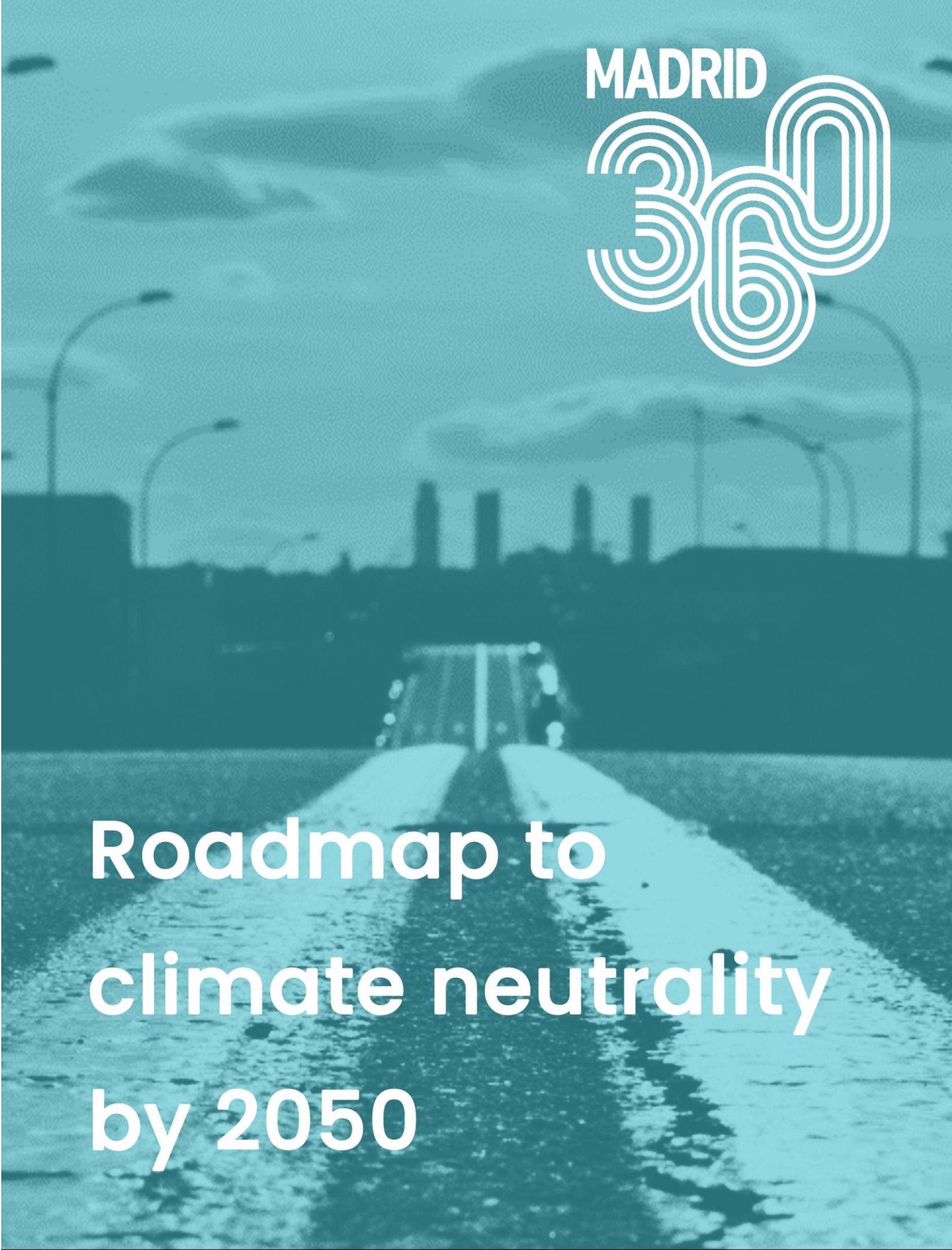


MADRID 360

# Roadmap to climate neutrality by 2050

2022 update

MADRID

# MADRID

## Roadmap to Climate Neutrality by 2050

# 1 Vision and commitment

Climate Change is the greatest environmental challenge that our planet is currently facing. However, its consequences transcend the environment and have a direct and intense impact on society and the economy. The climate crisis materialises in different forms and magnitudes both globally and locally.

Cities are key elements in this crisis. They are high-energy-intensity centres and, consequently, they are responsible for a large part of the greenhouse gas emissions released into the atmosphere. But at the same time, they are subject to the impacts derived from climatic alterations that jeopardise urban systems – from those related to the supply of essential resources such as water, energy or food, to those related to health, migratory flows or economic activity. In any case, cities are key to the solution to this challenge, with the development of their potential in terms of resources, knowledge and action.

The Madrid 360 Environmental Sustainability Strategy, presented in September 2019, already pointed out in its introduction that "*the compelling need to curb climate change led the European Union to establish clearer and more ambitious limits on gas emissions in cities*". In 2020, the European Council endorsed the new binding target for the EU to reduce net greenhouse gas emissions in the EU by at least 55% by 2030 – compared to 1990 levels (European Green Pact) – and, consequently, the Madrid 360 Strategy develops this Roadmap, which not only responds to this call, but also establishes a higher level of ambition, as befits those cities that want to be at the forefront of the fight against Climate Change.

Thus, the climate action reflected in this Roadmap derives from the general objective established by the Madrid 360 Environmental Strategy to transform Madrid into a more environmentally sustainable city, directly affecting an improvement in the quality of life, the development of a low-carbon economy and greater security and resilience in the face of climate risks. It identifies and develops those actions especially relevant to Madrid 360 in terms of reducing greenhouse gas emissions in order to stop, revert and mitigate the effects of Climate Change.

The **Roadmap to Climate Neutrality by 2050 of the City of Madrid** aligns municipal policies with European and state policies, while taking the most ambitious challenges for reducing greenhouse gas emissions as its own. This Roadmap aims at **reducing emissions in the city of Madrid by 65% by 2030, as compared to 1990, and to achieve climate neutrality by 2050** (sustainable scenario).

But this journey does not start at this point in time; Madrid has already begun a path in this direction. This Roadmap adds to a set of commitments, plans and instruments that make up the climate planning of the city of Madrid, a living plan that is in constant evolution and expansion with the addition of new initiatives.

The Roadmap is, therefore, a technical analysis that aims to support the political commitment to fight climate change in the city of Madrid. This commitment responds, above all, to movements and tools of an international nature, among which we highlight:

European Green Deal. On 11 December 2019, the Commission presented its Communication on the **European Green Deal**. It is a new growth strategy for the EU that leads to a climate-neutral, equitable and prosperous society with a modern, resource-efficient and competitive economy. At the European Council meeting in December 2019, EU leaders reiterated their commitment to playing a driving role in the global fight against climate change, confirming the goal of climate neutrality by 2050. In December 2020, the European Council endorsed a new EU binding target to reduce the EU's net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, which is 15 pp above the 2030 target agreed in 2014. EU leaders have urged the Council and Parliament to reflect this new target in the proposed European Climate Law and to pass this law as soon as possible.

**Recovery, Transformation and Resilience Funds** (Next Generation EU). Ambitious financing plan that includes, as one of the main objectives in Spain's programme, "A country committed to decarbonisation, investing in green infrastructure and moving from fossil fuels to a clean energy system", with the ecological transition being one of its four core elements. The climate variable is therefore one of the focal points for allocating the funds associated with the Plan.

The **Paris Agreement** reached within the framework of the Conference of the Parties (COP21, December 2015) to the Convention on Climate Change, which establishes, in accordance with the conclusions of the scientific community (IPCC), the objective of limiting the rise in global temperature to below 2°C, recommending that this increase be kept below 1.5°C in order to avoid irreversible consequences and which, in terms of emission reductions, must be translated into the specification of nationally determined contributions. It is also worth highlighting Madrid's relevant role in the celebration of **COP 25** (December 2019) in which the climate vision and ambition of our city was reiterated.

The challenge taken on by the Madrid City Council as a member of the **C40** Cities Climate Change Leadership Network, which requires the development of a roadmap by 2020 (Deadline 2020 Initiative) to achieve greenhouse gas emission neutrality by 2050, with an interim target for 2030.

Covenant of Mayors for Climate and Energy, of which Madrid is part since its foundation in 2008 with the purpose of bringing together local governments that voluntarily commit to achieve and exceed the EU climate and energy targets.

The Roadmap develops the climate action already reflected in a generic way in the **Madrid 360 Environmental Strategy and in the Air Quality and Climate Change Plan** which **is** also specifically included in different institutional declarations such as:

Villa 2020 Agreements, with the MEC.GT1.067/274 Agreement pointing out the need for specific municipal actions to fight against Climate Change in order to achieve at least the national and European goals for the years 2030 and 2050 on decarbonisation and climate neutrality.

Declaration of Climate Emergency (25/09/2019), by which the municipal plenary approved the need to establish the political commitments, regulations and resources necessary to ensure the progressive reduction of greenhouse gases.

The Roadmap means for Madrid a great challenge that implies an urban transformation and the integration of climate action in municipal policies at all levels. To this end, the city has recently joined the **Deep Demo Climate-KIC** project of the European Institute of Innovation and Technology. This adhesion, approved by the Municipal Plenary in July 2020, involves assessing and innovating in the processes and mechanisms of collaboration that will accelerate the transition to climate neutrality.

Moreover, on a climate innovation approach, in 2020 Madrid submitted its proposal to join the **EU Mission for climate-neutral and smart cities,** which belongs to "Horizon Europe" - a funding programme for research and innovation – scheduled for 2021-2027, and whose aim is to support, promote and showcase the transformation of 100 European cities towards climate neutrality in 2030, to turn them into experiment and innovation centres as an example to other cities. In this context, the Mayor of the City of Madrid signed - along with Barcelona, Seville, and Valencia - the **"Climate Neutral CitiES 2030"** official statement on September 2021. This initiative serves as inspiration for the EU Mission at a national level, and thus places Madrid at the forefront of cities already working in collaborations tools with the State and with other administrations to make progress in urban decarbonization.

The following document is the result of an analysis, coordinated by the Environment and Mobility Area, with the contribution of different sources:

- Technical guidelines of the C40 cities network
- EIT- Climate KIC Project
- Consultants specialising in decarbonisation: *Monitor Deloitte*, for modelling decarbonisation scenarios and estimating abatements, among others, and *Material Economics* for complementary economic analysis of mitigation actions
- Collaboration of various municipal departments, which has served to align policies, goals and seek the necessary synergy in municipal climate action

# 2 Starting situation

In recent years, the city of Madrid has implemented policies, plans and actions to reduce greenhouse gas (GHG) emissions. Usually these actions have been associated with other municipal plans such as air quality, mobility or urban regeneration, using resources, developing synergies and trying to guide the different municipal policies in the same direction.

In order to know the status and evolution of these emissions into the atmosphere, the Madrid City Council prepares an annual GHG Inventory of the city of Madrid. The inventory provides information on direct emissions (scope 1) and indirect emissions due to electricity consumption and distribution losses (scopes 2 and 3), broken down by sector of activity.

The Inventory follows the methodology of the European CORINAIR project, coordinated by the European Environment Agency (EEA) and complies with the requirements established by the Intergovernmental Panel on Climate Change (IPCC) and the Working Group on Atmospheric Emission Inventories and Projections of the United Nations Economic Commission for Europe (TFEIP–UNECE). The collection, analysis and consolidation of information implies a time lag in the publication of the inventory. Therefore, the latest report corresponds to 2019. The 2019 GHG Emissions Inventory

values show a total volume of emissions of **10,048 ktCO2eq**, of which **7,208 ktCO2eq** (71.7%) are direct emissions and **2,840 ktCO2eq** (28.3%) are indirect emissions.

*Sectoral breakdown of total GHG emissions (year 2019)*

| Sector | Emissions kt $CO_2$ eq | Contribution (%) |
|---|---|---|
| **Residencial, Comercial e Institucional** | 4.630,0 | 46,1 |
| **Industry*** | 596,3 | 5,9 |
| **Road transport** | 2.591,3 | 25,8 |
| **Other transport** | 1.093,3 | 10,9 |
| **Waste treatment and disposal**** | 744,7 | 7,4 |
| **Other***** | 392,0 | 3,9 |
| **TOTAL** | **10.047,6** | **100** |

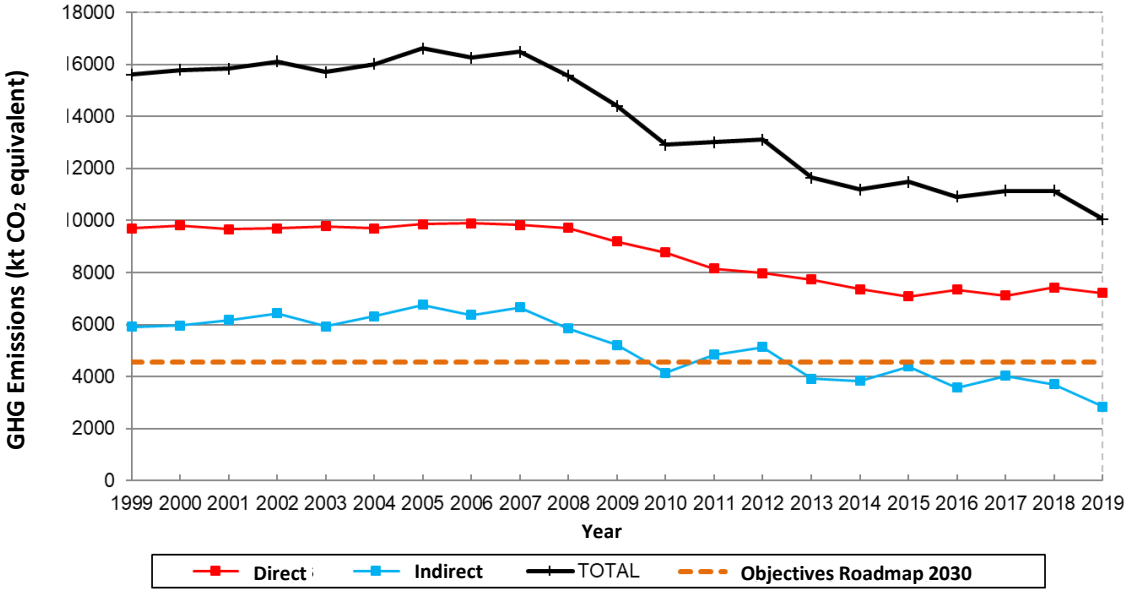
*(*) Includes industrial emissions from combustion and non-combustion processes (SNAP groups 03 and 04)*
*(**) Includes waste treatment and wastewater treatment*
*(***) Includes extraction and distribution of fossil fuels, use of solvents and other products, agriculture and nature (excluding CO2 absorption by sinks)*

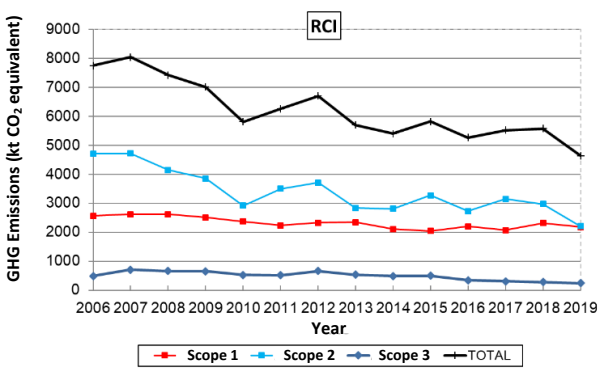
*Direct and indirect GHG emissions (year 2019)*

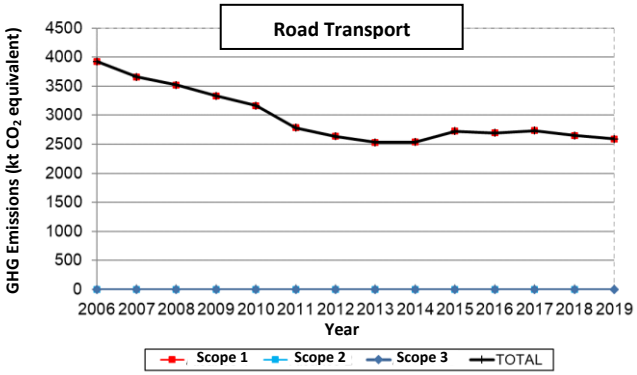
| Year 2019 | Emissions kt $CO_2$ eq | Contribution (%) |
|---|---|---|
| **Directs** | 7.207,7 | 71,7 |
| **Indirects** | 2.839,6 | 28,3 |
| **TOTAL** | **10.047,6** | **100** |

By activity sectors, Residential, Commercial and Institutional (RCI) is the one with the highest emissions **4,630 ktCO2eq** (46.1%), followed by Road Transport **2,591 ktCO2eq** (25.8%) and other means of transport **1,093 ktCO2eq** (10.9%), given the influence of Barajas Airport in the overall municipal contribution.

