens to take active part in city governmental decisions. Local governments are then able to tap into the ingenuity of their residents, gaining **valuable ideas**. This two-way feedback makes cities more **democratic and dynamic**. Residents can also play an active role in verifying and contributing to data. London provides a good example.

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Digital Public Goods

To establish that cross-cutting enablers in digital way for other areas, other transversal solutions are needed as well in cities, such as **data strategy** (like in Helsinki), **measurement and monitoring services** (for instance using the LORDI framework), **public Code Management** (like Dutch municipalities working with Foundation for Public Code), **documentation of ownership of data**, **application of Open Standards** (see this survey), **open Data Models & Ontologies** (like in Amsterdam), **Local Data Spaces Policy** (starting with Energy, adding Smart Cities and Mobility later on), etc.

Digital solutions can provide a basis for progress in urban processes and facilitate decision-making by cities with citizens to drive action.

It is also very important the **interoperability mechanisms and frameworks**, such as the **Living.in-EU / MIM Plus**, the European Interoperability Framework for Smart Cities and Communities (**EIF4SCC**) and the United for Smart Sustainable Cities (**U4SSC**); as well as **agile systems development**.

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Table 7: Digital solutions

Digital Solutions		**https://netzerocities.app/resource-2645**
Analytics modelling solutions	Predictive Modelling	https://netzerocities.app/resource-1955
	Digital Twin (Built environment)	https://netzerocities.app/resource-1965
	Local Digital Twin (Planning / Decision Making, cross-cutting)	https://netzerocities.app/resource-1975
	Scenario-based analysis (Mobility & Energy - One Model)	https://netzerocities.app/resource-1985
	Artificial Intelligence (AI) applications to climate neutrality	https://netzerocities.app/resource-1999
	GHG Monitoring from Space	https://netzerocities.app/resource-2013
	BIM/ CIM	https://netzerocities.app/resource-2023
Urban Digital Platforms	Platform Architecture	https://netzerocities.app/resource-2033
	CO_2 Emission Trading Platforms	https://netzerocities.app/resource-2047
	City Dashboards	https://netzerocities.app/resource-2065
	Predictive Maintenance supporting tools	https://netzerocities.app/resource-2075
	Advanced Renovation Support	https://netzerocities.app/resource-2085
	Data and Solution Catalogues	https://netzerocities.app/resource-2095
Digital infrastructure	IoT Sensor & Edge Computing for Environmental Monitoring	https://netzerocities.app/resource-2105
Disaster and Resilience Management	Vulnerability and risk information systems	https://netzerocities.app/resource-2115
	Satellite and Geospatial Data	https://netzerocities.app/resource-2125
E-governance solutions	Citizen Participation Platforms	https://netzerocities.app/resource-2139
Digital Public Goods	Data Strategy / Governance	https://netzerocities.app/resource-2149
	Measuring & Monitoring (green & digital transition)	https://netzerocities.app/resource-2159
	Public Code Management	https://netzerocities.app/resource-2183
	Documentation of ownership of data	https://netzerocities.app/resource-2193
	Applying Open Standards	https://netzerocities.app/resource-2203
	Open Data Models & Ontologies	https://netzerocities.app/resource-2213
	Local Data Spaces Policy	https://netzerocities.app/resource-2223
	Living.in-EU / MIM Plus	https://netzerocities.app/resource-2237
	European Interoperability Framework for Smart Cities and Communities: EIF4SCC	https://netzerocities.app/resource-2247
	United for Smart Sustainable Cities (U4SSC) Publications	https://netzerocities.app/resource-2267
	Agile systems development (prototyping & sandboxes)	https://netzerocities.app/resource-2277

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2.8 Enabling Instruments

- **Knowledge Repository: Enabling Instruments:** https://netzerocities.app/resource-2646

Lead	***No lead since it was distributed all over the other thematic areas working groups***
Contributors	CARTIF, Energy Cities, Tecnalia, REGEA, LGI, METABOLIC, Resilient Cities Network, South Pole, EIT Urban Mobility, TNO, Rupprecht, UITP, VTT, CEREMA, Climate KIC, POLIMI

Radically reducing greenhouse gas emissions requires urgent and transformative action at scale. Quick technological fixes are not enough. The **problems cities face in mitigating and adapting to climate change** are complex, rooted in technological, economic, financial, organisational, political, cultural and social systems. These are **all interconnected and constantly adapting to one another**, meaning their interdependencies can block necessary change. Inherited structures – such as planning policies, existing infrastructure, deeply ingrained organisational and/or individual practices and mind-sets – can reinforce the status quo and get in the way of necessary transformations.

Systems innovation means **intervening across existing systems, in a coordinated way, to unlock pathways towards climate-neutrality**. To do this, a deep understanding of local systems is necessary, as well as connecting climate actions in whole-city cross-sectoral portfolios and intentionally collaborating with many actors – locally and across all levels of governance.

Working on portfolios of actions across systems (across traditional divisions between technology, finance, politics/ policy/ regulation, social innovation, democracy, governance) requires working with new actors in new ways, multiplying the number of actors of change. This means focusing on impact by working collaboratively, building and orchestrating a city ecosystem where local citizens, businesses and all necessary stakeholders can contribute to the change needed.

Working across systems will need:

- Instruments to increase **Capacity Building** and **Learning** (**education**) across actors (citizens, stakeholders)
- Instruments to increase **awareness raising**, as well as to **involve, collaborate and empower**, as a higher levels of citizen and stakeholder engagement in the spectrum of participation
- **Financial** instruments
- **Planning** instruments
- **Policy** instruments
- **Regulatory** instruments
- **Technical** instruments

In this first deliverable of Task 10.2, we have only focused on few instruments very much linked with the different thematic areas (as non-technical solutions to act as driver of the other solutions). But, instruments category will be feed in a jointly manner by many other different work Packages in the NZC, such as the WP7 for the financial instruments, the WP8 for the related citizen and urban stakeholder engagement, WP9 on different instruments related to social innovation acting as driver of the rest of solutions, and WP14 for the policy and regulatory aspects.

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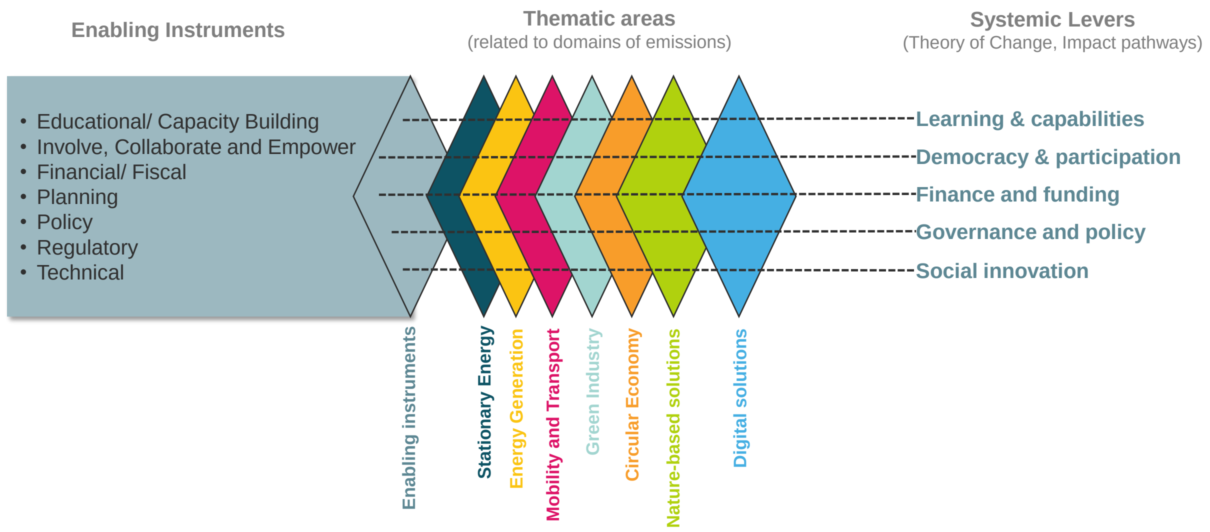

Figure 24: Relation between thematic areas addressing emission domains of emission (including enabling instruments) and the systemic levers

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Table 8: Enabling Instruments solutions

Enabling Instruments		**https://netzerocities.app/resource-2646**
Educational, Capacity Building instruments	User Engagement for Energy Performance Improvement	https://netzerocities.app/resource-1498
	Local energy communities	https://netzerocities.app/resource-618
	Cooperatives	https://netzerocities.app/resource-1508
	Educational activities on NBS	https://netzerocities.app/resource-1518
	Supporting municipalities to monitor resource flows in line with impact targets and measurement processes	https://netzerocities.app/resource-1528
	Capacity building and engagement with municipalities to identify and co-create circular solutions and roadmaps	https://netzerocities.app/resource-1548
	Capacity building for city officials to understand urban metabolisms and circular solution opportunities	https://netzerocities.app/resource-1568
	Capacity building and training	https://netzerocities.app/resource-1578
	Educational/ Capacity building barriers identification	https://netzerocities.app/resource-1588
Involving, Collaborating and Empowering instruments	Urban-scale environmental decision support system (DSS) based on EPC (Energy Performance Certificate) databases	https://netzerocities.app/resource-1598
	Engagement, co-creation and co-design of NBS and Green Infrastructure plans and interventions	https://netzerocities.app/resource-1608
	City coaching in NBS	https://netzerocities.app/resource-1618
	Platform for Enhancing Multi Stakeholder Dialogue to Implement NBS across EU	https://netzerocities.app/resource-1628
	Gender diversity considerations in urban mobility	https://netzerocities.app/resource-1638
Financial instruments	Loans for Energy Efficiency (EE)	https://netzerocities.app/resource-1648
	Blended finance for Energy Efficiency (EE)	https://netzerocities.app/resource-1658
	Road/ Congestion pricing in transport	https://netzerocities.app/resource-1668
Planning instruments	Integrated land use and urban planning with energy and climate	https://netzerocities.app/resource-1678
	Integrated land use planning and urban space management with mobility planning	https://netzerocities.app/resource-1688
	Integrated climate plans for cities (i.e.: SECAPs)	https://netzerocities.app/resource-1698
	Sustainable Urban Mobility Plan (SUMP)	https://netzerocities.app/resource-1708
	Decarbonisation Plans for Industry	https://netzerocities.app/resource-1718

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Enabling Instruments		**https://netzerocities.app/resource-2646**
	City water resilience assessment	https://netzerocities.app/resource-1738
Policy instruments	Governance EU Climate Neutrality Framework	https://netzerocities.app/resource-1728
Regulatory instruments	Public procurement for innovative NBS and Green Infrastructure interventions	https://netzerocities.app/resource-588
	Building Renovation Passport (BRP)	https://netzerocities.app/resource-1748
	Smart Readiness Indicator (SRI)	https://netzerocities.app/resource-1758
	Mobility Management	https://netzerocities.app/resource-1768
	Urban Vehicle Access Regulations	https://netzerocities.app/resource-1778
	Low-Emission Zones	https://netzerocities.app/resource-1788
	NBS and Green Infrastructure regulation and ordinances	https://netzerocities.app/resource-1813
	NBS and Green Infrastructure plans and strategy design and governance	https://netzerocities.app/resource-1823
	Building Material Passport (BIM-based)	https://netzerocities.app/resource-1833
Technical instruments	Turnkey Retrofit service	https://netzerocities.app/resource-1843
	Integrated Energy and GHGs scenario mapping tools	https://netzerocities.app/resource-1853
	NBS and Green Infrastructure Mapping	https://netzerocities.app/resource-1863
	Analysis of City/ (Building) circularity	https://netzerocities.app/resource-1873
	Circular economy design principles to increase the durability, reparability, upgradability or reusability of products	https://netzerocities.app/resource-1883
	Urban metabolism mapping	https://netzerocities.app/resource-1893
	Circular Life Cycle Assessment/Analysis for material and products	https://netzerocities.app/resource-1903
	One-stop-shop for building renovation	https://netzerocities.app/resource-1913
	User Engagement for Energy Performance Improvement	https://netzerocities.app/resource-1498

3 Co-benefits

Cities will need to link local actions (across domains of emissions and sectors) for climate neutrality with their indirect positive impacts in other areas and sectors, i.e. with their co-benefits. The identification of these co-benefits will help to develop "ownership" of the overall climate neutrality objective and thereby induce stronger local commitment and behaviour change[52]. For example, electrifying the mobility sector leads to environmental and economic co-benefits, such as clean air and lower congestion, but it also leads to indirect co-benefits on the public health system (more clean air leads to less respiratory diseases and less costs in the health system).

Co-benefits are meant to measure or point out an indirect impact from the implementation of a certain solution. It could lead to an indirect reduction of GHG emissions or just as an additional positive impact in other field (e.g. in society, in economy, etc.) as a result of climate neutrality.

The experts of Net Zero Cities have mapped and categorised the following co-benefits (See Figure 25):

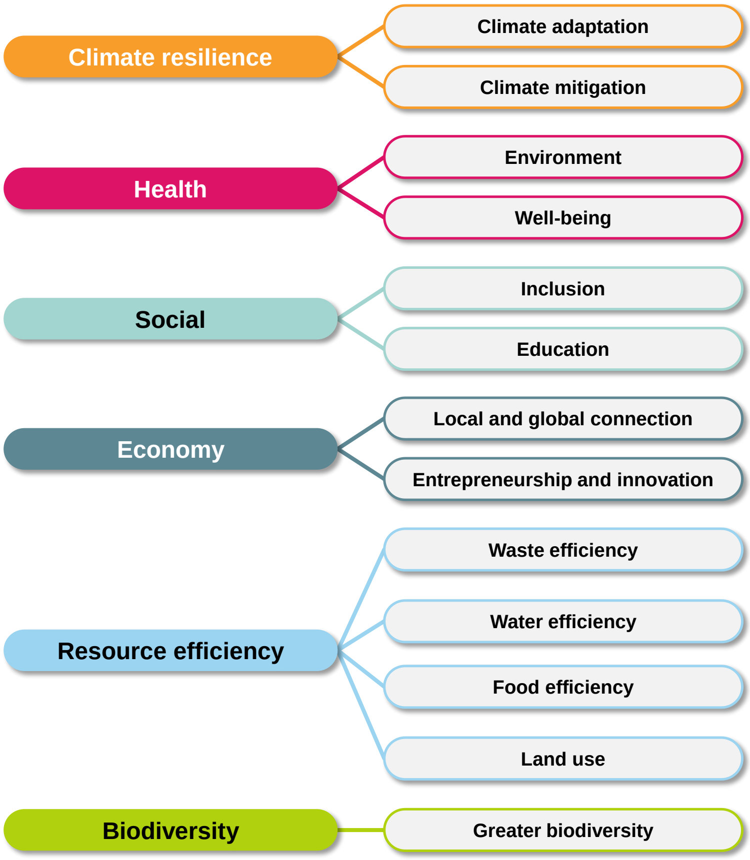

Figure 25: NetZeroCities Co-benefits definition

Further details on what each category and sub-category for the defined co-benefits can be seen in the Table 9, this helps understanding what is behind each co-benefit and the kind of elements or related benefits that includes when defining it for a solution.