Compared to 1990, in 2019 the municipality's direct GHG emissions have decreased by 14% and indirect emissions by 39.2%, which implies a reduction in total emissions of 23%. In the 1999–2019 period, direct emissions from the RCI sector have decreased by 11,9% and those from the Road transport sector by 34%.




The indicators show a much lower figure of per capita emissions in the municipality of Madrid in relation to the national average, as well as a higher energy intensity.

In 2019 the municipality of Madrid hosted 7% of the national population and generated 3% of total GHG emissions. Thus, municipal per capita emissions were 54% lower than the national average (3.1 vs 6.7 t/inhabitant). Similarly, Madrid generated 13% of the national GDP, so its "emission intensity per unit of GDP" was 75% lower than the national value (70 vs 275 t/M€2010). These important differences are largely due to the productive structure of the municipality, whose economic activity is based on the tertiary sector (services) and not on industry, which generates more emissions due to its higher energy consumption.

*Municipal and national emission indicators (year 2019)*

| Year 2019 | Per capita emission (t $CO_2$ eq/inhab) | Emission per unit of GDP (t $CO_2$eq / M€$_{2010}$) |
|---|---|---|
| **Madrid** | 3,1 | 70 |
| **Spain** | 6,7 | 275 |
| **Ratio Madrid/Spain** | 0,46 | 0,25 |

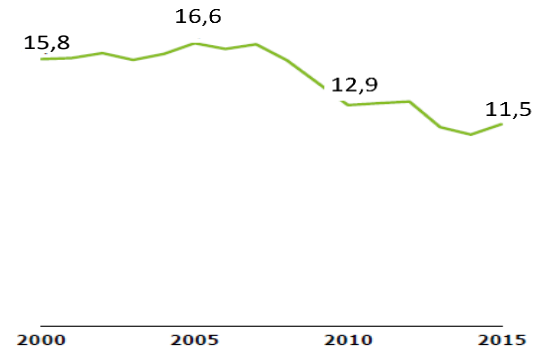
During the period assessed (2000–2019), municipal per capita emissions have decreased more than the national total (44% in Madrid, as opposed to 30% in Spain) and, from the point of view of emissions per unit of GDP, this indicator shows a reduction of 58% in Madrid in the 2000–2019 period.

Mitigation efforts have focused on the most highly emitting sectors, such as transport and building, associated with the development of convergent policies such as Air Quality, building refurbishment or energy efficiency.

In general, the city of Madrid, thanks to the set of municipal actions and those of other institutions and sectors, is following a successful path in the reduction of emissions. However, trends show the need to accelerate and increase the reduction rates.

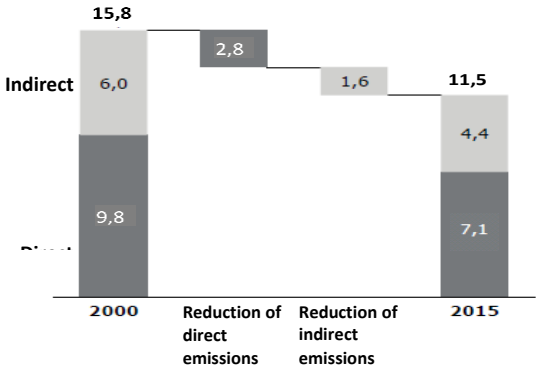
Regarding the 2000–2015 period, the evolution of GHG emissions shows a downward trend, from 15.8 MtCO2eq at the beginning of the period to 11.5 MtCO2eq in 2015. The reduction of indirect emissions (those associated with electricity consumption and distribution losses) exceeds 26.4%, while that of direct emissions has reached 27.7%.

**Evolution of total GHG emissions in Madrid**
(Mt $CO_2$eq; 2000-2015)




Fuente: Inventario de emisiones de gases de efecto invernadero del municipio de Madrid

**Evolution of direct and indirect emissions in Madrid between 2000 and 2015**
(Mt $CO_2$eq; 2000-2015)



In any case, the achievement of the goals set out in this Roadmap stresses the need to continue and intensify policies to mitigate emissions, facing challenges such as **detaching economic growth from increased energy consumption and emissions**, and promoting inclusive development that involves citizens and helps social cohesion, driving urban transformation towards sustainable models.

## Socio-economic context

The fulfilment of the objectives set out in the Roadmap will be closely linked to the evolution of the socio-economic context in which the process develops. The implementation of many of the measures will require financial investment, both from the public and private sectors, and an explicit goal of social cohesion and inclusive development.

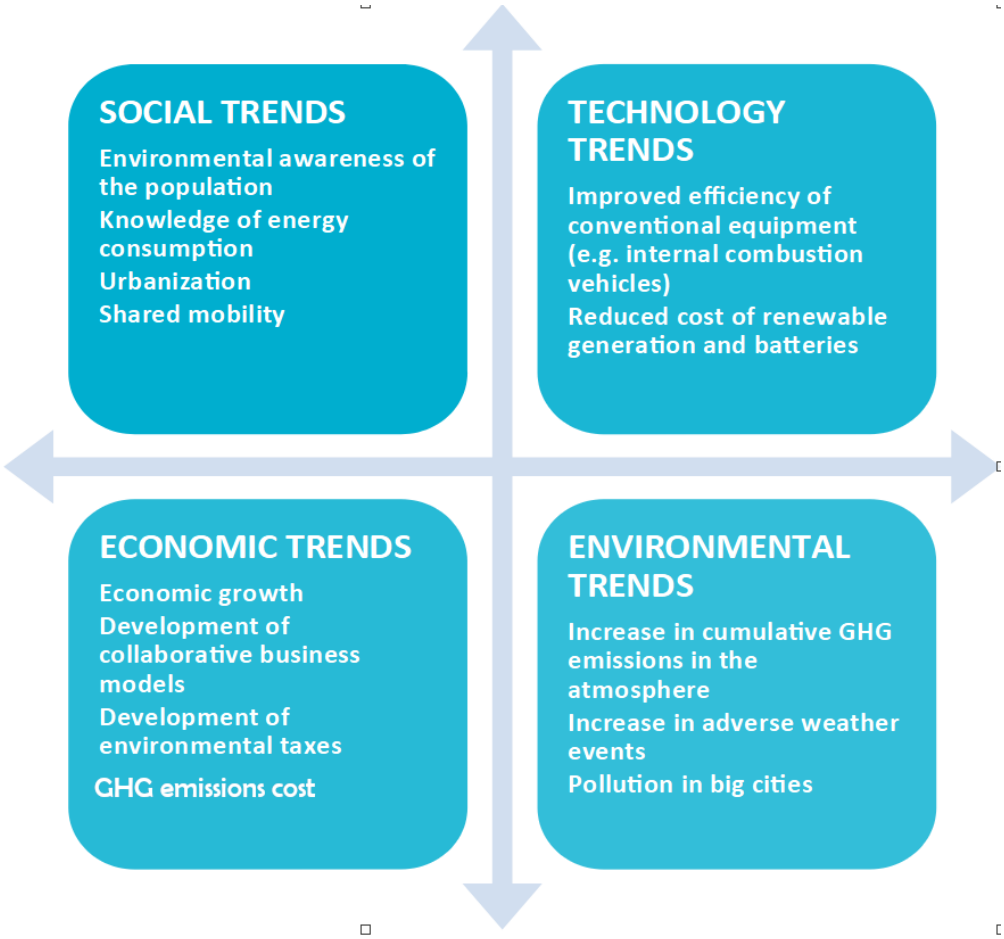
The City Council publishes the annual report Madrid Economía, which analyses the city's socio-economic situation and provides an overview of the current situation and trends. The 2021 edition shows a situation of sustained economic growth in recent years, on a clear path of recovery from the crisis at the end of the first decade of this century. However, the health crisis caused by the pandemic is generating a great amount of uncertainty and a discontinuation of this trend in the short term, due to the fall in employment and activity in some strategic sectors.

In demographic terms, the city's population has experienced five years of growth, reaching 3,334,730 inhabitants in 2020, with a 0,8% drop in 2021 to 3.305.408, according to final data from the Continuos Register Statistics, published by the National Statistics Institute (INE) The arrival of people from outside Spain has allowed the incorporation of workers into productive activity, with a widening of the population pyramid in the most active age groups and a rejuvenation of the population.

The city's productive structure is dominated by services (88.3%), followed by industry (7.4%) and construction (4.3%). Within services, the most outstanding branches are Information and Communications, Professional, Scientific and Technical activities, Real Estate Activities and Financial Activities. These four groups account for 40% of the total added value generated by Madrid's economy.

Madrid's economy has stood out in recent years for its relative strength, accompanied by an upward business dynamic. GDP grew by 2.4% in 2019, the highest in Spain. Due to the pandemic the economic activity in Madrid has dropped to 10,5% last 2021, somewhat less than the rest of Spain, although it is projected to rise, and expected to surpass in 2021 the pre-pandemic levels of activity. The analysis highlights the importance for the city of strategic sectors such as tourism, transport infrastructures, research and training or the financial sector and exports. Beyond this general image, the Roadmap's principle is to incorporate, in the development of actions and measures, methodologies for the analysis of the socio-economic context. This analysis is fundamental, both in the scope of mitigation and adaptation, although it is especially relevant in the latter and specifically in actions located in high vulnerability neighbourhoods and areas. The City Council has numerous tools at its disposal that allow it to approach an urban diagnosis, such as the socio-economic analysis, diagnostic reports by district, vulnerability rates by district, or

the city diagnosis carried out on the occasion of the PGOUM Revision works, among others. The preparation of this Roadmap and the estimation of abatement potentials has incorporated the socio-economic context through the analysis of the following variables.




# 3 Emission reduction targets

The urgency to accelerate emission reduction processes has led to the need to increase the level of ambition in terms of decarbonisation targets and reduce the deadlines for achieving carbon neutrality.

The Paris Agreement and the objectives set by the European Union in the Framework on Climate and Energy for 2030 are the references at European level. At the local level, Madrid City Council initially adopted the objectives set out in Plan A, the Air Quality and Climate Change Plan for the city of Madrid. However, in order to reach the most advanced European targets and observing the context of the European Green Pact, the City of Madrid not only takes up the challenge of the European Commission to intensify Europe's

climate ambition for 2030, but also seeks a more ambitious commitment within its Madrid 360° Environmental Strategy:

**65% reduction in greenhouse gas emissions by 2030 (compared to 1990), exceeding the European objective by 10 points and placing Madrid on the path to climate neutrality by 2050**

Therefore, considering that emissions in 1990 were **12,954 ktn$CO_{2eq}$ (13 Mt$CO_{2eq}$)** and that, in accordance with the evolution experienced to date and the foreseeable trajectory (trend scenario) it is not possible to achieve the targets set, the following GHG emission reduction scenarios are proposed for the city of Madrid:

Following the **sustainable scenario**, which involves accentuating the reduction measures with the greatest abatement capacity and establishing innovative implementation tools as described below, the volume of emissions forecast for **2030** will be **4.5 Mt$CO_{2eq}$**, which represents a reduction of **65.3% Mt$CO_{2eq}$** compared to 1990, reaching **1.4 Mt$CO_{2eq}$** in **2050**, and achieving neutrality through offsetting mechanisms.

Following the **extended scenario**, which requires unlikely but technically feasible socio-economic changes, the volume of emissions forecast for **2030** will be **3.4 Mtn$CO_{2eq}$**, which represents a reduction of **73.8% Mtn$CO_{2eq}$** compared to 1990, reaching **0.6 Mtn$CO_{2eq}$** in **2050**, and achieving neutrality through offsetting mechanisms.

## Emission reduction scenarios

Achieving the proposed objectives implies the development of policies, plans and actions that, from all spheres of society, but especially from the different administrations, promote a transformation of the industries and drivers responsible for emissions.

Carbon neutrality for the year 2050 means a gradual annual reduction that will have to meet partial targets until then. The intensity in the reduction of emissions will be determined by the set of measures that are applied, both at the local level and in the supra-municipal context.

Depending on the implementation of measures and context conditions, three trajectories are defined for the decarbonisation pathway:

**TREND SCENARIO**

The forecast economic growth, emissions reductions in line with current rates of evolution of energy demand, technology penetration and current activity and consumption patterns are taken into account.

- Trend evolution of the emission reduction drivers (e.g. replacement of equipment at the end of its useful life for more efficient ones, but with the same technology).
- Reduction of the emission factor associated with the electricity mix of approx. 60%. (2030 vs 2015) and 100% in accordance with the projections contained in the Integrated National Energy and Climate Plan (PENIEC).
- Economic growth trend as expected.

**SUSTAINABLE SCENARIO**

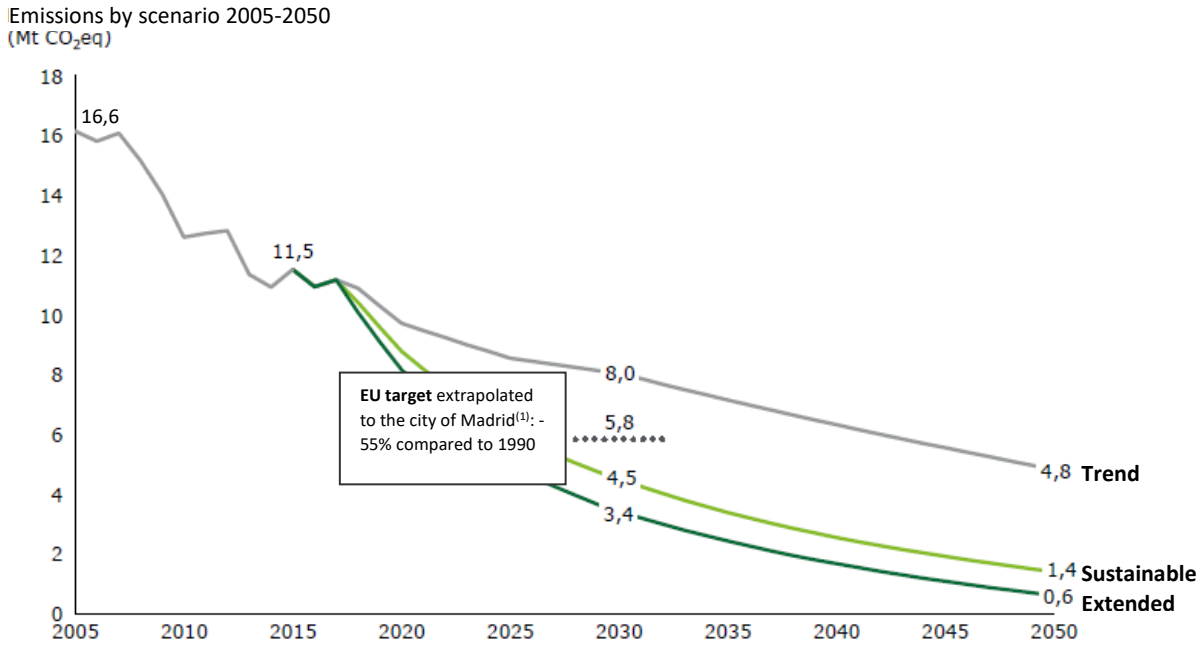
In addition to the expected economic growth and the trend evolution, given the contextual conditions, the implementation of ambitious and more intensive measures to reduce emissions.

- Economic growth trend as expected and application of measures on activity and consumption patterns reducing energy demand (e.g. urban proximity schemes, teleworking, etc.).
- Implementation of ambitious measures that intensify the reduction of GHG emissions (e.g. replacement of equipment ahead of its useful life, boosting the penetration of new technologies, heat pumps, electric vehicles, refurbishments, etc.).
- Increased ambition in the reduction of the emission factor associated with the electricity mix to reach 85% approx. (2030 vs 2015) and 100% in accordance with the projections set out in the PENIEC.

**EXTENDED SCENARIO**

Additional and more intensive measures regarding demand reduction and penetration of new technologies are applied on the expected projections of the sustainable scenario, although the degree of uncertainty is increased by projecting less defined political, social or technical contexts.

- The economic projections of the trend scenario are maintained, but there is a greater emphasis on measures to reduce energy demand.
- The measures applied in the trend scenario are intensified to achieve greater reductions, but on less reliable political, social, and technological context assumptions.
- Reduction of the emission factor associated with the electricity mix to 85% approx. (2030 vs 2015) and 100% in accordance with the projections contained in the PENIEC.




According to the development of the scenarios, both in the sustainable scenario and in the extended scenario, the EU's ambitious targets for 2030 are met. The sustainable scenario shows a level of emissions in that year of **4.5 $MtCO_{2eq}$**, reducing the volume of tonnes by 61% compared to 2015 and 65.3% compared to 1990, thus improving on the targets proposed by the EU.

The extended scenario increases this ambition to 3.4 $MtCO_{2eq}$ in 2030, 70.4% less than in 2015 and 73.8% less than in 1990.

In 2050, there would still be residual emissions of **1.4 MtCO2eq** in the sustainable scenario and **0.6 MtCO2eq** in the extended scenario, which should be neutralized through complementary offsetting measures such as absorption through forest plantations.

As the graph shows, the 2020–2030 period is particularly relevant in the decarbonisation trajectories, with a marked intensity in the implementation of measures and in creating the conditions to bring about inertial decarbonisation in the second period, 2030–2050.

## Co-benefits of mitigation policies

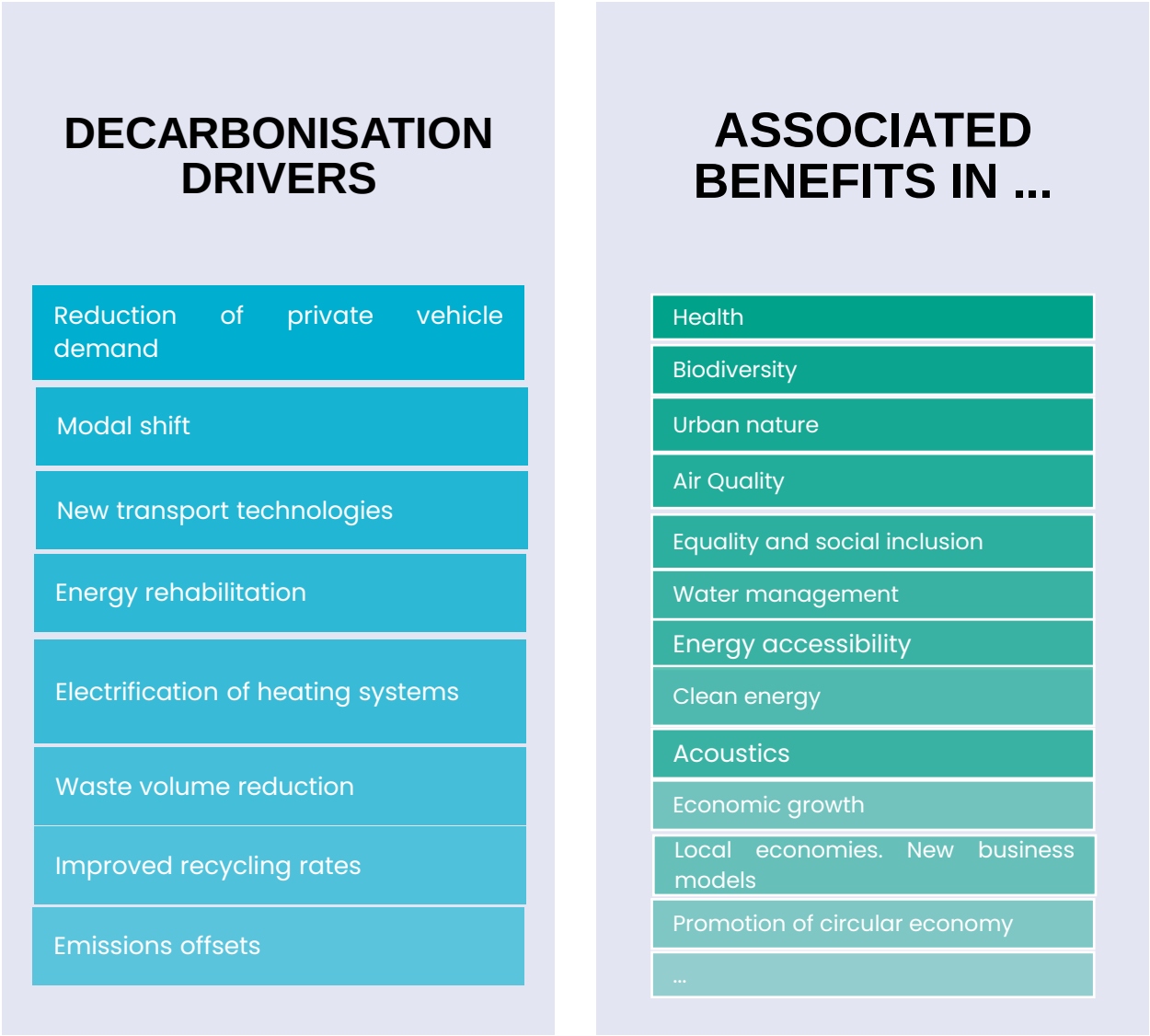
The road to neutrality implies an evolution of many of the current urban models and a social and economic transformation. In this process, the importance of the co-benefits that will occur in association with decarbonisation actions should be highlighted.

Energy efficiency actions on the building stock will have the associated effect of improving the quality of housing, especially in the most vulnerable buildings and areas of the city, and will also improve the conditions of access to energy, reducing situations of energy poverty.

The evolution in mobility will have a direct effect on the city's air quality and noise impact, due to the reduction in demand and the penetration of new technologies. The incorporation of behaviours such as teleworking or the development of proximity urban planning will lead to a reduction in the demand for travel and will increase the presence of non-motorised transport such as pedestrians and cyclists.

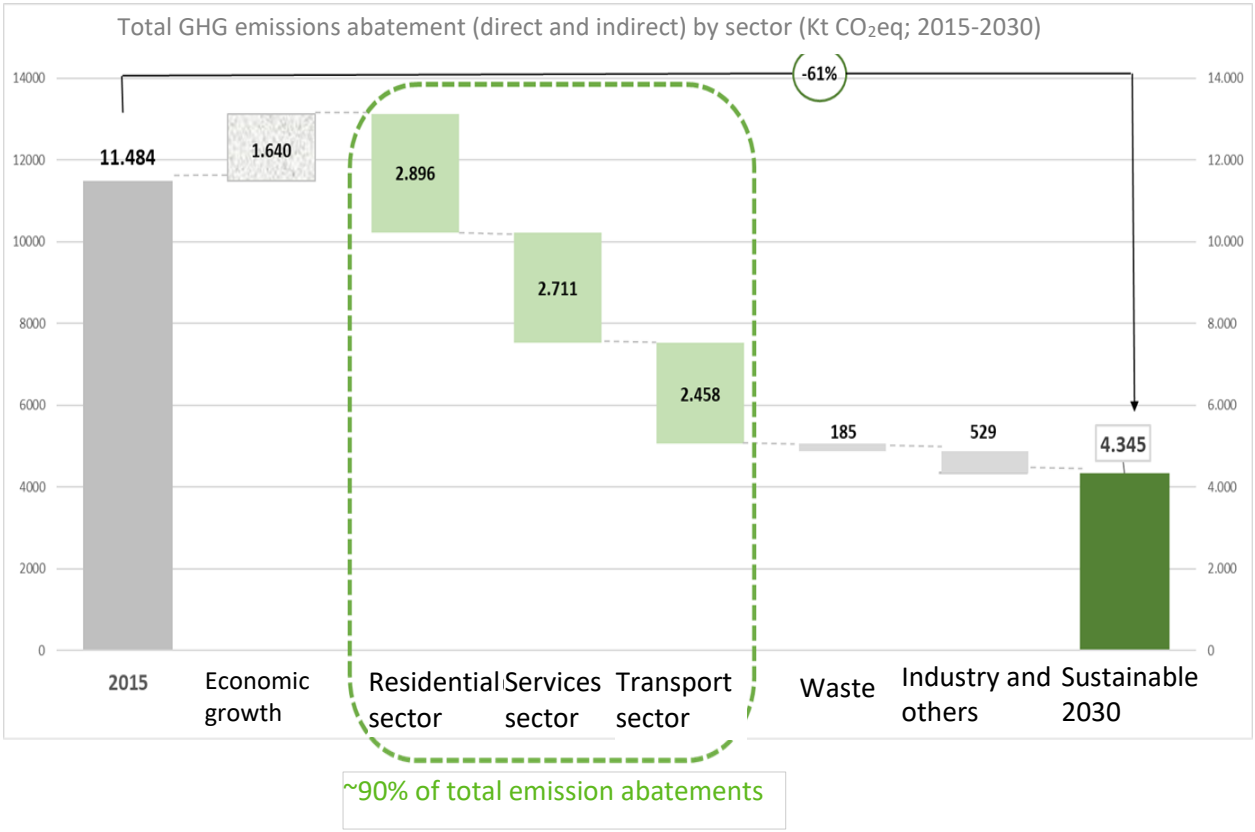
The development of offsetting mechanisms, such as the creation of carbon sink forests, will substantially increase the presence of nature and biodiversity in the city with all the associated benefits that this entails.

In addition to the mitigation actions, there will also be Climate Change Adaptation actions in the city. To the reduction of climate impacts produced by these measures, we should add the multiple benefits they provide, from the improvement of citizens' health, the quality of public spaces, the stimulation of local economies, water management or the reduction of insurance costs, among a myriad of other effects.



# 4 Industries and transformation drivers

The overall GHG emission reduction target will be achieved by aggregating the abatements produced in each of the sectors. The trajectory set by the sustainable scenario shows a contribution by sector in the 2015–2030 period as shown in the graph below.




The sum of sectoral abatements from 2015 to 2030 is equivalent to an emission reduction of 61%, and 65.3% compared to 1990. (Compliance with EU objectives).

The **residential sector** is to contribute the largest volume of reductions (**2.9 MtCO2eq**), followed by the services sector (**2.7 MtCO2eq**) and transport (**2.4 MtCO2eq**). As shown in the graph, the sum of abated emissions from the transport, residential and services sectors accounts for most of the emissions to be reduced: 91%.

It is, therefore, in these sectors where action must be intensified, without failing to act in other areas, since decarbonisation strategies must be comprehensive, understanding the interrelationships and complexities of the urban system.

Although the aim of this Roadmap is to identify and accelerate those measures which have a significant reduction potential, it should be stressed that its general frame can't ignore the much needed **intervention hierarchy** towards a new urban model, and the development of iconic politics, disregarding the short-term reduction potential of the transformation drivers. This politics hierarchy towards sustainability takes on the **AVOID-SHIFT-IMPROVE** focus:

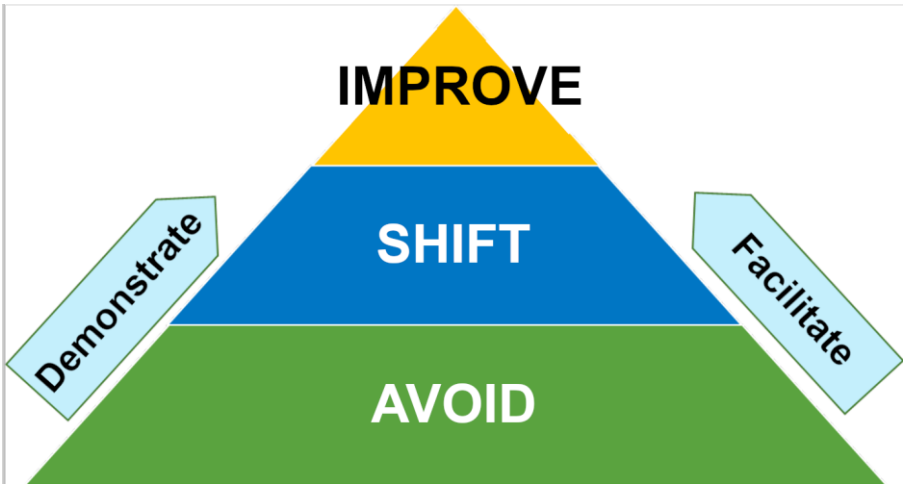
1-**AVOID**: the isolation, refurbishment or energy efficiency in the building sector, the reduction on the demand of motorised travel, and on waste generation are basic examples of a sustainable urban model, although its impact on GHG emissions would be gradual or difficult to evaluate.

2-**SHIFT**: this hierarchy's second step is choosing the most efficient mode or option. Thus, some action examples would be adopting active mobility modes (pedestrian, cycling) or public transport, high efficiency technologies like heat pumps or plans for reusing material.

3-**IMPROVE**: including improved technologies to reduce emissions is the third step in the transformation after implementing actions towards avoiding consumption and adopting the most efficient modes. Some examples are electric mobility, electricity and thermal generation from renewable sources, or reusing materials from recycling and waste recovery.

The role of the City Council on this action hierarchy is twofold. On the one hand, it should prompt its development through enabling acts, a goal-aligned urban planning and municipal services which boost its scaling up and, on the other hand, it should act as demonstrator to set an example and to experiment of innovative climate solutions.

Next, the main drivers for abating emissions for the main sectors are analysed. At the end of the section an overview chart and the key actions to develop related to said reduction drivers are included. Moreover, on section 7 actions and key processes from a municipal perspective are studied in deep.



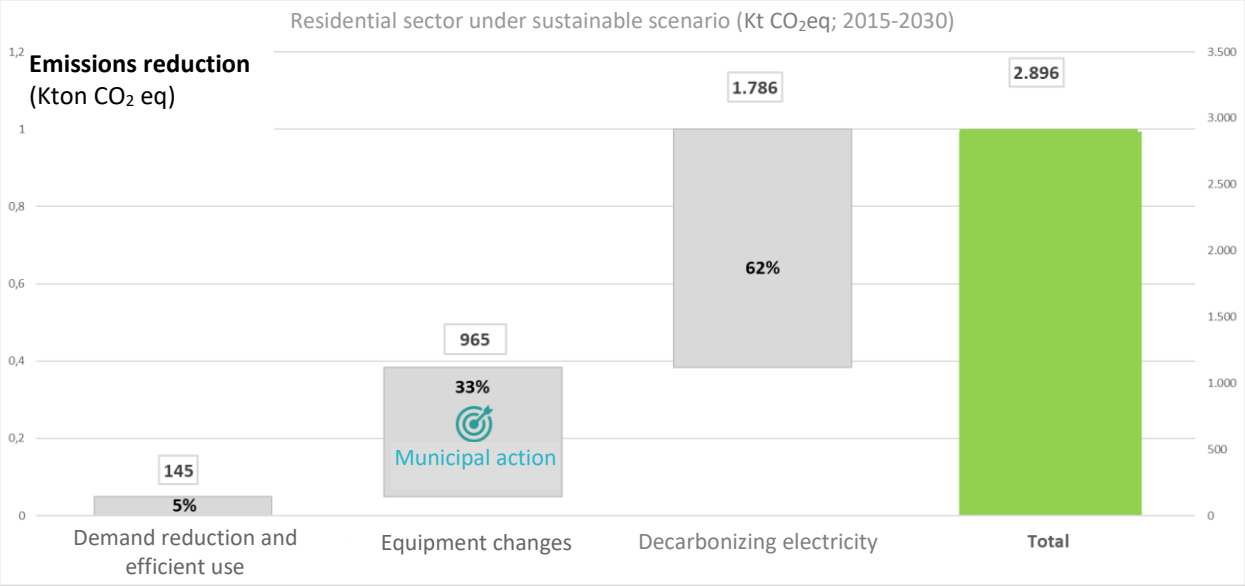
# Analysis of emission reductions in the main sectors in the period 2015–2030

## Residential sector

Since the residential sector generates a high amount of indirect emissions due to electric consumption and to the electric energy demand to meet air conditioning needs the reduction of emissions associated with the electricity mix decarbonisation thanks to using renewable sources is particularly relevant. In the sustainable scenario, the expected decarbonisation of the energy matrix in the period 2015–2030 implies a reduction in emissions of **1.8 MtCO2eq**, more than 60% in this sector.

Secondly, the renewal of thermal equipment to NG condensing boilers and preferably to heat pumps, with the consequent improvement in performance and energy efficiency, will reduce **1 MtCO2eq**, 33% of emissions, in this sector in the period 2015–2030.