52 https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_eu-mission-climate-neutral-cities-infokit.pdf

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Table 9: Detailed relation of co-benefits

Climate resilience	**Climate adaptation**	• Reduce risk to natural and climate hazards • Enhance stability of the urban infrastructure
	Climate mitigation	• Reduce GHG emissions • Reduce energy needs • Increase access to clean, affordable and secure energy • Increase carbon sequestration capacity
Health	**Environment**	• Improve air quality • Reduce noise pollution • Reduce hot spots/urban heat islands • Reduction of road danger
	Well-being	• Enhance attractiveness of the cities • Healthier and more attractive lifestyles • Better physical activity of individuals • Better access to living areas
Social	**Inclusion**	• Social cohesion • Social capacity building • Enhance citizen participation, connectivity and community
	Education	• Improve access to information • Raise awareness/behavioural change • Increase skill development • Improve access to job opportunities
Economy	**Local and global connection**	• Boost local business (km 0) • Proximity economy • Sharing economy
	Entrepreneurship and innovation	• Increase employment rate and jobs • Increase technological readiness • Decrease future maintenance costs
Resource efficiency	**Waste efficiency**	• Better waste management • Promote the materials cycle
	Water efficiency	• Better water quality • Better water management
	Food efficiency	• Sustainable and resilient food systems • Reduce food waste
	Land use	• Improve land use management • Improve soil health
Biodiversity	**Greater biodiversity**	• Species increase • Pollinator increase • Increase ecological connectivity • Reduce risk of epidemics • Reduce ecological footprint • Green awareness

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4 Solution Factsheet

The initial idea of the task (see Figure 26 below), which is both to delve into State-of-the-Art solutions and to create a consistent catalogue of solutions for cities. From this idea, WP10 the created a template for developing such a catalogue in a coherent and consistent manner.

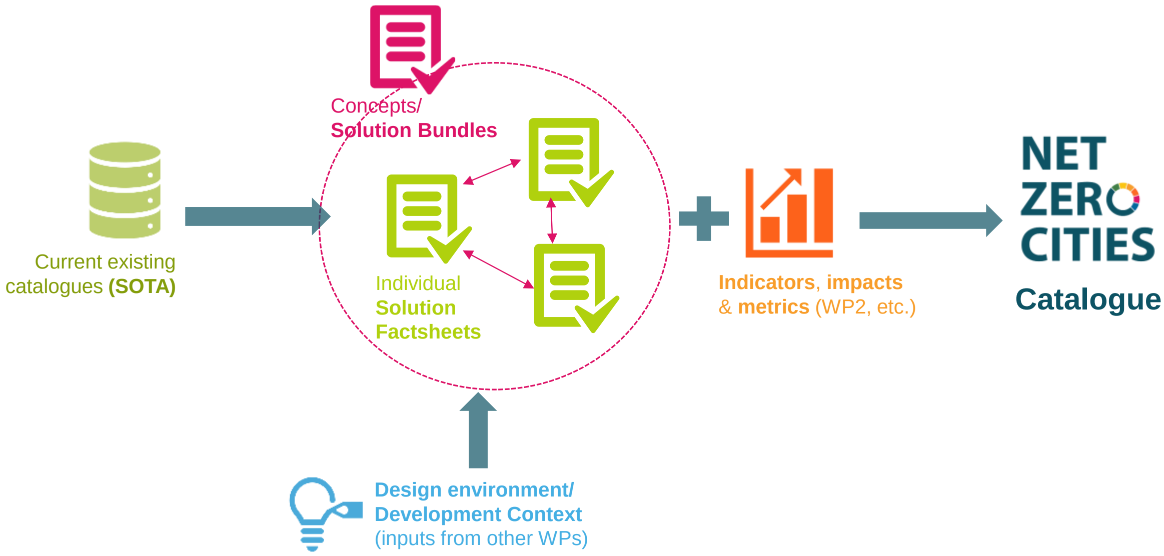

Figure 26: Catalogue of solutions for the NZC Knowledge Repository structure from WP10's perspective

For each solution, the template includes:

- "**Orange**" fields:
  - Name
  - **Description**
  - Technology Readiness Level (**TRL**)
  - Thematic areas involved (and categories within them)
  - Related **co-benefits**
  - Relationships with other solutions (keywords)
  - **Visuals**, as attractive visual aid (images, diagrams…)
  - **External links** (including references, examples or case studies…)

- "**Pink**" fields:
  - **Instruments** or Processes for implementation
  - **Pre-conditions** and enabling conditions
  - **Constraints** or barriers for implementation
  - **Drawbacks** or adverse impacts of the solutions –after implementation– (based on "what went wrong" in some examples or case studies)
  - **Impacts**, including relevant indicators (e.g. estimation of investment costs, operational costs and estimation of GHG emissions reduction; based on the impact of some examples/ case studies) and DNSH (do no significant harm) considerations.

This was thoroughly discussed within the experts in WP10, and after a feedback process and maturing of the ideas, this was the final structure that has been filled by the WP10 partners. It needs to be taken into account that, according to the Grant Agreement schedule, the initial part of our task was to focus only on the "orange" fields from the template (those with a more general description of the solution, including co-benefits, external links with examples and some visuals), leaving the "pink" ones (those related with the enabling conditions, i.e. ideal design environment, constraints/barriers and drawbacks/pros/cons of the solutions; as well as the target audience of the Factsheet) for a next iteration (next deadline of Task 10.2, which is the D10.3 for March 2023).

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After the Template definition, we established contact and conversations with **JRC to collaborate** on the development of this solutions catalogue. Thus, and since from WP10 we were more advanced in the process of defining the taxonomy, solutions and partners contributing, it was decided that **WP10 partners complete the "orange" fields**, and then, it was shared with JRC by end of June 2022. Then, **JRC**, building upon the general description of the solutions already provided in the first part of the template**, contributed to the "pink" fields of the template** (except the last one of impacts).

Figures below detail the different template fields within the Factsheet, as well as the general instructions that were provided to have a common approach and result for all the resources.

SOLUTION FACTSHEET NET ZERO CITIES

SOLUTION	**Name in short version**		
DESCRIPTION	**Description of the solution**, why is it useful, what can be achieved by deploying the solution, how it can be connected with other solutions/areas, etc. - *Minimum of 100 words* - ***Maximum of 200** /300 words*		
MATURITY	*Two options: I **nnovative solution** (Tested in pilots* or ***Solution in the market** (already tested)*		
THEMATIC AREA(S)	**Thematic area**	*Add more thematic areas if necessary*	…
CATEGORIES	*Add related categories to the above thematic areas*	…	…
	…	…	…
CO-BENEFITS	Text explaining the relation of co-benefits that the solution has (**co-benefits** from the list highlighted in **bold text**)		
KEYWORDS	ADD other solutions with **direct connection** with the present one or that can have an **indirect connection** (i.e. to form a package or bundle of solution, to form a concept or an integrated solution).		
	ADD initial ideas on the possible connections that the solution can have with solutions and developments from **other WPs**: **WP7** (financing models), **WP8** (citizen and urban stakeholder engagement), **WP9** (social innovation), **WP14** (policy and regulation aspects). ***This will be revisit and be the basis to build the links with the different resources in the Platform.***		
VISUAL	ADD **attractive visual aid** (images, videos, diagrams…) - *At least one visual reference!*		
EXTERNAL LINKS	ADD **external links to websites**, other catalogues (if in PDF, indicate page), or Case Studies (**examples** of implementation in cities), with relevant related information - *When possible, add **at least two external sources** of information/references* - *When possible, add **more than one example***		

Figure 27: Template for the Solution Factsheets (orange fields) with instructions to fill it in

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INSTRUMENTS/ Processes for implementation	Instruments that can help as **enablers** to deploy or promote the implementation of such solutions *Linked (and to be further linked) to second part of keywords (* ***other NZC WPs' resources*** *)*
PRE-CONDITIONS & ENABLING CONDITIONS	**Potential enablers, conditions for success** (political, economical, governance, social, legal, technical, etc.) OR **what is needed in the city environment ideally** (prior to the implementation) to ensure a successful implementation of the solution
CONSTRAINTS/ BARRIERS FOR IMPLEMENTATION	**Main barriers/ obstacles** that should be considered and what are the most typical barriers found that **can hinder the implementation** of the solution
DRAWBACKS/ ADVERSE IMPACTS OF THE SOLUTIONS after implementation	**What went wrong** in some Case Studies/examples, what can be wrong with the implementation of the solution.
IMPACTS (Indicators + DNSH)	Relevant indicators related to **investment costs**, **operational costs** and estimation to measure the impact of the solution in terms of **GHG emissions reduction.** *To be linked in a second stage with developments in WP2 (MEL, metrics and NZC indicator framework)*
	General considerations to be taken into account for the **Do No Significant Harm (DNSH)** principle. Risks infriging the DNSH principle (to the environmental objectives of the EU) when deploying in a city environment.