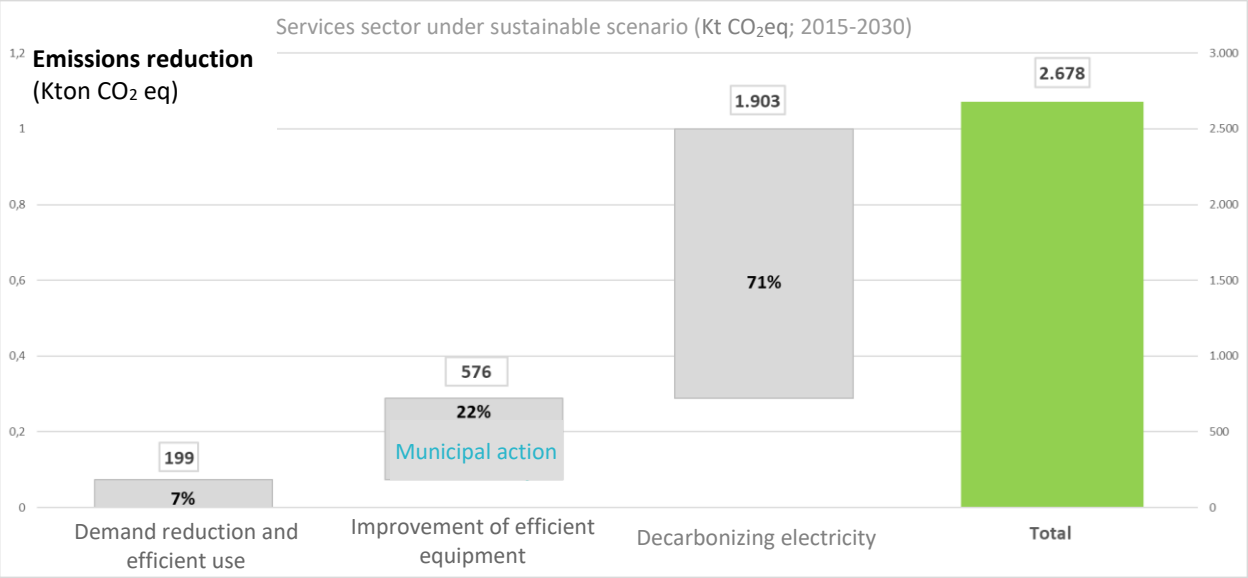
Other energy efficiency actions (renovation of household appliances, lighting, etc.) and refurbishment and isolation participate to a lesser extent in the decarbonisation of the sector on this limited timeframe. However, action in these areas is essential for the additional benefits they bring in efficient energy use, comfort and air quality in buildings, as well as for being the main foundation of the above mentioned hierarchy for a sustainable urban model.



## Services sector

The services sector, which includes - both private and public- commercial, institutional, cultural and sport buildings, as well as street elements from municipal services (street lightning, tunnels, traffic lights, fountains...) makes a significant contribution to emission reduction (**2.7 MtCO2eq**) in the 2015–2030 period. Similarly to the residential sector,the largest volumes of abatement occur through the decarbonisation of the electricity mix **1.9 MtCO2eq** (71%) and the renewal/replacement of thermal equipment **0.6 MtCO2eq** (22%).

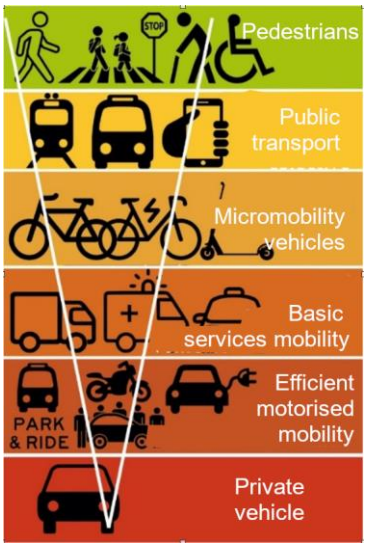
The greater degree of electrification of this sector, which can implement efficient electric equipments like heat pumps, implies a greater impact of the improvement of the emission factor of the electricity mix in the reduction of emissions, so it plays a quite relevant role in showcasing emissions-free electric solutions for buildings. Municipal buildings and services should lead the way due to their driving potential and setting-example duty.



## Transport sector

The strategy to reduce emissions from the transport sector is developed following the Avoid-Shift-Improve (ASI) scheme. This hierarchy includes the combined action of demand reduction (proximity urban planning, teleworking, efficiency, etc.) **0.6 MtCO2eq** (23%), the transfer of journeys from private vehicles to other shared means of transport **0.3 MtCO2eq** (14%), or the penetration of new, less emitting technologies like electric mobility.

The renewal of the vehicle fleet is included into the improve strategy. This driver contributes with the largest emission reduction **1,2 MtCO2eq** (50%), although the trend scenario already includes a large part of this renovation and therefore the sustainable scenario will address a smaller part of this change. Furthermore, the fact that the trend scenario envisages this action indicates a high degree of certainty in its achievement.

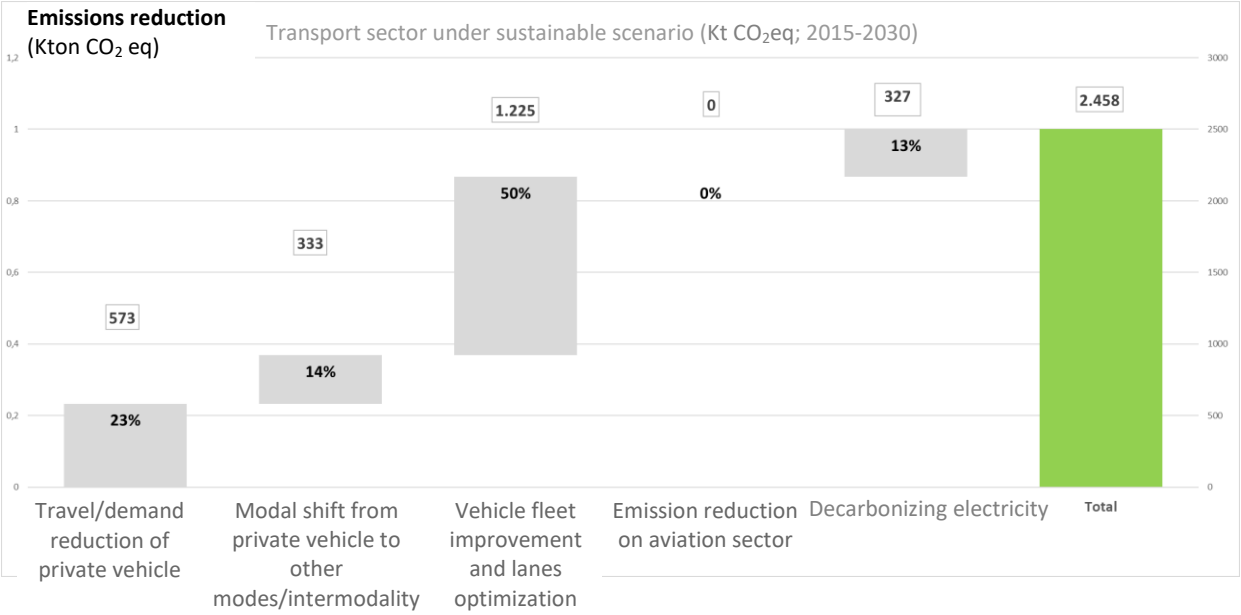



Concerning modal change, the current Madrid modal distribution – like other European cities of similar size – show a balanced reality in terms of vehicle use. However, different outcomes are obtained if the analysis is scaled down to areas, showing unequal modal distributions. The modal distribution in the city centre is very balanced, whereas it is very unbalanced towards vehicle use both in the cross-cutting mobility of suburbs, and in the incoming traffic from the metropolitan area. If results are branched off by area, the most ambitious goal would be improving the sustainability of suburb mobility, aiming to reduce vehicle travel from 30% to 22%.

***Source: PMS Madrid (2021) Multimodal pyramid.***

Travel distribution in areas by mode of transport (PMS 2021)

| Residence area | By Foot | Public Transport | Private Vehicle | Other |
|---|---|---|---|---|
| City centre | 40,0% | 34,8% | 20,3% | 4,9% |
| Suburbs | 32,2% | 32,8% | 32,4% | 2,6% |
| Metropolitan area | 34,0% | 16,4% | 47,7% | 1,9% |
| Region | 29,6% | 10,8% | 56,2% | 3,4% |
| **Community of Madrid** | **34,0%** | **24,3%** | **39,0%** | **2,7%** |




The municipal ability of acting on different drivers affecting urban mobility patters, and the trend of decreasing emissions during recent years is worth mentioning on this sector. Aviation sector emissions should also be mentioned, keeping in mind that the high level of emissions related to Adolfo Suárez-Barajas Airport mean a significant input on transport, and that there is no foreseeable short-term reduction.

## Waste sector

Considering direct emissions of greenhouse gases (like methane and carbon dioxide), organic waste collection and management plays a key role on this sector. Minimizing organic waste, which also implies ethical considerations related to food waste, and its proper sorting out, selective collection, and management at Valdemingómez waste management centre, are the main drivers to achieve a significant emission reduction. Treatment of organic waste should focus on anaerobic digestion and later biogas refining in order to generate biomethane, which will be further injected into the gas network, together with the use of its solid remnants (digestate) as compost. Moreover, controlling and using the methane outcome is also important.

However, the Roadmap towards climate neutrality also means actions that, although they don't have a direct impact on GHG emissions inventories due to its methodology and scope, they do impact on a new, more sustainable and resource- and material-friendly urban model. On this matter it should be highlighted the reduction of construction waste, which present a high level of embodied carbon due to its production and transportation, and other ethical consumerism actions embodied into circular economy and knowledge and awareness of products and materials' carbon footprint strategies.

## Industrial sector and carbon sinks (nature)

Greenhouse gas emissions into the city from the industrial sector are scarce, thus its ability to contribute to reach reduction goals is very limited. The needed reduction of refrigerant gases and the progressive electrification of industrial processes should be highlighted as main actions.

Concerning other sources and sinks (nature), it should be note the urban forest mass' ability to capturing emissions. Green areas have special prominence in Madrid, where approximately a third of its area is covered by trees or gardens and has an estimate capacity as carbon sink of 30.000 t/year (Source: “El Valor del Bosque Urbano” AG Medio Ambiente y Movilidad ["The Worth of Urban Forest" AG Environment and Mobility], 2018).

## Abatements by drivers and main lines of action 2030–2050

| Action | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Line of action 1**: **electric system decarbonization; 100% renewable energy**<br>Goals:<br><br>1. Promoting renewable energy on residential, commercial and transport sectors.<br>2. Improving national goals of renewable electric energy production on the city.<br>3. Facilitate the access to renewable energy to citizens (municipal energy communities). | | |  | | |
| **Advocate for a more ambitious renewable energy target and changes to national government** | - On residential sector<br>- On transport sector<br>- On services, commercial, and institutional sectors. | 3.997 | | Regional and national administrations<br>.<br>Private sector. | National plan |
| **Study and research new consumption models: energy communities.** | - Study of photovoltaic potential and legal formulations to set the roles of energy communities. | N/A | N/A | Regional and national administrations<br>. | Ordinary budget and plan |
| **Local actions to decarbonize the electric system** | - Increasing renewable energy generation on municipal buildings and facilities.<br>- Facilitate renewable energy generation for self- consumption: ‘ Madrid autosuficiente’.<br>- Working together with different administrations (regional and national) towards almost near-zero emissions energy and self-consumption urban buildings. | 19 | 19 | Regional administration.<br>Energy companies | Specific national plans.<br>Private Funding.<br>‘Madrid rehabilita’ ('Madrid refurbishes')<br>Plan (subsidies) |

| Action | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Line of action 2**: **zero emissions residential buildings**<br>Goals:<br><br>1. Raise awareness among citizens about energy consumption from renewable sources and using more efficient systems and installations.<br>2. Promote the electrification of both low-cost and socially accessible air conditioning and domestic hot water (DHW) demand.<br>3. Promote electric energy generation through self- consumption. | | | | | |
| **Reduce energy demand improving buildings isolation and energy efficiency** | Improve buildings isolation and energy efficiency through:<br>- refurbishing roofs, façades and windows,<br>- implementing new control systems as in air conditioning | 145 | 134 | Regional and national administrations<br>.<br>Private sector | Specific national plans.<br>Private Funding.<br>'Madrid rehabilita' Plan (subsidies) |
| **Shifting to more efficient equipment and installations** | **Air conditioning improvements:**<br>- Shifting to heat pumps<br>- Shifting natural gas condensing boilers.<br>**Other equipments:**<br>- Other equipments like garage or elevator ventilation systems.<br>- Shifting to more efficient household appliances (A+++ vs A++) and lightning. | 965 | 751 | Regional and national administrations<br>.<br>Private sector | Specific national plans.<br>Private Funding.<br>'Cambia 360' ('Change 360') Plan (subsidies) |
| **Local actions for electric system decarbonization (see Line of action 1)** | Renewable energy generation for self-consumption: 'Madrid autosuficiente'. | See "Line of action 1" | | | |

| Action | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Line of action 3: Zero emission transport**<br>Goals:<br><br>1. Raise awareness about reducing private motorised transport.<br>2. Promoting sustainable transport modes.<br>3. Improving public transport and municipal vehicle fleet towards electrification. |  | | | | |
| **Reducing travel/private transport demand** | - Reduce work-related travel (private transport)<br>- Reduce domestic travel by promoting proximity urban planning (15 minutes city)<br>- Promoting deterrent policies like the controlled parking restricted service (SER), or creating new low-emission (ZBE) and special protection (ZEE) areas. | 573 | 296 | Regional and national administrations. | Ordinary budget and plan. Specific national plans |
| **Modal shift from private vehicle towards different modes/intermodality** | - Prioritise pedestrian mobility on new urban development, and shift towards it on the rest of the city<br>- Promote public transport (bus, train, and underground)<br>- Keep creating new cycling lanes to promote cycling and micromobility vehicles (VMP)<br>- Promote shared mobility modes like carpool, carsharing or motorcycle sharing. | 333 | 389 | Regional administration. Private sector, shared modes | Ordinary budget and plan. Specific national plans |

| Action (cont.) | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Fleet electrification and renovation. Service optimization (Public transport and urban freight transport)** | **Renovation and electrification of vehicle fleet:**<br>- Vehicle fleet will be renovated gradually by implementing more efficient technologies (private vehicle, freight transport, taxi/vehicle for hire and municipal fleet)<br>- Promoting fleet electrification (private vehicle, freight transport, taxi/vehicle for hire and municipal fleet, public transport buses)<br><br>**Technological innovation and improvement:**<br>- Optimise urban goods distribution services.<br>- Develop logistic hubs and optimise logistic processes (reverse logistics)<br>- Promote innovation – Mobility future:<br>- On-demand public transport systems and routes optimization.<br>- Improving the efficiency of non-shared public transport like taxi or vehicles for hire. | 1225 | 884 | Regional and national administrations<br>.<br>Private sector | Specific national plans.<br>Private Funding.<br>'Cambia 360' Plan (subsidies) |
| **Reducing emissions on aviation sector** | Advocate national government for implementation plans to reduce emissions on the aviation sector, by cutting down short flights, promoting road travel, using alternative fuels, and improving take-offs and landings. | - | - | National | National programs |

| Action | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Line of action 4**: **Zero-emissions service sector buildings and premises**<br>Goals:<br><br>1. Promoting more efficient systems and installations on institutions and activities.<br>2. Promoting self-consumption electric energy generation.<br>3. Sharing the vision of municipal and institutional buildings as energy generation hubs for urban supply. | | | |  | |
| **Reducing energy demand by building isolation and boosting energy efficiency** | Refurbish building isolation and boost energy efficiency by:<br>- Working on commercial and institutional buildings and premises out of municipal scope.<br>- Working on municipal buildings and premises.<br>- Implementing smart heating and lighting control systems on premises and buildings. | 232 | 145 | Regional and national administrations. Private sector | Ordinary budget and plan. Specific national plans |
| **Shifting to more efficient equipments and installations** | **Improving air conditioning:**<br>- Shift to heat pumps.<br>- Improve current equipments.<br><br>**Other equipments:**<br>- Other equipments like garage or elevator ventilation systems.<br>- Shifting to more efficient household appliances (A+++ vs A++) and lightning. | 576 | 253 | Regional and national administrations. Private sector | Specific national plans. Private Funding. 'Cambia 360' Plan (subsidies) |
| **Local actions for electric system decarbonization** | - Renewable energy generation for self-consumption: 'Madrid autosuficiente'.<br>- Working together with different administrations (regional and national) towards almost near-zero emissions energy and own energy self- consumption urban buildings. | See "Line of action 1" | | | |

| Action | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Line of action 5: Reducing waste impact**<br>Goals:<br><br>1. Raising awareness about reducing waste.<br>2. Improving waste recovery processes.<br>3. Improving waste management efficiency. |  | | | | |
| **Reducing waste generation** | - Procedures, platforms, and methods for product reusing for citizens.<br>- Packaging cut down and identify reverse logistics processes on supply chains.<br>- Reduce food waste.<br>- Reduce construction and demolition waste on urban public works | 37 | 36 | Regional and national administrations.<br>Private sector | Ordinary budget and plan.<br>Specific national plans.<br>Private funding |
| **Raising recovery rates on residential, services and municipal sectors.** | - Update and revise recruitment documents for waste management centres, with ambitious recovery goals in mind.<br>- Improve rates on local waste facilities | 19 | 18 | Regional administration | Ordinary budget and plan |
| **Organic waste collection and management** | - Raise the volume of waste management by creating a new plant-based and selective-collection organic fraction waste digestate composting facility on 2022<br>- Reduce emissions by transforming waste into energy, by improving biomethanation process and by generating more electric energy for self- consumption.<br>- Improve the purity of selective-collection organic fraction waste through awareness campaigns.<br>- Injecting higher volumes of biogas into the gas network. | 129 | 125 | Regional administration.<br>Private sector | Ordinary budget and plan.<br>Specific national plans.<br>Private funding |

| Action | Description | Emission reduction in 2030 (Kton CO2 -e) | Additional emission reduction in 2050 (Kton CO2 -e) | Collaborations and alliances | Funding sources |
|---|---|---|---|---|---|
| **Line of action 6**: **Reducing emissions in other sectors**<br>Goals:<br><br>1. Reducing the impact of solvent and refrigerant gases.<br>2. Reducing emissions of industrial sector.<br>3. Promoting and supporting urban reforestation. | | | | | |
| **Reducing the impact of solvent and refrigerant gases** | - Support research focused on cutting down the impact of solvent and refrigerant gases on the atmosphere, e. g. replacing gases for less pollutant products. | 426 | 171 | Regional and national administrations. Private sector | Specific national plans. Private funding |
| **Reducing emissions of industrial sector** | - Improve the efficiency of industrial processes.<br>- Boost electric energy use of processes and activities. | 100 | 120 | Regional and national administrations. Private sector | Specific national plans. Private funding |
| **Naturalised areas and reforested city** | - Plant trees: boosting 'Madrid Compensa' (Madrid campaign as an offset greenhouse gases emissions program)<br>- Integrate nature on urbanization and regeneration projects (using Nature-based solutions NBS) | 3 | 3 | Administrations and private sector | Ordinary budget and plan |

## Main assumptions

The Roadmap of the city of Madrid towards climate neutrality is developed through six lines of action for a drastic reduction of emissions:

- Establish governance and funding models in line with climate sustainability targets.
- Boost renewable energy sources on electricity generation (decarbonization of the electric mix), raising it at a local level.
- Promote energy efficiency and electrification in services and residential buildings.
- Promote sustainable transport of passengers and goods.
- Improve the sustainability of waste management and industry.
- Contribute at the municipal administration level, setting an example of sustainable energy models.

Based on these lines of action, the neutrality roadmap is proposed according to strategic assumptions for each of the analysed sectors. These assumptions apply to the main emission reduction drivers.

### Electricity sector assumptions

The **evolution of the electricity sector** is a determining factor in the achievement of the decarbonisation goals. The reduction of the emissions factor of the electricity mix due to the penetration of renewable energies and the gradual closure of conventional thermal power plants (coal and combined cycle plants) are the main assumptions of its evolution.

| DRIVERS | SCENARIOS | | | | |
|---|---|---|---|---|---|
| | TREND | SUSTAINABLE | | EXTENDED | |
| | | 2030 | 2050 | 2030 | 2050 |
| **Emission factor for the electricity sector** | •Reduction of ~60% (2030 vs 2015) (according to the trend scenario of the PNIEC)<br>•Reduction of 100% (2050 vs 2030)<br>•Electricity generation from renewable sources: 51% in 2030 and 100% in 2050 | •Reduction by ~85% (2030 vs 2015) (according to target scenario of the PNIEC)<br>• Electricity generation from renewable sources: 73% | • 100% emissions reduction by 2050<br>• Electricity generation 100% GHG neutral | • Reduction by ~85% (2030 vs. 2015) (according to target scenario of the PNIEC)<br>• Electricity generation from renewable sources: 73% | • 100% emissions reduction by 2050<br>• Electricity generation 100% GHG neutral |
| **Annual emission reductions in other sectors** | • Reduction of 5.9% of annual emissions (according to the trend scenario of the PNIEC, matching the target scenario) | • 5.9% annual emissions reduction (according to target scenario of the PNIEC) | • 5.9% annual emissions reduction (according to target scenario of the PNIEC) | • 5.9% annual emissions reduction (according to target scenario of the PNIEC) | • 5.9% annual emissions reduction (according to target scenario of the PNIEC) |

## Residential sector assumptions

The penetration of **heat pumps** to replace conventional air conditioning systems (combustion and electric) is essential given the superior energy efficiency of these systems (≈ 200–300% compared to 90–100% of electric heaters). The trend scenario envisages the replacement in the short term of conventional thermal boilers, both gas and other fuels (oil products, coal) to **efficient condensing natural gas boilers,** significantly improving the performance of this equipment (≈ 110% compared to 70–90% of conventional boilers).

The energy rehabilitation of buildings is another key driver. These interventions include window replacement (10–15% savings), façade renovation (30–50% savings) and roof renovation (5–15% savings). The integral intervention of a building that includes all these actions can achieve savings in heating consumption of 60–70%[1].

| DRIVERS | SCENARIOS | | | | |
|---|---|---|---|---|---|
| | TREND | SUSTAINABLE | | EXTENDED | |
| | | 2030 | 2050 | 2030 | 2050 |
| **Heat Pump Penetration** | Renewals only,<br>no additional installations | Annual increase in surface area **~0.9%**<br>12,000 new units per year | Between 2030-2050 Increase in surface area **~0.9%**<br>14,000 new units per year | Annual increase in surface area **~1.2 %**<br>17,000 new units per year | Between 2030–2050 Increase in surface area **~1.5%**<br>24,000 new units per year |
| **Replacement of natural gas boilers** | End-of-life replacement (~15 years)<br>~40,000 boilers/year | Replacement every **~13 years**.<br>~50,000 boilers/year | Replacement every **~13 years**.<br>~50,000 boilers/year | Replacement every **~12 years**.<br>~60,000 boilers/year | Replacement every **~8–9 years**.<br>~80,000 boilers/year |
| **Refurbishments** | Refurbishments are not considered | Refurbishment **~1%** surface/year<br>13,000 refurb./year | Refurbishment **~1%** surface/year until 2050<br>16,000 refurb./year | Refurbishment **~1.5%** surface/year<br>20,000 refurb./year | Refurbishment **~1.5%** surface/year until 2050<br>24,000 refurb./year |

1 Estimates for residential buildings built prior to 1980.

## Service sector assumptions

The **heat pump** can have a faster penetration in the service sector than in the residential sector, given the more favourable circumstances of this type of building with higher air conditioning demands and better construction conditions for installation.

Efficiency improvements are also expected in this sector due to the **replacement of conventional thermal equipment with high-efficiency natural gas equipment**. **Smart control of lighting and heating systems** can achieve consumption reductions of 15 to 30%.

Similarly to the residential sector, the **energy refurbishment of buildings dedicated to services,** with actions on windows (10–15% savings), façades (30–50% savings) and roofs (5–15% savings) can achieve savings in heating consumption of 60–70%.

| DRIVERS | SCENARIOS | | | | |
|---|---|---|---|---|---|
| | TREND | SUSTAINABLE | | EXTENDED | |
| | | 2030 | 2050 | 2030 | 2050 |
| **Heat Pump Penetration** | Current penetration rate | Annual installation of **2.7%** of the surface area | Annual installation of **2.7%** of the surface area | Annual installation of **3%** of the surface area | Annual installation of **3%** of the surface area |
| **Smart heating & cooling. Smart lighting** | Installations are not considered | Annual installation of **2.7%** of the surface area | Annual installation of **2.7%** of the surface area | Annual installation of **3%** of the surface area | Annual installation of **3%** of the surface area |
| **Refurbishments** | No refurbishments are to be carried out | Annual installation of **1.5%** of the surface area | Annual installation of **1.5%** of the surface area | Annual installation of **1.5%** of the surface area | Annual installation of **1.5%** of the surface area |

## Transport sector assumptions

Decarbonisation must also be a consequence of the transformation of current mobility patterns and lifestyles. These new models should be oriented towards **reducing the demand for transport** through the promotion of teleworking, the development of proximity urban planning or the change of transport and consumption behaviour.

The **modal shift in mobility from private vehicles** (≈180–200 gCO2/passenger-km) **to public transport** allows for a reduction in emissions per passenger-km up to 70% in the case of conventional buses (≈50gCO2/passenger-km) and over 90% in the case of trains or subways (≈5gCO2/passenger-km).

The **modal shift to non-motorised transport** (walking, cycling, etc.) is considered to be encouraged by the development of dedicated lanes, promotion of dedicated parking, promotion of rental systems, etc.

The **penetration of the electric vehicle, replacing the conventional technology vehicle**, implies a reduction in emissions. The GHG emissions of the electric vehicle are six to seven times lower than those of a conventional EURO III vehicle, four to five times lower than those of a EURO IV vehicle and two to three times lower than those of a EURO VI vehicle.

The **replacement of the fleet of older conventional vehicles with more efficient and less polluting ones** is the driver with the greatest potential for reducing emissions in the period 2030–2050. Most of this renovation is already contemplated in the trend scenario, to which the additional effort is added in the sustainable scenario. An older Euro III diesel vehicle emits twice as much as a new Euro VI diesel vehicle.

The **aviation industry** is expected to grow in proportion to the annual growth in routes and passengers. Emission reduction actions envisaged in the 2050 extended scenario using fuels with lower emissions not yet commercially available are considered.

| DRIVERS | SCENARIOS | | | | |
|---|---|---|---|---|---|
| | TREND | SUSTAINABLE | | EXTENDED | |
| | | 2030 | 2050 | 2030 | 2050 |
| **Reduction of transport demand** | Annual growth of journeys<br>0.5 % | Annual reduction of journeys<br>1.5% | Annual reduction of journeys<br>1.5% | Annual reduction of journeys<br>1.5% | Annual reduction of journeys<br>1.5% |
| **Passenger modal shift** | Non-motorized<br>31%<br>Public transport<br>32%<br>Private vehicle<br>37% | Non-motorized<br>30%<br>Public transport<br>40%<br>Private vehicle<br>30% | Non-motorized<br>46%<br>Public transport<br>45%<br>Private vehicle<br>9% | Non-motorized<br>46%<br>Public transport<br>45%<br>Private vehicle<br>9% | Non-motorized<br>47%<br>Public transport<br>45%<br>Private vehicle<br>8% |
| **Electric vehicle penetration** | Current penetration<br>≈ 0% | ≈ 20%<br>≈290,000 | ≈ 100%<br>≈1,450,000 | ≈ 40%<br>≈580,000 | ≈ 100%<br>≈1,450,000 |
| **Renewal of the vehicle fleet** | Increase in the current age of the fleet to<br>11–12 years | Decrease in the average age of the fleet up to<br>9–10 years | Decrease in the average age of the fleet up to<br>6–7 years | Decrease in the average age of the fleet up to<br>6–7 years | Decrease in the average age of the fleet up to<br>6–7 years |
| **Air sector** | Emissions growth<br>0.5% p.a. until 2030 and 0.25% until 2050<br>Growth rates in proportion to the growth of journeys | Annual emissions reduction<br>1.50%<br>Growth rates in proportion to the growth of journeys | Annual emissions reduction<br>1.50%<br>Growth rates in proportion to the growth of journeys | Annual emissions reduction<br>1.50%<br>Growth rates in proportion to the growth of journeys | Annual emissions reduction<br>5.10%<br>Possibility of using non-polluting fuels, pilot phase |

## Other sectors (waste treatment, industrial, and forestry sectors) assumptions

The **reduction of emissions from waste treatment** is addressed by reducing waste generation through the promotion of prevention and implementation of circular economy approaches, improvement of selective collection and increase of recycling rates and, due essentially to its contribution to local emissions, improvement on organic waste collection and management.

The **emissions reduction in the industrial sector** will be achieved by improving energy efficiency through improvements in technologies and industrial process management systems, and by increasing electrification in the final consumption mix.

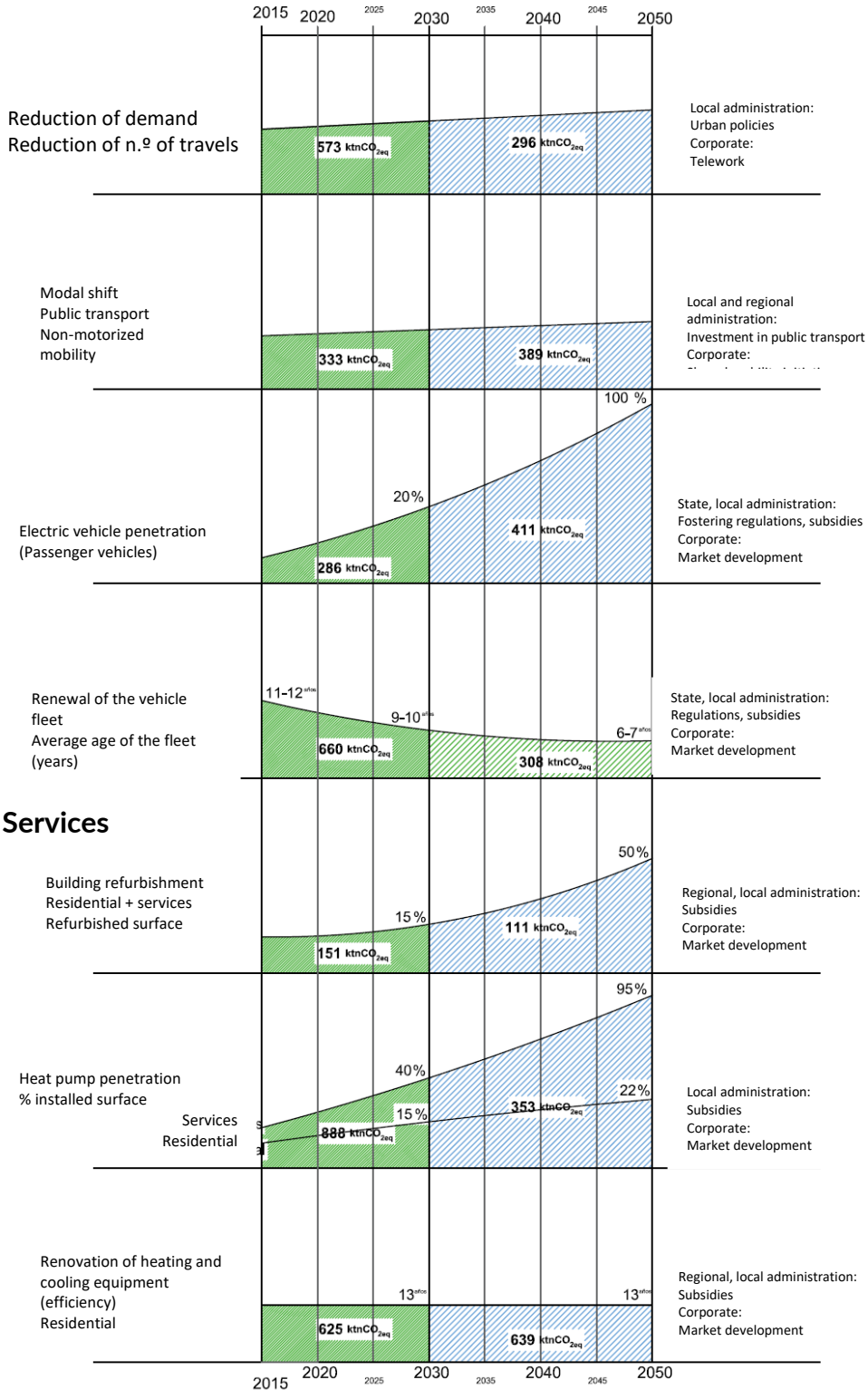
The extended scenario considers the decentralization of industry as a decarbonization factor in the municipality. The decarbonisation assumption considers the replacement of high-warming potential fluorinated gases with gases with lower or no effect gases.