Figure 28: Template for the Solution Factsheets (pink fields) with instructions to fill it in

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5 Innovation ecosystem mapping

Local innovation ecosystems play a key role towards climate neutrality, as helps towards:

- **underpin innovation** in cities in various sectors;
- **enabling environments** to exchange (co-working spaces), to iterate;
- being **test beds for generation solutions** that address local challenges;
- **raising awareness** and acceptance of local needs;
- creating **local innovative business models** to sustain the transition;
- offering **citizens** the opportunity to gain **new roles as co-innovators-explorers**, **ideators**, designers and diffusers (and create jobs).

The Mission platform will integrate a **map of incubators and accelerators in cities in all sectors** (energy, mobility, buildings, circular economy, etc.), which will help cities to know their possibilities for engagement and for setting up specific programmes towards climate neutrality. To integrate that, both LGI and CKIC conducted a review of innovation ecosystems to detect solutions being developed by start-ups and innovative SMEs in the relevant fields. The main categories will be: incubators, accelerators and start-up studies (see Table 10). Incubators carry on the development of a start-up, helping it through various tools, while accelerators come into play at a more advanced stage, namely when the start-up has already defined its business model and announced a product or service. Accelerator programmes generally have a fixed duration (usually six months or one year) and are mostly managed by private funds. The incubator provides long-term services by supporting itself through different business models while almost all accelerators invest in start-ups and usually do the investment in exchange for equity. Mainly, start-up studios develop their ideas internally and have a niche focus, while accelerators and incubators can have a broader scope.

Table 10: Innovation ecosystem mapping categories

INCUBATOR	ACCELERATOR	START UP STUDIOS
Business incubators are companies that offer 'protected environments' in which start-ups, new companies, companies wanting to open a new business unit and professionals can benefit from a range of services and resources to support their growth.	Start-up accelerators (or seed accelerators) are collaborative programmes aimed at accelerating the development of start-ups and enterprises. These programmes, which include mentorship, training, networking, sharing of workstations, may end with a public pitch event or demo day.	Start-up studios' teams are not just coaches or advisors. They are also executors. They build start-ups from the ground up. They study if there is a real market needs for their ideas, and then they hire an external individual who will become the start-up's CEO. The CEO of this newly founded company will obtain a share of the start-up's equity.

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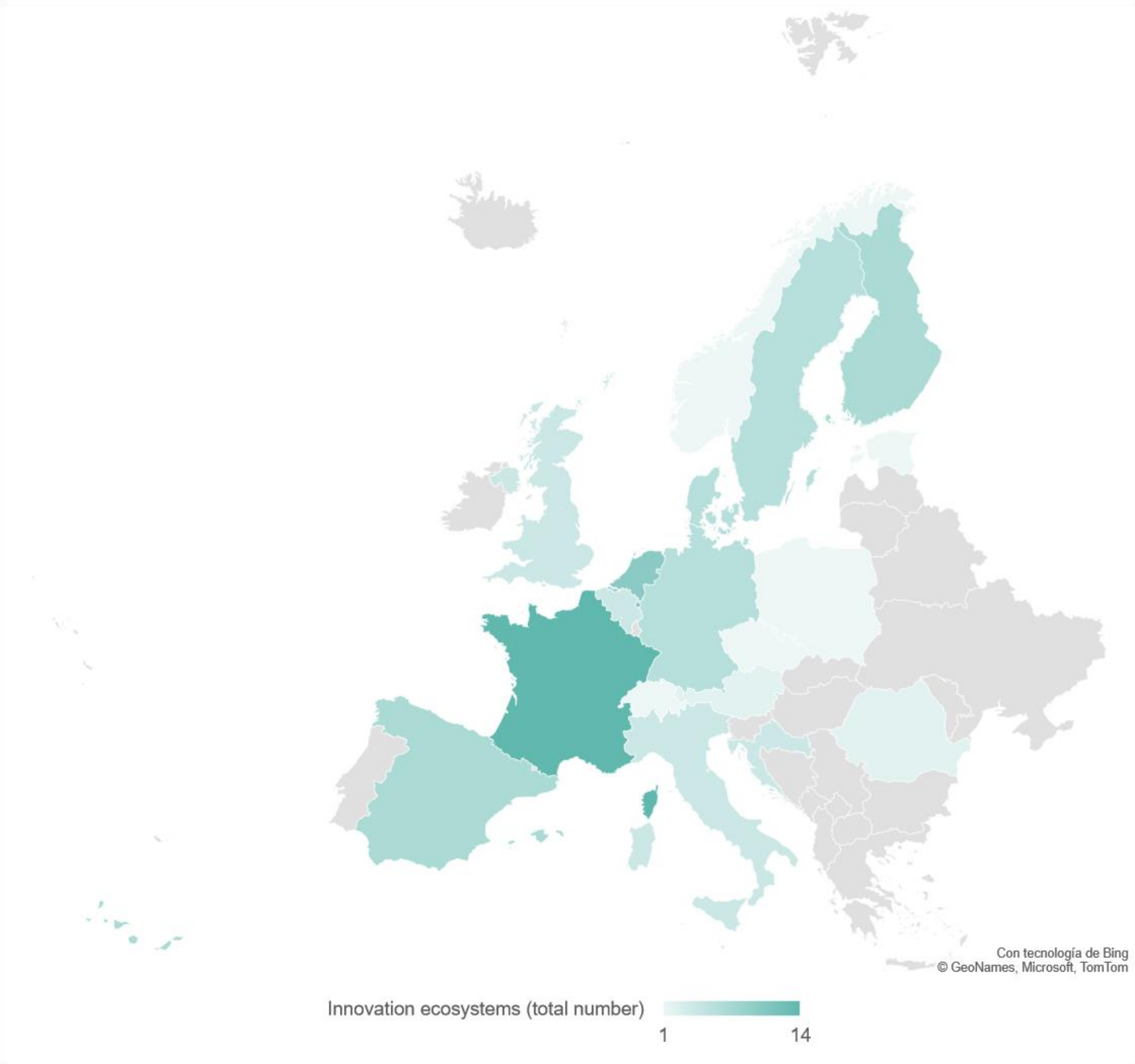

Figure 29: Innovation ecosystem mapped. Note that: the portal will be continuously updated, and this map will be further populated

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6 Next Steps

Task 10.2 "*Analysis of solutions, co-benefits and barriers to adoption"* is aimed to last 6 more months after this submission (until March 2023). This Task will finish with the submission of Deliverable 10.3 "*Design environment of solutions",* which will be an update of the present catalogue, including further information on the solutions:

- Adding the JRC's contribution to the Solutions, which consist of (and prior revision by RTD):
  - in some cases, a review of the "**orange**" fields;
  - "**pink**" fields development: **Instruments** or Processes for implementation, **Pre-conditions** and enabling conditions, **Constraints** or barriers for implementation, **Drawbacks** or adverse impacts of the solutions.
- WP10 partners will include the **impacts**, which is mainly the inclusion of **relevant indicators** (with input from WP2 indicators' set), mainly focusing on an estimation of investment costs, operational costs and estimation of potential GHG emission reduction, based on the impact and figures of some examples/ case studies that have implemented such solution. This field will include as well the **DNSH** (Do No Significant Harm) **principle considerations**, focusing on identifying risks that infringing the DNSH principle (to the environmental objectives of the EU) when deploying in a city environment, and recommendations to avoid it.
- WP10 partners will complement the rest of "**pink**" fields when necessary (if JRC's contribution is missing some of them or whether the JRC did not cover a certain solution).
- WP10 partners, together with the partners in the other NZC WPs, will establish links between the different resources added in the Knowledge Repository, mainly:
  - In the field of **Instruments or processes for implementation** within the Solution Factsheets, links can be added across WPs for such instruments that help in the implementation of solutions, e.g. **financial and funding mechanisms and instruments** can be linked with the resources from **WP7**, **citizen and stakeholder engagement methods** can be linked with resources from **WP8**, **social innovation methods or case studies** (as examples) can be linked with resources from **WP9**.
  - In the field of **Preconditions and enabling conditions** within the Solution Factsheets, links can be established with the resources from **T14.4 "*Policy Framework*"**. This preconditions field describes the "ideal" design environment (before implementing a solution) that helps a city to implement such specific solution according to their city context. Policy plays a key role here for promoting and supporting the use of a solution. Thus, an alignment between the WP10 taxonomy and thematic areas and the Policy Framework being developed in task 14.4 was established from the beginning, so as to then create such links between the solutions and specific policies (at EU level, national level, regional or local level…).
- WP10 partners will create the **Solution Bundles**, which consist of grouping a set of solutions across the different thematic areas focusing on achieving an objective related to climate neutrality. This comes from the logic that to achieve a greater impact in a city, to implement a combination of solutions is needed. The work on the Solution Bundles has already started, and it will be further worked in the coming months; and main progress and ideas on this is depicted below.

The timeline for the next months of the Task 10.2 "*Analysis of Solutions, co-benefits and barriers to adoption*" can be seen in the following Figure 30.

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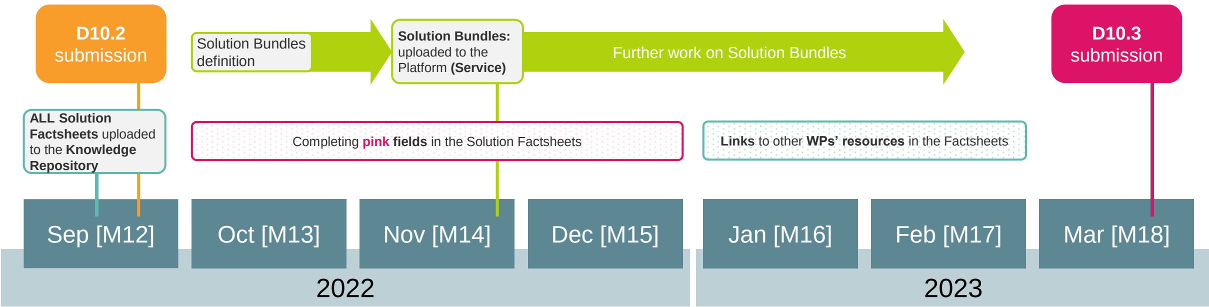

Figure 30: Task 10.2 timeline after the D10.2 submission (work for the next 6 months)

SOLUTION BUNDLES

The IEA in their latest report "Net zero by 2050" analysed the different mitigation measures that could lead to reach climate neutrality by 2050. The identified key solutions are the following:

- Energy efficiency
- Electrification and renewable energy technologies
- Bioenergy (sustainable)
- CCUS
- Hydrogen and hydrogen-based fuels
- Behavioural change: eco driving, improvement of average space heating and cooling temperatures, sustainable mobility, etc.

Following the IPCC report summary approach, which is aligned also to what is stated in the Info Kit for Mission Cities, climate neutrality should be reached by:

- Using energy and materials efficiently;
- Electrification (considering the electricity sources and demand);
- Carbon capture

Taking this into account, we organised a **co-creation Workshop** to define the themes or objectives around which the Solution Bundles would be. Each **Solution Bundle** is aimed to inspire **cities** towards **reaching climate neutrality, by grouping solutions together and analysing the synergies between solutions**, their **carbon abatement** as well as the **co-benefits that can come with it.**

As a result, the following bundles were defined:

- **RES Generation – Low Carbon Electrification**: focusing on RES generation, all **sectors are electrified and connected** in a smart way with low carbon technologies.

- **RES Generation – Low Carbon Energy via Sector Coupling**: it focuses on the importance of connecting sectors through the different energy streams (heating, cooling, fuels, and electricity), and, **when electrification is not possible**, other fuels (such as **hydrogen**) will be used. Circular Economy is seen as cross-cutting and a way of **reusing waste** from one sector to another.

- **Energy Efficiency – Reduction of Energy and Resources needs**: mainly focusing on **"passive" solutions** towards the **reduction of energy needs in the built environment**, as well as incorporating the **circular economy approach** to include the **resource efficiency** as well.

- **Carbon Capture, Storage and Removal**: focused on the **reduction of energy needs in the built environment through carbon sinks**, as well as on **removing residual emissions** from the power, transport and industry sector.

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Conclusions

For cities to reach net zero emissions, transformational change in all sectors is required. Addressing emission sources is central to this challenge. Fortunately, there are a range of **technologies and innovative solutions** that can be implemented and deployed to **drastically cut these emissions**. These technologies and solutions cover all emission domains, including buildings, industry and transport, waste treatment (both solid waste and wastewater), agriculture and forestry, and, of course, energy from fossil fuels (whether from the power grid energy supply or district heating networks, or other).

Having said this, the purpose of the present document is to provide this overview of **solutions to address the reduction in emissions across all sectors in cities**. These solutions were classified in **Thematic Areas**, and a whole classification and taxonomy was created around them, to define the complete set of solutions within them. All this information is available in the **Knowledge Repository** of the Mission Platform (https://netzerocities.app/knowledge); which has been added in the form of resources (Factsheets) for the single solutions, and in the form of "**Articles**" for the thematic areas, which act as a "**nodes**" that connect all solutions defined inside them.

Thematic areas are:

- **Stationary Energy** (Buildings): https://netzerocities.app/resource-327
- **Energy Generation**: https://netzerocities.app/resource-338
- **Mobility and Transport**: https://netzerocities.app/resource-2488
- **Green Industry**: https://netzerocities.app/resource-2643
- **Circular Economy**: https://netzerocities.app/resource-2615
- **Nature-based solutions**: https://netzerocities.app/resource-2644
- **Digital Solutions**: https://netzerocities.app/resource-2645
- **Enabling Instruments**: https://netzerocities.app/resource-2646

Cities need to link local actions (across domains of emissions and sectors) for climate neutrality with their indirect positive impacts on other areas and sectors, i.e. with their **co-benefits**. The identification of these co-benefits have been mapped for each solution, according to the classification made within WP10 for the whole NZC project. It includes as main or high level categories of co-benefits:

- **Climate resilience**, including both climate adaptation and mitigation.
- **Health**, including environment and well-being.
- **Social**, including inclusion and education.
- **Economy**, including local and global connection and entrepreneurship and innovation.
- **Resource efficiency**, which includes waste, water and food efficiency, as well as land use.
- **Biodiversity**, referred to a greater biodiversity.