Regarding **carbon sinks**, assumptions are created regarding the increase of the forest mass, with its subsequent raise on storage capacity.

| DRIVERS | SCENARIOS | | | | |
|---|---|---|---|---|---|
| | TREND | SUSTAINABLE | | EXTENDED | |
| | | 2030 | 2050 | 2030 | 2050 |
| **Annual reduction in waste emissions** | •1.1% annual reduction in emissions (according to the PNIEC trend scenario) | •2.6% annual reduction in emissions (according to the PNIEC target scenario) | •2.6% annual reduction in emissions (according to the PNIEC target scenario) | •2.6% annual reduction in emissions (according to the PNIEC target scenario) | • 5.2% annual emissions reduction<br>•The use of advanced waste treatment technologies and ambitious recycling and circular economy rates are considered |
| **Annual emissions reduction in industry** | •0.7% annual reduction in emissions (according to the PNIEC trend scenario) | •1.3% annual reduction in emissions (according to the PNIEC target scenario) | •1.3% annual reduction in emissions (according to the PNIEC target scenario) | • 8.3% annual emissions reduction<br>•A certain decentralization of the current industry from the city of Madrid to surrounding areas is considered | •Reduction of 6.7% per year<br>•A certain decentralization of the current industry from the city of Madrid to surrounding areas is considered |
| **Reforestation** | •No additional tree planting is considered | •A 10% raise of forest mass is considered | •A 20% raise of forest mass is considered | •A 15% raise of forest mass is considered | •A 25% raise of forest mass is considered |

## ABATEMENT OF EMISSIONS FROM THE MAIN DRIVERS

2015-2030 period
2030-2050 period



# 5 Economic analysis

The tool used to measure the efficiency of the proposed drivers and measures, both in terms of their potential to reduce emissions ($CO_2$ eq) linked to their cost (€2016) is the Abatement Curve. This analysis provides us with an overview of the drivers proposed in the Roadmap of the city of Madrid towards neutrality and allows us to prioritize the implementation of measures that, at a lower cost, offer a greater potential for reducing direct emissions of $CO_2$ eq. Abatement cost is defined as the additional costs (or perceived benefits) of replacing a reference (commonly used) technology with a low-emission alternative.

Some of the proposed actions that offer the greatest potential for the reduction of direct emissions in the 2015–2030 period will require a boost from the competent administrations to encourage changes in equipment or habits.

24% of the emission reductions by 2030 are achieved with economically viable measures, while 22% are achieved with measures that require financial support from the competent administrations.

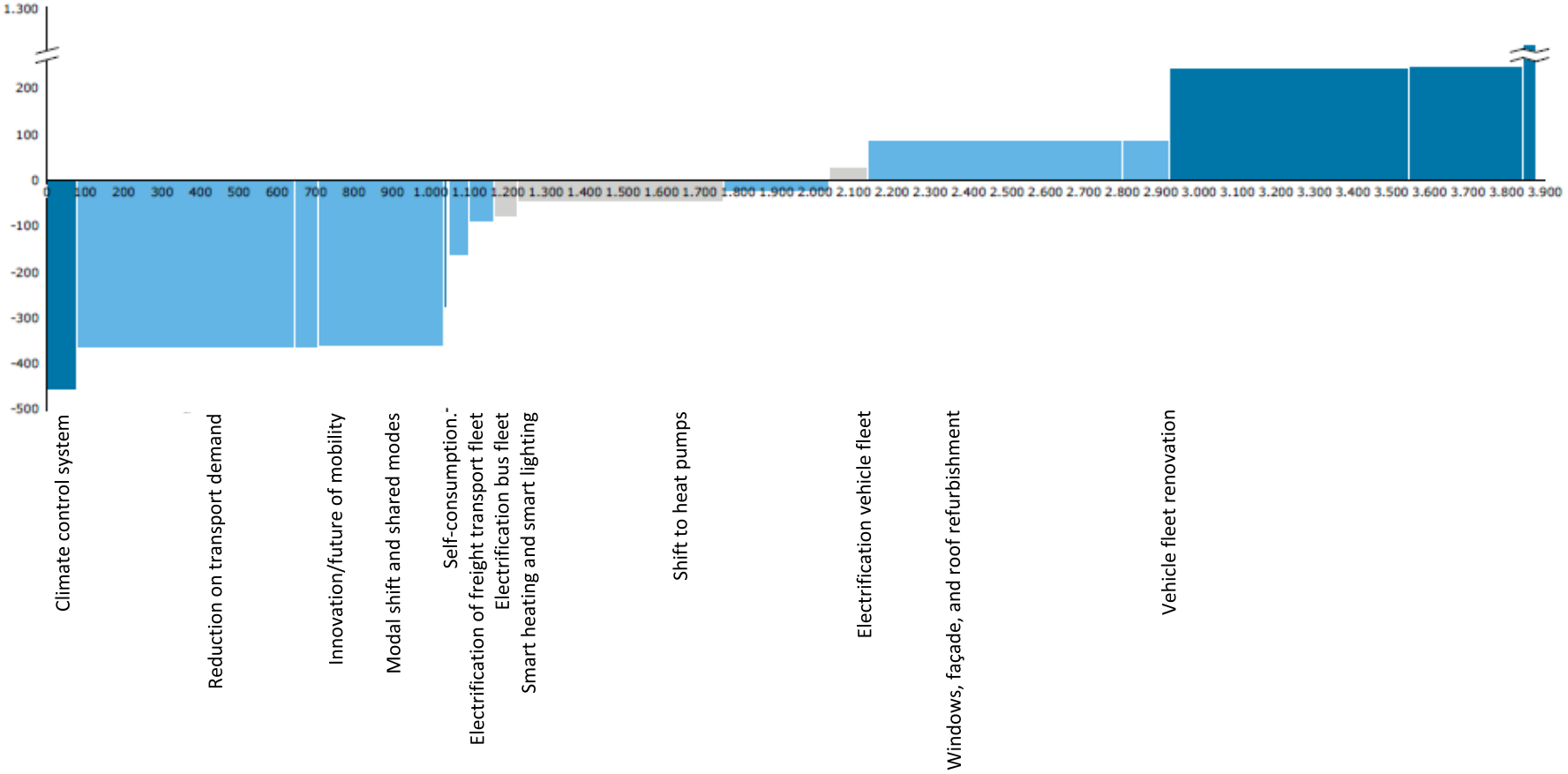
It is important to carry out an analysis at sector or driver level to identify which measures offer the greatest potential.

In the transport driver, the action that offers the greatest potential for reducing emissions is the renewal of the vehicle fleet, which will allow a 0.9 Mt CO2 eq reduction in the period 2015–2030. Its abatement cost is positive (100 €2016/ tCO2eq), which means that it is necessary for its implementation to articulate aid and incentive programs that encourage the renewal of the vehicle fleet by incorporating the most efficient automotive technologies. The electrification of the vehicle fleet, with a negative abatement cost, will also play an important role in the decarbonisation of transport and will make it possible to achieve cumulative direct emissions savings of 0.3 Mt CO2eq in the 2015–2030 period.

The actions that allow a greater volume of direct GHG emissions to be reduced at a lower cost are those focused on reducing transport demand, modal shift and the promotion of shared mobility, with a joint reduction potential that reaches 0.9 Mt CO2 eq in the 2015–2030 period.

In the residential sector, actions with the highest direct emission reduction potential (1 Mt CO2 eq) have a positive (≈ 200 €2016/tCO2eq). For its implementation it will be necessary to articulate programs to encourage the replacement of boilers and air conditioning equipment and allow the incorporation of modern natural gas condensing boilers and heat pumps that incorporate aerothermal technology. Measures such as building refurbishments offer little direct emission reduction potential and a high , even so, the city of Madrid will continue to articulate aid programs focused on the refurbishment of the housing stock.

**Abatement curve (direct emissions) for the City of Madrid between 2030 and 2015** [(1)] (€ $_{2016}$/$tCO_2eq$)

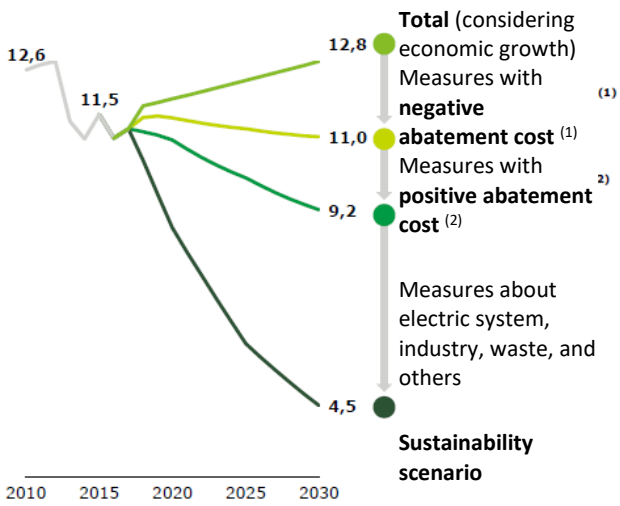



(1) Does not include abatement of direct emissions from waste, industry and other sectors
Source: Madrid City Council

The action that will have the greatest impact on the reduction of emissions in the residential sector is the reduction of emissions in the electricity sector at national level, contemplated in the PNIEC, with a potential of 1.8 $MtCO_2eq$. This has not been included in the abatement analysis because emissions from the electricity sector fall under the category of indirect emissions.

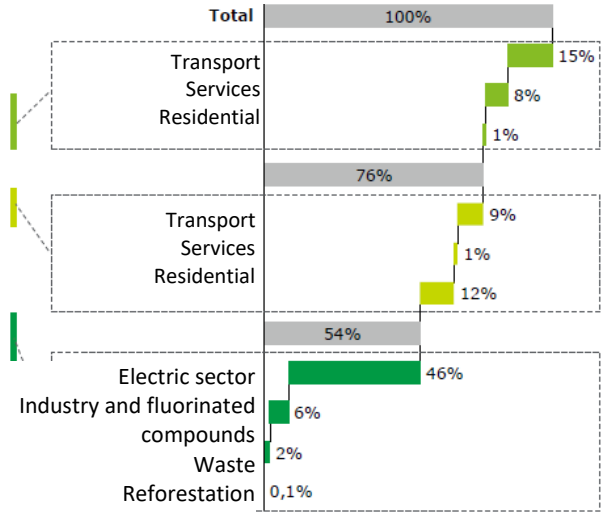
In the services sector, the enormous potential offered by heat pump technology should be highlighted, with an estimated reduction in direct emissions for the period 2015–2030 of 0.5 $MtCO_2eq$ and a negative abatement cost, which will allow the sector to undertake the renovation of the building stock, amortising the investments in a short payback period.

**Evolution of emissions 2010-2030 according to the type of measures applied (economic, technical or on the electricity** system) (Mt $CO_2$ eq)



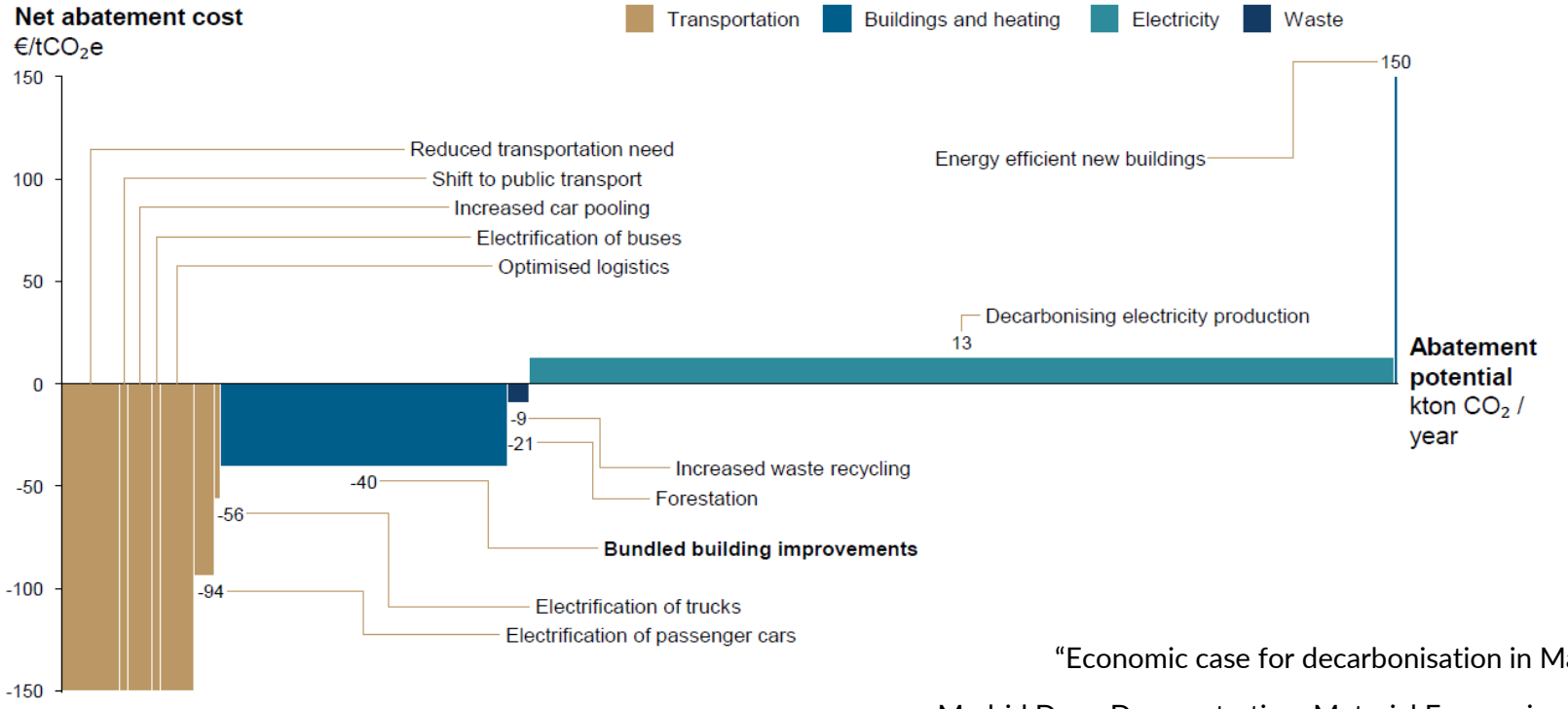

(1): Medidas a través de las cuales se genera un ahorro económico
(2): Medidas a través de las cuales se genera un coste económico
Fuente: Ayuntamiento de Madrid

**Emission reductions by sector according to type of measures** (%; 2030)




Furthermore an economic analysis within the framework of the Climate-KIC Initiative' s Madrid Deep Demo, "*Economic case for decarbonisation in Madrid*", has been conducted by *Material Economics*, by using a common methodology in several European cities, in order to allow comparing their different economic scenarios, and using the same abatement potential analysis premises of the proposed drivers in total $CO_2$ eq emissions in the 2020–2050 period. The main conclusion is that the decarbonisation of the electricity system is the most relevant action in the Roadmap towards climate neutrality in the city of Madrid. Its low abatement cost in terms of €/$tCO_2eq$ and its high potential for reducing GHG emissions make it a strategic driver on which the success of other measures depends. The decarbonisation of air conditioning and domestic hot water systems in the residential and services sector, and the incorporation of energy efficient devices, will also play a relevant role with low abatement costs and high emission reduction potential.

**Updated Madrid abatement cost curve**
kton $CO_2e$ emissions in 2030, abatement costs and benefits annualised based on investments in 2020-2030, and recurring costs/savings and co-benefits in 2020-2050




"Economic case for decarbonisation in Madrid" Julio 2021

Madrid Deep Demonstration, Material Economics- EIT Climate-KIC

## 6 Coordination between administrations and public-private partnership

Carbon neutrality cannot be addressed by acting exclusively on emission sources but requires a social transformation that changes current paradigms and lifestyles. This is a joint effort in which many actors must be involved, from administrations to the private sector, academia and citizens.

The strategic vision, the legal and regulatory framework and the economic impulse of the administrations are crucial. The local action of local councils is in many cases conditioned by the contexts offered by higher administrations. In this sense, EU policies such as the European Green Deal, or the communication of the European Commission to intensify Europe's climate ambition for 2030, proposing an emission reduction of 55% by 2030 (versus 1990), without being binding, set the pace for municipal policies.

National policies are determinant for the achievement of the objectives and the development of local plans. They are fundamental in the development of legal bodies, regulations and technical guidelines and, specifically, in the configuration of the energy and electricity mix on which the new energy model and neutrality strategies are based. National policies for the coming years are projected in the National Law on Climate Change, the PNIEC or the Long Term Strategy (ELP), all of which coincide in the objective of neutrality by the year 2050.

This Roadmap integrates national plans into local action. It integrates the objective of increasing the presence of renewable sources in electricity generation to 74%, or the principle of energy efficiency in the time horizon of 2030, as stated in the PNIEC and carbon neutrality by 2050 of the ELP.

The Ministry for Ecological Transition and Demographic Challenge (MITECO) and the Spanish Office for Climate Change, responsible for the development of state policies, are key actors in this process with whom continuous communication is maintained at local level in order to align actions.

Academia is another pillar of climate action in the city of Madrid. The relationship with this actor occurs on several levels, constituting a university-city pairing. The Universidad Politécnica de Madrid, commissioned by the City Council, prepares annual emission inventories of the city and other sectoral studies such as the study of the vehicle fleet that provide the basis for the inventories. On a strategic context, the relationship with the university has been consolidated with the approval, in the Municipal Plenary of July 2020, of the adhesion of the municipality to the European initiative for innovation in climate action Climate–KIC and the Deep Demo project. This initiative, which brings together many actors from various fields, aims to research and test actions to achieve carbon neutrality by 2050. Being part of it has allowed the creation of a working platform in which there is representation of the local administration, private companies of reference in strategic sectors, especially energy and urban planning, and the academia itself. In this space, the university, through the Centre for Innovation in Technology for Development (ITD), acts as a connector of the public-private relationship, with research and innovation groups in multiple fields.

One of the first actions of this platform was the creation of an interdepartmental collaboration tool ("Grupo Clima 360") that connects different services of the municipal structure considered key in the development of climate action, such as environment, urban planning, innovation, budget and economic management, energy, mobility, heritage, culture, etc. This working team allows climate challenges to be addressed in a comprehensive way and projects under development to be connected.

The Roadmap also implies a profound social change. Therefore, citizens must take part in the process, evolve in habits and lifestyles, but also participate in decisions. Citizen participation has precedents in numerous experiences associated with projects, but through the platform created around Climate–KIC, the aim is to systematise the involvement of people, establish direct communication channels and create steady frameworks for collaboration.

The global and complex dimension of the climate crisis requires networking. In this sense, the Roadmap outlines a path that cannot be followed in isolation. It is essential to connect with other cities, sharing knowledge and experience. At state level, Madrid is part of the "citiES 2030" initiative, which was created on 2021 as a mirror platform of the EU Mission for climate-neutral and smart cities at a national level, and also of the Cities for Climate Network of the Spanish Federation of Municipalities and Provinces, and on the international scene it is integrated in initiatives such as the Covenant of Mayors for Energy and Climate, the EUROCITIES network, and the Cities for Climate Leadership Group C40.

# 7 Key actions and processes at municipal level

Once the main drivers of transformation have been identified and the competence framework has been analysed, it is necessary to establish priorities for action at the municipal level to maximise the impact in those areas in which the City Council can intervene more directly. In this sense, two levels of action can be distinguished: identification of key drivers for municipal action and enabling processes for implementation and scaling.

For the prioritization of these actions at the municipal level, the weight in terms of emission reduction potential must obviously be taken into account, but this should not be the only criterion, and special emphasis should be placed on transforming actions that imply a modification in the established model of behaviour ("business as usual") towards more sustainable schemes in accordance with the ambitious scenario that is being pursued.

## Key Actions

Based on the contents of Chapter 4, on the transformation drivers by sector, and taking into account the economic and competence analyses in Chapters 5 and 6, a prioritisation criterion can be established for action on a municipal level.

## Transport sector

Although the renewal of the vehicle fleet is the action that brings about the greatest reduction in emissions, it should be borne in mind that it is incremental and not transformational in nature, already naturally driven by the trend scenario, so that only the usual measures to shorten the renewal cycles are contemplated, such as subsidies, tax policies fostering the use of less polluting vehicles and the promotion of demanding regulations relating to the maximum emission values for vehicles.
Furthermore, the roadmap towards climate neutrality assigns an important weight to other lines of action for which it is necessary to generate innovative policies and which follow the hierarchical concept of mobility actions A-S-I (Avoid-Shift-Improve).

### REDUCTION IN TRANSPORT DEMAND

Actions aimed at reducing the need for motorised journeys and the length of journeys through urban planning on a human scale, with mixed and proximity uses, flexible timetables and teleworking, as well as innovative demand management tools are fundamental to the roadmap

### MODAL SHIFT AND VEHICLE SHARING

Madrid is in a privileged position in terms of its public transport network, the contribution of pedestrian mobility to the modal split and shared mobility initiatives. This situation is, however, fragile and needs to be boosted by decisive actions towards active mobility, improved public transport service and widespread accessibility to shared transport.

### ELECTRIFICATION

The promotion of electric mobility, mainly associated to key fleets such as public transport, urban distribution of goods or shared mobility models, is crucial and will be the main objective of the municipal actions of the roadmap.

## Residential sector

Short-term municipal priority is given to actions of technological transformation towards low-emission elements, boosting at the same time a large-scale a residential energy refurbishment, with a mid- and long-term impact.

Replacement of existing equipment with more efficient ones is undoubtedly a necessary line of action in terms of reducing emissions, but it is the transformation of technology and habits that requires greater attention and resources. In accordance with this multi-criteria approach, three priority objectives deserve to be highlighted:

### HEAT PUMP INTEGRATION

Promoting the electrification of domestic conditioning demand is the main objective at municipal level, which implies tools to increase accessibility to heating/cooling systems both from the technical perspective – with a necessary boost in technological innovation – and from the economic perspective to allow its widespread implementation.

The accompaniment of the private sector is fundamental.

### CLIMATE CONTROL SYSTEMS

The incorporation of consumption control tools entails an awareness, on the part of the citizen, of their capacity in terms of management, consumption and even generation.

Accessible and clear online information on consumption and costs will create a culture of efficiency and empower the consumer.

### REPLACEMENT OF NATURAL GAS BOILERS.

Various municipal support actions can shorten renovation cycles towards more efficient models. Given the widespread use of natural gas in domestic heating, replacement with high-efficiency condensing boilers has a significant potential impact on emissions.

However, natural gas should be considered as a transition fuel towards other technological options that allow climate neutrality to be achieved.

## Services sector

Action in the commercial, administrative, and institutional sector is key in the city of Madrid, with an almost equivalent impact to the residential sector in terms of emissions reduction. The main decarbonisation levers to be prioritised at municipal level include equipment renewal, refurbishment and energy efficiency.
The specific lines of action to be highlighted within these drivers are:

### REPLACEMENT OF SYSTEMS USING FOSSIL FUELS (DIESEL AND NATURAL GAS) BY HEAT PUMPS OR OTHER LOW-EMISSION TECHNOLOGIES

The commercial and institutional sector must lead the transformation of the electrification of demand in the building stock and, as far as municipal facilities (health, cultural and sports buildings and complexes) are concerned, fulfil the exemplary role required of the administration.

### ENERGY EFFICIENCY IN LIGHTING

The concept of smart lighting in public lighting services is a high impact action. Likewise, the involvement of the commercial sector in the implementation of efficient lighting systems is also a priority, so specific collaboration channels will be established for the service sector.

### EFFICIENCY AND REHABILITATION OF MUNICIPAL BUILDINGS

Saving and energy efficiency in municipal facilities is an unavoidable objective that will be addressed through monitoring tools, equipment renewal and investment facilities for the comprehensive energy rehabilitation of buildings.

## Other sectors

Along with mobility and building as the main sectors emitting diffuse GHG sources, the Roadmap identifies other actions of significant impact that need to be addressed at the municipal level, specially concerning waste urban management considering the local capacity for action:

### WASTE MANAGEMENT

Actions concerning waste reduction hierarchy, recycling materials, and improvement on treatment processes will be promoted.
Organic waste management and treatment is a key element at a municipal level, therefore process optimization towards methane reduction on emissions from Valdemingómez Technology Park (PTV) will be worked on. Thus organic waste treatment will be boosted through its biomethanization (anaerobic digestion) and biogas use by injecting it into the natural gas network.
The generation of biomethane and electricity of renewable origin, from the waste produced by citizens and treated at the Valdemingómez Technology Park, contributes to the reduction of fossil fuel consumption in the automotive sector asa well as in the residential, industrial or service sectors in general. Therefore, progress will continue to be made in the improvement of the production and transformation procesess of these renewable energy sources and in the application of the best available techniques in reducting emissions into the atmosphere.
The City Council will advance in the self-consumption of electricity and biomethane generated from municipal waste in the Valdemingómez Technology Park, so that these can play a key role in the neutrality of emissions from municipal services, specifically in services such as the public bus service (EMT), waste collection vehicles or municipal buildings themselves.

### REDUCTION OF THE IMPACT OF REFRIGERANT GASES

Many of the gasaes used in refrigeration and air conditining are fluorinated, have a high global warming potential and their use has increased significantly in recent years. Madrid aims to encourage alternative technologies to fluorinated greenhouse gases, those which use other gases with lower global warming potential, as well as to improve the maintenance and recovery of these gaes in existing equipment.

## Implementation and scaling driving processes

The transformation drivers structure the Roadmap to climate neutrality, but it should not be forgotten that a systemic transformation is necessary, i.e. not only a technological innovation, but also a social, political, economic, financial and institutional one. Therefore, it is essential to create new enabling tools that favour implementation and scaling. The city of Madrid has proposed the following actions for the development of its Roadmap aimed at promoting processes:

- INTERDEPARTMENTAL WORK TEAM (**Grupo Clima 360**): made up of representatives from different municipal areas (Environment and Mobility, Urban Development, Economy, Innovation, Finance, Culture, International, etc.) who contribute the multiple visions required by the Roadmap.

- NORMATIVE REVIEW: review processes of regulations, ordinances and municipal plans under the perspective of climate neutrality. Opportunity to generate regulatory sandboxes that allow experimentation with decarbonisation models not contemplated or difficult to implement with the existing regulatory framework.

- The **"Áreas demostradoras de acción climática"** ("Climate Action Demo Areas"), as featured on the Ordenanza de Calidad del Aire y Sostenibilidad (Air Quality and Sustainability Norm) of March 2021 should be highlighted. They will develop measures to accelerate decarbonization, which will help to meet climate neutrality goals. These Areas will rely on an action plan featuring the necessary measures to achieve a higher emission reduction than those required by current regulations. Thus, this action plan will also boost their air quality, and could be implemented in the rest of the city.

- CLIMATE FINANCING: implementation of financing schemes that allow the Roadmap to be developed based on economic analysis. Integration of the climate variable in municipal budgets.

- MULTIAGENT COLLABORATION PLATFORM: based on the experience of Madrid as a demonstrator city of the Climate-KIC programme “Clean and Healthy Cities”, consolidation of a platform that promotes systemic innovation, accelerating portfolios of transformative projects. This platform is made up of the City Council, the scientific community, the private sector and citizens.

- NATIONAL AND INTERNATIONAL COLLABORATION NETWORKS.

# 8 Vulnerability to impacts and adaptation to climate change

Reducing GHG emissions should be the priority objective of Climate Action. However, the consequences of Global Warming make it necessary to respond to the existing threats and impacts. The modification of the global climate system generates chain effects that reach the local scale and are not limited to environmental aspects, but also have a social and economic impact.

This Roadmap aims to guide the city of Madrid towards compliance with the Paris Agreement, reducing its emissions with the objective of achieving neutrality in 2050, but also incorporates the other objectives set out in Article 2. "*Enhance adaptive capacity to the adverse effects of climate change and promote climate resilience*."

The European Green Deal, which expresses the political commitment to transform the EU into an equitable and prosperous society with a modern, resource-efficient and competitive economy, also incorporates in its goals to protect, maintain and enhance the EU's natural capital, as well as to protect the health and well-being of citizens from environmental risks and impacts.

At the national level, the draft Climate Change and Energy Transition Law provides the institutional framework for the implementation of the objectives of the Paris Agreement and strengthens the role of adaptation in the development of these policies. More specifically, the National Plan for Adaptation to Climate Change (PNACC) is a reference to guide local plans and actions.

The local dimension of Climate Change Adaptation should be highlighted. The impacts derived from the alteration of climate become real and close risks that affect urban systems, from the provision of resources, water management, energy demand or the degradation of natural spaces, but above all they have an impact on the most vulnerable social groups and on economic activity.

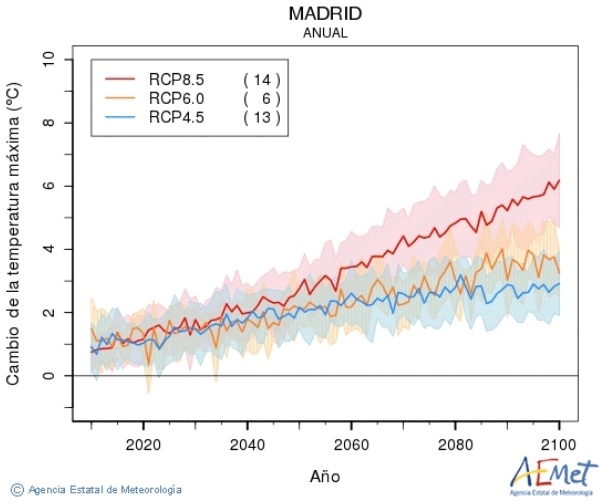
## Climate scenarios and risk assessment

The evolution of the climate in Madrid is inferred from the regionalised climate scenarios. Despite the influence of the city on certain variables, the basis of its climate depends on the climate of the whole region. Based on the regionalised projections provided by the State Meteorological Agency (AEMET) and the platform AdapteCCa (Adaptation Platform of the Spanish Office of CC), it is possible to know the future scenarios.

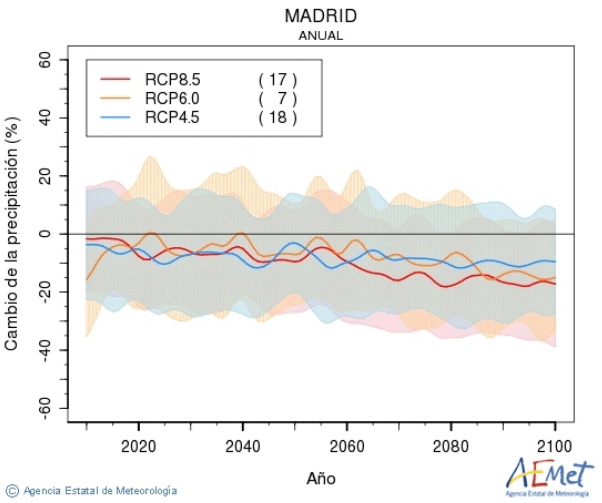
With regard to temperatures, the trend observed is an increase in maximum temperatures, an increase in the number of warm days and hot nights (those exceeding 20° C minimum), and an increase in the duration of heat wave episodes. The evolution of these variables becomes more pronounced in the representative concentration trajectory (RCP 8.5) with increases of more than 5°C in maximum temperatures at the end of this century or the increase in heat wave episodes.

Regarding rainfall, there is a decreasing trend in the volume and number of rainy days. Furthermore, the dry periods show an increasing evolution.