Each solution uploaded to the Knowledge Repository contains, at least, information on: **description**, **thematic areas** involved, other related tags, **co-benefits**, relationship with other solutions (keywords), **visuals** (images, diagrams…), **external links** (both for references and for examples or case studies of implemented solution). In **further steps**, during the next months, additional information will be added to them, related to instruments (or processes that help the implementation), pre-conditions and enabling conditions, constraints or barriers for implementation, drawbacks or adverse impacts of the solutions, and impacts (including relevant indicators and DNSH considerations).

Next steps include as well the establishment of **links between the Solution Factsheets and the resources from other Work Packages**, referring to financial and funding instruments, citizens and stakeholders engagement methods, social innovation methods (and case studies for examples), as well as to policy frameworks. The other next step is the creation and definition of the **Solution Bundles**, as groups of solutions that can be implemented together in relation to a higher relevant objective (Low carbon electrification; Low carbon energy via sector coupling; Reduction of energy and resources needs; and Carbon capture, storage and removal).

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

The present document delves also in **mapping incubators and accelerators in cities in all sectors**, to help cities to know their possibilities for engagement and for setting up specific programmes towards climate neutrality, since it should not be forgotten the importance of the local challenges, business models and conditions/ context.

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

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7 ANNEX: Circular economy analysis

To date, European policies have focused mainly on the **supply side**, with measures oriented to the increase of the energy efficiency or the deployment of low-carbon energy sources. However, the decarbonisation of the economy requires additional strategies in the **demand side**, in order to make a better use of the materials produced and so, reduce the need for new production. Circular economy offers this **integrated and systemic approach** through strategies such as recirculating a larger share of materials, reducing waste in production, light-weighting products and structures, extending the lifetimes of products, or deploying new business models. According to the 2018 report "Material Economics. The Circular Economy a Powerful Force for Climate Mitigation" a more circular economy can cut emissions from heavy industry (plastics, steel, cement or aluminium) by 56% by 2050.

Three circular-economy strategies have been defined to cut emissions from materials and products:

- Material recirculation — reducing emission intensity per tonne of material.
- Product material efficiency — using less materials per product.
- New circular business models — fewer products to achieve the same useful service.

These strategies can support to close the loop in material streams and move from linear value chains towards circular approaches as shown in Figure 31.

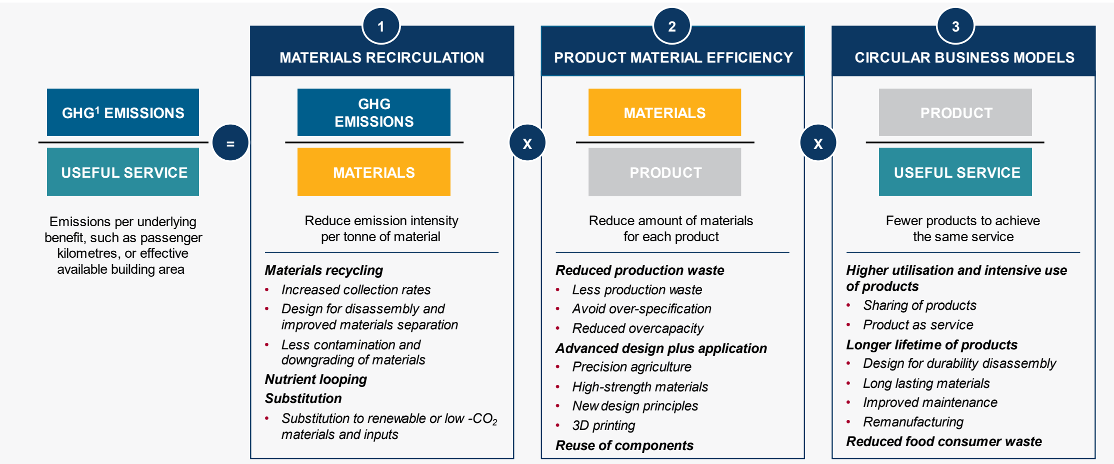

Figure 31: Three circular economy strategies work together to cut emissions from materials and products[53]

Four solutions can be considered for **food circularity** in cities:

Reduction of food waste
Various players can reduce food waste along the value chain for food, especially those located in cities. For example, retailers can better match supply with fluctuating demand for different food types, discounting soon-to-expire products and using products that have gone beyond their shelf-life date in in-store restaurants. Innovative companies can develop **new business models**: for example, MIWA provides an online service for customers to buy precise amounts of food in reusable packaging, allowing customers in the Czech Republic to avoid food waste. Food brands can use 'ugly' fruits and vegetables as ingredients for food products, such as baby food and spreads, while also ensuring expiration dates reflect the actual shelf-life of products. **Digital technology and supporting policy initiatives** can play an essential role in ensuring surplus edible food is redistributed for human consumption, helping divert food waste from landfills, and providing high-quality nutrition to food-insecure neighbourhoods. Redistribution initiatives are already being championed by organisations such as Feedback (UK) and Food Shift (US), enabled through digital platforms such as Denmark's

[53] Material Economics, 2018, "The Circular Economy - A Powerful Force for Climate Mitigation".

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Too Good to Go. Scaling up these types of interventions, combined with essential measures to encourage behavioural change, can reduce edible food waste by 50% by 2030, with a potential annual emissions reduction from across the food value chain totalling 1.4 billion tonnes/CO_2e
→ Circularity food cities

Composting by-products and green waste (nutrient looping)
Composting by-products and green waste is mainly an aerobic process that generates CO_2, which has a much lower global warming potential than methane. Besides carbon, compost contains other nutrients that can nourish and strengthen soils, so using compost in food growing can mean fewer chemical fertilisers and less irrigation are required. This consequently reduces emissions in sectors such as mining (mineral extraction), industry (ammonia production), and energy (pumping power for irrigation). In previous work, the emissions-reduction potential has been modelled as 0.3 Gt CO_2e per year in 2050 based on the high organic material recovery potential (>70%) demonstrated by cities such as San Francisco.
→ Urban biodegradable waste for compost

Regenerative farming
Regenerative natural systems represent the most significant opportunity to turn the food system from a major contributor to climate change to a prominent actor in the solution. The broad definition of regenerative farming is growing food to improve soil health, agrobiodiversity, and local ecosystems. How this is done in practice depends on the context, scale, and other factors. However, all approaches share a mindset that views the farm as part of a larger mutually supportive ecosystem and the critical importance of building soil organic content. The latter's effect improves the soil's physical structure and nurtures beneficial microbes, leading to a cascade of system benefits: carbon sequestration, better water retention, and reduced reliance on synthetic fertilisers. On pastureland, the main drive is to build organic matter levels on the land using livestock and plant growth. One way to achieve this is through managed grazing (modelled for this paper, see below) or other methods such as silvopasture that integrate tree crops within the grazing area. For cropland, carbon benefits are achieved by minimising soil disturbance and reducing or even eliminating synthetic inputs. Croplands can also sequester carbon in the root mass of perennial crops or by applying organic fertilisers, biosolids, and other green wastes to the soil. Material Economics generally models the carbon benefit using a broad category of regenerative agriculture
→Circularity food cities

Diet shift
Diet shift mainly concerns eating less meat and dairy by switching to a plant-based diet. Meat and dairy production make up roughly 14% of global emissions, where, for example, beef has an emission factor of ~60 kg CO_2/kg beef, and legumes have roughly ~1 kg CO_2/kg.
→ Encompassing the full value chain of producing food for human consumption - valorisation of low value fish species

These solutions have a carbon abatement and impacts shown in the following figure:

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	Reduce food waste	Composting & high-quality processing of organic waste	Regenerative agriculture	Shift to healthy and sustainable diet
Description	• Cities can support reduction of food waste across the value-chain • Examples include incentivising discounting soon-to-expire products or redistribution initiatives	• High-quality treatment of organic waste, composting or producing e.g., biogas or methanol that can be used as low-carbon fuel	• Regenerative farming is growing food in ways that improve soil health, biodiversity, and local ecosystems • A city does not grow its own food, but can influence the food that is bought and eaten in the area	• Changing diets through behavioural change is a key solution to reduce the environmental impact of food production • Not a circular lever per se but has been included here because of its importance for climate impact
Impact on materials and CO_2	• Reduce total food that needs to be produced and transported • Food waste can generally be reduced with 50% by 2030	• Limited impact on new raw materials use • Contributes to a more circular economy for waste • Can reduce CO_2 if waste is diverted from landfill and from replacing fossil fuels	• Regenerative agriculture can significantly reduce the carbon impact and circularity of food production • Does not reduce total amount of "new" food eaten, e.g. no impact on amounts of materials	• Shifting to plant-rich diets reduce resources need even though the same amount of food is consumed • Emissions could be reduced by as much as 63% through adopting a vegetarian diet

Figure 32: Overview of four circular economy solutions to cut emissions from the consumption of food[54]

The solutions have a potential to cut emissions by around 30% from food:

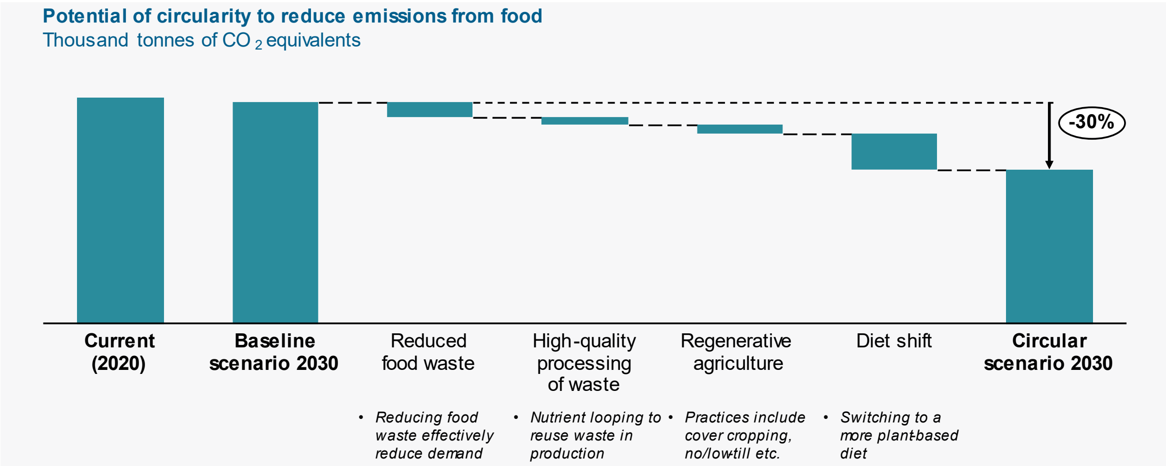

Figure 33: Circularity can cut emissions by around 30% from food[55]

[54] Solution categories and specific solution definitions may vary between publications due to different foci and circumstances of studies. For more information on circular solutions, see the report on The Circular Economy: Material Economics, 2018, "The Circular Economy - A Powerful Force for Climate Mitigation."
[55] Solutions are not independent, e.g. a heavy shift of diet reducing food waste would not be as impactful. Source: Material Economics analysis based on multiple sources: Material Economics analysis focused on the city of Amsterdam, based multiple sources including:

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In **the building a construction sector**, the following solutions can be considered:

Material efficiency building designs
Eliminating waste from building designs may appear trivial yet entails the massive potential for emissions reductions as construction projects often use more materials than is needed. For example, it is often possible to achieve the same structural strength using only 50–60% of the cement currently being used. Cities can achieve this both by reducing the cement content of concrete and by using less concrete in structures. Cities can also stimulate designing buildings with less material through less over-specification, improved design, and using high-strength materials. For example, high-strength steel, along with techniques such as post-tensioning, could reduce material needs by 30%.
→ Urban mining model to assess circular construction opportunities and optimize resource use and exchange → Circular Life Cycle Cost (C-LCC) for deep renovation

Reduce construction waste
Eliminating waste in construction could considerably reduce the input of base materials in the construction value chain. Up to 40% of urban solid waste is construction and demolition waste (CDW), and Europe currently landfills 54% of this waste. Industrialising construction processes such as **prefabricated building elements**, **offsite construction**, and **3D printing** can reduce material demand and waste generation while offering up to 60% in material cost savings. For example, moving modular construction activities offsite into a controlled environment allows manufacturers to achieve high-quality standards, high productivity and better overall waste minimisation. Compared to traditional construction, this could reduce on-site waste generation by up to 90%.
→ Residual Value Calculator for construction parts/material, consumers products etc. (as part of business model/value chain)

Recycled building materials
Recycling materials is perhaps the most well-known way to decrease the emissions from new material production. However, to scale materials recycling, it is necessary to design materials and products for disassembly and high-value recycling already from the start. This is vital to ensure that they can be used as inputs for new products when they reach their end-of-life. For the built environment, cities can apply recycling to materials that come from end-of-life buildings. Recycled aggregates generate 40–98% fewer CO_2 emissions than virgin aggregates. Designing recyclable materials, upscaling recycling volumes, and improving the quality of secondary materials would be essential for such a scenario. While this is already well-established for steel, improvements are needed to recycle cement and plastics. For plastics, mainly, designing recyclable materials within a system where products can be effectively collected, sorted, and recycled at high value will be vital in achieving the stated ambitions.
→ Optimal management of waste at the end of building life cycle → Re-using local building waste (e.g. local waste material bank) → Online register with building and infrastructure material/parts/products for reuse/circular use → Building material passport

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Reuse of building components
Reusing building materials could reduce the amount of virgin material needed to be added in the production of new buildings. Currently, only 20–30% of CDW is recycled or reused. This is often due to poor design and information about a building's material composition. Designing materials for reuse ensures that they can be reintroduced at their highest value, eliminating the need for new primary material. For example, in Amsterdam, improving the reuse of materials in the construction of 70,000 new apartments before 2040 could save 500,000 tonnes of materials
→ Re-using local building waste (e.g. local waste material bank) → Online register with building and infrastructure material/parts/products for reuse/circular use → Building material passport

Sharing business models
Sharing business models could increase the utilisation of existing buildings and thus reduce the need for new office space to be built. Today, buildings are often underutilised. In Europe, for example, 60% of office space is unused even during working hours, while 49% of homes are 'under-occupied' with at least two bedrooms in excess in the UK. In the circular economy, service-based business models, such as sharing, increase the utilisation of underused buildings, spaces, and construction components. For example, in London, peer-to-peer renting, better urban planning, office sharing, repurposed buildings, and multi-purposed buildings increase the value of new buildings and can double the utilisation of 20% of the city's buildings in 2036, saving over GBP 600 million annually
→ Residual Value Calculator for construction parts/material, consumers products etc. (as part of business model/value chain)

Prolonging the lifetime of buildings
Prolonging the lifetime of buildings is a way to reduce the amount of new material and thereby the associated emissions. A structure built traditionally has an expected technical lifespan of 50–100 years, but usually, after 20–30 years, it is not economically valuable. Demolition is often the go-to solution. In the circular economy, the economic value of a building is maintained by extending its 'functional' lifespan. Cities can stimulate longevity in buildings through modular, flexible, and durable designs. Modular design typically reuses 80% of the components in a building's exterior so that it can stand for 100 years or more, coupling modularity with durability. Such design approaches also ensure a building can be adapted to changing user needs and offer easier maintenance and renovations
→ Circular Life Cycle Cost (C-LCC) for deep renovation

The circularity solutions have a potential to cut emissions by around 30% from the buildings sector:

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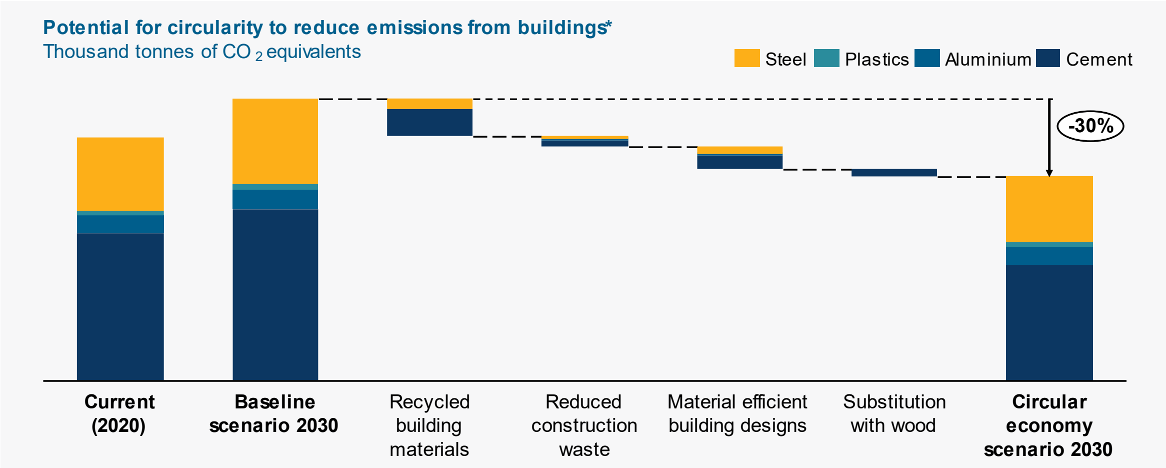

Figure 34: Circularity can cut emissions by around 30% from buildings and construction sector[56]

	Material efficient building designs	Reduced construction waste	Recycled building materials	Reuse of building components	Sharing business models	Prolonging lifetime
Description	• Construction projects often use more materials than is actually needed • It is often possible to achieve the same structural strength using only 50-60% of the amount of cement that is currently being used	• 54% of construction and demolition waste in Europe is landfilled • Industrialising construction processes (e.g., prefabricated building element and offsite construction) can reduce waste generated	• Recycling of materials from end of-life buildings • Involves designing materials for disassembly and high-value recycling to ensure that they can be used as inputs for new production	• Only 20-30% of demolition waste is recycled or reused. • This is often due to poor design and lack of information about a building's material composition	• Buildings are often underutilised. • In the circular economy, sharing increase the utilisation of underused buildings and spaces	• Structurally buildings last much longer than the time they are used • The lifespan of buildings can be stimulated through modular, flexible, and durable designs
Impact on materials and CO_2	• Reduced overspecification means less material need and consequently less CO_2 per building constructed	• Less waste would mean less procured materials and thus a smaller carbon footprint for construction	• The use of recycled materials reduces the demand for virgin materials • Recycled materials can generate 40–70% less CO_2 emissions	• Designing materials for reuse eliminates the need for new primary material • Current design initiatives will have effect after 2050 due to the long lifetime of buildings	• Lowers material demand and the carbon footprint as fewer new buildings are needed • Effects achieved in the long-term	• Reduce demand of new materials as fewer buildings are constructed (even though some materials are used to extend the functional lifetime)

Figure 35: Overview of potential solutions to cut emissions from the consumption of materials for buildings[57]

The costs of the solutions have been quantified, and Figure 36 summarises Material Economics findings in a cost curve. One axis shows the estimated cost of each measure, expressed in EUR per tonne of CO_2 avoided.

It is striking how many measures appear to be economically attractive, with low and even negative costs. Many others cost no more than 50 EUR/t CO_2, less than many other ways to reduce emissions (including many supply-side opportunities for material-related emissions). We caution that this cost curve is indicative, with many uncertainties, and must be followed up with deeper analysis to improve

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[56] Solutions are not independent, e.g. a heavy shift of diet reducing food waste would not be as impactful. Source: Material Economics analysis based on multiple sources: Material Economics analysis focused on the city of Amsterdam, based multiple sources including:

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the estimates. Moreover, ex-ante studies of this kind often fail to capture many of the technological developments that will become available. Nonetheless, the results show a clear potential for circular economy strategies to make very cost-effective contributions to a low-carbon economy.

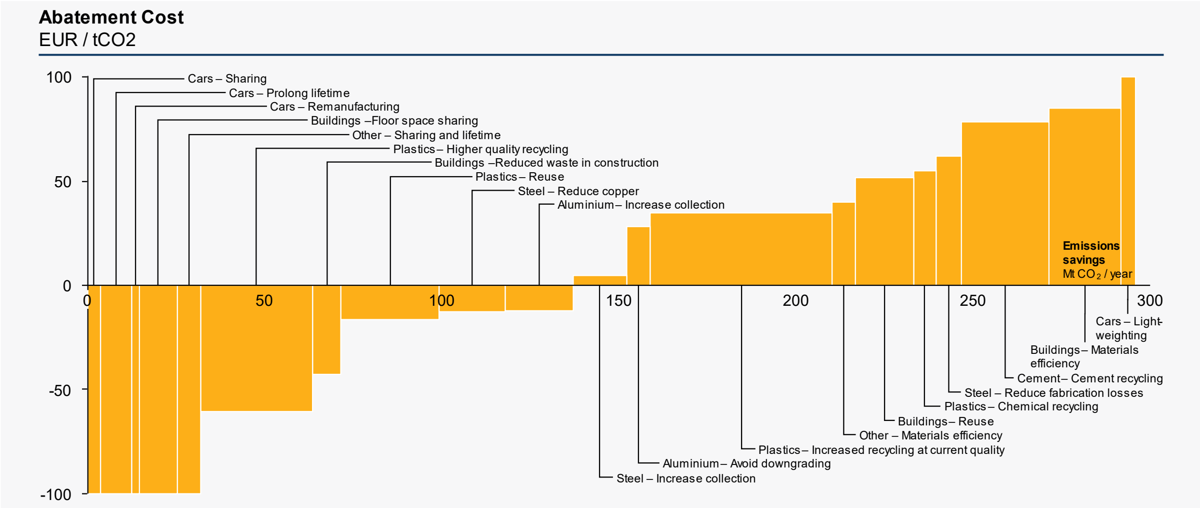

Figure 36: A first abatement cost curve for circular solutions – much of the potential is cost-effective[58]

Cities should interpret a cost curve of this type with care. While a negative cost shows that a measure can 'pay for itself' when viewed from a societal perspective, that does not mean that it will be implemented without policy action. If measures that have net benefits remain, it is because there are barriers or market failures that prevent their implementation. In such situations, the market will not act by itself, even if prices are favourable; policy interventions will be needed to overcome the barriers.

Negative cost measures may also require systemic shifts in a value chain or sector. Car-sharing is a case in point; shared fleets of cars could lower costs significantly relative to individual ownership, but this would require a large-scale shift towards a different innovation focus and overall system for serving mobility. Therefore, realising the potential CO_2 and economic benefits requires large-scale and systemic changes.

[58] The CO_2 abatement cost curve summarises the opportunities to reduce CO_2 emissions through circular economy opportunities. The width of each bar represents the CO_2 potential of that opportunity to reduce CO_2 emissions in 2050, relative to a baseline scenario. It accounts for overlaps and interactions that arise when all the opportunities are pursued simultaneously. The height of each bar represents the average cost of avoiding 1 tonne of CO_2 emissions by 2050 through that opportunity. In several cases, the cost is a weighted average across several sub-opportunities. All costs are in 2015 real Euros. The abatement cost is calculated from a societal perspective (excluding taxes and subsidies) but does not account for reduced externalities or other benefits. The opportunities are ordered left to right with the lowest-cost abatement opportunities to the right and highest to the left. Of course, both volume and cost estimates are uncertain in such a long timeframe.

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