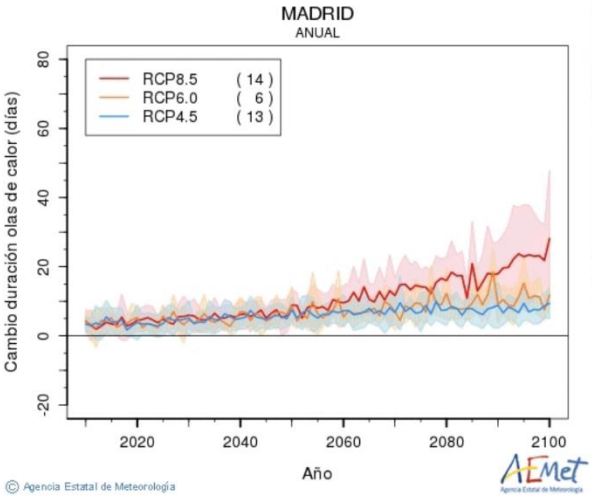
**Change in maximum temperature**



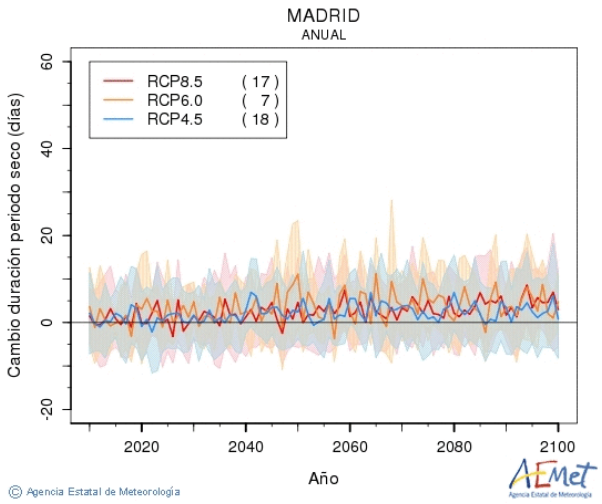

**Change in precipitation**




**Change in duration of heat waves**




**Change in duration of dry period**




Graphical results of regionalised projections of climate change (temperature y precipitation). Source: AEMET.
*Available en:* *http://www.aemet.es/en/serviciosclimaticos/cambio_climat/result_graficos*

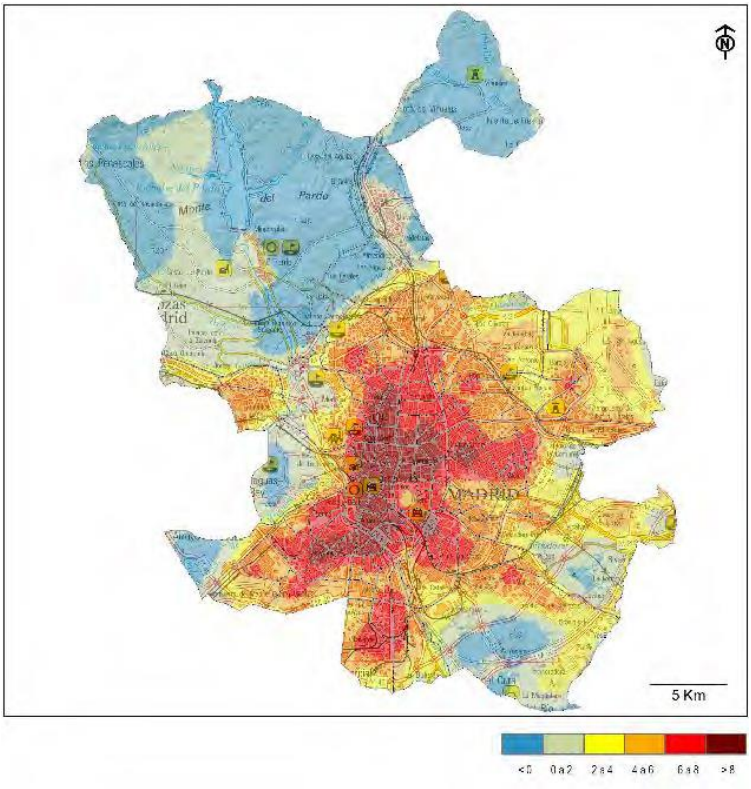
The alteration of climatic conditions shown in the predicted scenarios is at the origin of a series of chains of impacts. According to the municipal study *Análisis de vulnerabilidad ante el cambio climático del municipio de Madrid* (*Vulnerability Analysis in the face of Climate Change in the City of Madrid*), the city will be affected by the following:

- **Heat waves:** direct effects on health, mortality and morbidity, increased energy demand, increased water consumption, reduced work output, effects on tourism, etc.
- **Droughts:** drinking water supply problems, reduction of quality, impact on economy, business and tourism, degradation of natural spaces, etc.
- **Extreme weather events:** floods, storms, strong wind gusts, snowfalls, hailstorms... Personal injuries, impact on infrastructure and buildings, decrease on water quality, increase on emergencies, mobility problems.
- **Environmental degradation:** alteration or modification of ecosystems and loss of biodiversity, increase of vectors, pests, and diseases.

These impact chains generate a cascading effect with spin-off effects on multiple aspects of city life and activity, from health to air quality to working conditions and economy.
This same analysis assesses, at district level, the areas of Madrid most vulnerable to these effects, showing the spatial coincidence of climate vulnerability with social and economic vulnerability.
Although the climate of the city of Madrid is regional, like other large metropolises, the urban morphology, materials and urban activity, cause particular climatic conditions at a micro-scale and phenomena such as the Urban Heat Island effect.
The *Estudio de Detalle del Clima Urbano de Madrid* (*Detail Study of Madrid's Urban Climate*) carried out by the urban climate research group of the Universidad Autónoma de Madrid and commissioned by the Madrid City Council, deepens the knowledge of the Urban Heat Island effect, closely related to the impact of heat waves. The study coincides with the trends of the regional climate scenarios and draws up a map of the heat footprint in the city that makes it possible to locate the most exposed places or "hot spots".

## Adaptation objectives

The climate in Madrid is changing and, based on environmental projections, is expected to continue to evolve on the same trajectory over the coming decades. Changes in environmental conditions are generating risks to public health, the economy and the balance of natural and urban systems.
To cope with current and future climate impacts Madrid must adapt, **transforming itself into a more resilient, sustainable and healthy city**. Adaptation is a joint and cross-cutting transformation, which must align sectoral policies and the coordinated efforts of multiple agents from all sectors of society.




*Distribution of the physiological heat island in summer.*
*Detail of the Urban Climate of Madrid. April 2016. Madrid City Council. Felipe Fernandez et al. UAM.*

## **MORE HEAT.** Higher temperatures, more frequent and intense heat waves

Minimum and maximum temperatures are expected to continue to rise throughout the century. Heat waves will be more frequent, longer and more intense, aggravating the urban heat island effect.

### Strategic objective: A cooler city

Implement economically and environmentally sustainable initiatives that cool the city and prevent it from overheating during the warmer months. Protect the most exposed, most sensitive or least responsive populations from excessive heat. Incorporate **green and blue infrastructures** into the fabric of the city by taking advantage of vegetation and water to enhance public space through Nature-Based Solutions (NBS).

#### Specific objectives

- Increase green areas and tree canopy (tree cover), in order to improve thermal regulation on urban open spaces.
- Increase the number of green roofs on urban buildings.

- Mitigate the impact on most vulnerable population groups, senior citizens, child and young population, people with heat-aggravated illnesses.
- Promoting the use of high-albedo materials both on buildings and urban design.
- Integrate urban green infrastructure on urban planning: buildings, mobility, energy, etc.
- Improving early warning systems and emergency plans.

An analysis of the main barriers hindering the "Cooling the city" goal, and of the necessary measures to overcome said barriers is as follows:

1. Table 1:Barriers and measures concerning the "Cooling the city" goal

| Barriers concerning increase in temperatures | | Measures |
|---|---|---|
| 1 | Limited capacity to work on materials and morphology of the **already existing buildings and infrastructures**. | Develop innovative measures to implement NBS in urban rehabilitation. |
| 2 | Great residential areas with **scarce liveability conditions** during heat waves. | Promote energy refurbishment on buildings.<br>Boost a resilient facilities network.<br>Create a climate shelter network. |
| 3 | **Urban open spaces on inadequate conditions** during heat waves. | Implementing climate change adaptation criteria in refurbishment and new urban plans.<br>Increase of green infrastructure.<br>Resilient facilities network.<br>Climate shelters. |
| 4 | **Challenging climate conditions** for implementation, improvement and maintenance of green infrastructure. | Research on adapted species and improve revegetation techniques. |
| 5 | **Scarce knowledge** about heat-related impacts. | Improving communication and early warning systems. |

**LESS WATER, MORE CONCENTRATED**. More frequent and longer periods of drought, slightly less annual rainfall, but with an irregular distribution.

Climate projections point to a continued decline in annual precipitation, longer periods without rain and more days of heavy rainfall per year.

### Strategic objective: Reduce and reuse

Maximize **efficiency in water management** in the city. Harnessing alternative water resources by reducing the demand for potable water. Minimize losses by auditing, repairing, modifying and maintaining supply, irrigation and sanitation networks.

### Strategic objective: Ensuring access

Continue to promote **responsible consumption and ensure quality and access** with special attention to the most vulnerable groups.

#### Specific objectives

- Reduce water demand and encourage responsible use.
- Replace waterproof pavement with permeable or natural pavement.
- Extend the reclaimed water network for park irrigation.
- Reduce supply losses.
- Explore new sources of use and reuse alternatives.

Barriers hindering “Reduce and reuse" and “Ensuring access" goals, and measures to overcome them are summarised on the following table.

*Table 2: Barriers and measures concerning "Reduce and reuse" and "Ensuring access" goals*

| Barriers against water scarcity | | Measures |
|---|---|---|
| 1 | **High demand habits**. | Raise awareness of population and of large water-consumer sectors. |
| 2 | **Inefficient water management.** | Improvement on curbing water demand, and on water reuse and regeneration. Promote separate sewer networks, sustainable drainage systems, replacing potable water networks with regenerated water networks on irrigation systems. Decrease losses in distribution networks. |
| 3 | High **investment** needed. | Mobilize resources to promote efficient management.<br>Economic assessment of climate change impact in order to justify monetary inversion. |

## **MORE EXTREME EVENTS.** More frequent storms and floods.

Extreme weather events, storms, strong wind gusts and torrential rains will occur more frequently. Increased risk of flooding and damage to urban facilities and infrastructure.

### Strategic objective: Protect and secure

Implement measures to protect the city against extreme events, storms, torrential rains, snowfalls, calima, etc. with special attention to the most vulnerable population. Increase Madrid’s response capacity. Increase the resilience of infrastructures and services.

### Strategic objective: Transforming rainfall management in Madrid

Increase the retention and permeability of water in the city by means of Sustainable Urban Drainage Systems and the implementation of Nature-Based Solutions that

reduce the peak flows when entering the purification systems in order to minimise the discharge of polluted water into natural watercourses. Use water to improve the urban microclimate, recharge aquifers, promote urban biodiversity and enhance the well-being of citizens.

**Specific objectives**

- Extend the use of Sustainable Urban Drainage Systems.
- Increase rainwater retention and infiltration.
- Explore the expansion of greywater uses.
- Improving communication and early warning systems and communication of extreme weather events.
- Improving emergency plans.

Some of the barriers and measures concerning the above strategic objectives are summarised on table 3.

*Table 3: Barriers and measures concerning "Keep safe and secure" and "Transforming rainwater management in Madrid" goals*

| Barriers concerning extreme weather events | | Measures |
|---|---|---|
| 1 | Complex impact **early warning and forecast**. | Develop and improve early warning strategies. Integrate climate risks on emergency plans. |
| 2 | Rigid and non-flexible **urban infrastructures** and systems. | Implementing flexibility mechanisms on urban infrastructures and system management. Shift current urban water management towards more natural models. Implementation of Urban Sustainable Drainage Systems. |
| 3 | Lack of services **coordination**. | Create cross-sectional coordination strategies. |
| 4 | Lack of **response protocols** for climate impacts | Contingency plans development. |

# DIMINISHING BIODIVERSITY, NEW CHALLENGES.
## Degradation of natural areas, alteration of ecosystems

The accelerated change of climatic conditions will endanger the balance of existing ecosystems in the city. Linked to the warmer climate, new vectors, pests and diseases could appear, increasing the risk to public health or to the well-being of the flora and fauna of the city.

### Strategic objective: Promoting the inclusion of nature in the city

Protect and enhance **biodiversity** in the city in a sustainable manner through strategic approaches aimed at resilience and adaptation. Promote green infrastructures that facilitate the functioning of ecosystem services, improve connectivity, micro-climatic conditions, air quality, or energy efficiency, among other co-benefits.

### Strategic objective: Knowing and controlling biodiversity and ecosystems

Adapt municipal protocols and mechanisms to **anticipate, detect and control** the emergence of new vectors of disease transmission. Study and manage the appearance of new pests and risks for the vegetation and animals of Madrid.

#### Specific objectives

- Increase the connectivity of urban and surrounding green areas.
- Increase the diversity of plant species in the city.
- Generate attractive and suitable conditions for wildlife.
- Test and extend the design of green areas with natural habitat criteria.
- Monitor vectors, pests, and diseases associated with changes on ecosystems.
-

An analysis of the main barriers hindering “Promoting nature in the city" and "Knowing and controlling biodiversity and ecosystems" goals, and of the necessary measures to overcome said barriers is as follows:

*Table 4: Barriers and measures concerning "Promoting nature in the city" and "Knowing and controlling biodiversity and ecosystems" goals*

| Barriers concerning biodiversity promotion | | Measures |
|---|---|---|
| 1 | **Increase on vectors**, pests and diseases associated with changes on climate conditions. | Conduct monitoring and assessments studies. Set ecosystem- and species-friendly control strategies. |
| 2 | Simplification and **habitat destruction.** | Promote biodiversity hubs and connectors between urban green areas and natural landscapes. Boost requirements for spontaneous flora and fauna to thrive. |
| 3 | **Nature-phobia** and lack of information about the importance of urban biodiversity | Develop awareness programs and working on alliances with organizations promoting urban natural capital. |
| 4 | **Inadequate practices** on vectors, pests and diseases control; phytosanitary treatments, pests controts... | Revise current strategies and develop alternative, species- and habitat-friendly methods. |

As in the development of mitigation actions, adaptation requires a **cross-cutting and coordinated response**, due to the multiplicity of factors involved and the effects that derive from climate change. In this sense, the interdepartmental working team Grupo Clima will allow some emblematic projects of the city related to the development of green infrastructure and biodiversity to be comprehensively addressed, while acting as a platform to promote the necessary stable partnerships with stakeholders from the private, academic and citizen sectors.

# 9 Monitoring and communication

The tracking of the Roadmap towards climate neutrality is carried out through a three-pronged approach whichdeals with different needs and monitoring goals:

1) The results from the **Inventario de Emisiones de Gases de Efecto Invernadero** (Greenhouse Gases Emission Inventory) show Madrid's annual improvement towards neutrality. The Inventario is being used since 2006 and allows to know the annual Scope 1 and 2 (direct and indirect) emissions from the city, as well as their evolution record and trends. The Inventario has been collected a globally recognised methodology, provides total and disaggregated emission data, and helps to know climate action results in terms of reduction goals.
   The Inventario basic information is collected by directly surveying the main emissions sources; more information from regional and state administrations is added, as well as specific research like the Parque Circulante de la Ciudad de Madrid (Vehicle Fleet from the City of Madrid), el Modelo de Tráfico (Traffic Model), and the Balance Energético (Energy Balance), among others.
   The Annex I compiles the required indicators for a monitoring of this Roadmap. The GHG emissions inventory provides the general indicators which can be found on said Annex.

2) The emissions inventory has some limitations, like the 1-2 year temporal discrepancy due to the data collection methodology, or the difficulty on assessing the emission impact on given drivers. Thus, it is advisable to also use an urban trends indicator system which allows for a more detailed analysis of assumptions and scenarios achievement, the degree of measures implementation and its development during next years. This trend monitoring will integrate action adaptation assessment through resilience and/or vulnerability indicators.
   Besides general monitoring indicators, Annex I also identifies different indicators per sector, in order to assess and show the trends and impact of the Roadmap drivers and lines of action.

3) Lastly, an advanced system to diagnose and assess GHG and air pollutants emissions sources on the City of Madrid will be developed in order to follow up, simulate and asses the impact on air pollutants of different environmental policies and development scenarios of urban dynamics. This tool is based on numerous urban data from both public and private sources and will provide a geographic display of emissions with a high level of detail.

The Roadmap, the inventory data and the regular assessment reports **will be published on the municipal website and on specific publications, so the information will be transparent and available to anyone interested.**

### Communication strategy

The Roadmap is a guide for all those people or entities involved in mitigation and adaptation in the city. In this sense, its dissemination is considered part of the implementation and development process. The communication strategy will adapt its contents according to the target audience, communication channel and objective of each informative action.

Dissemination within the Madrid City Council is important in order to align the policies of the different municipal areas, but it is especially necessary to involve the private sector, organised society and citizens in general. This message and ambition must reach all of them in a way that is appropriate to their position and capacity for action.

## 10 Threats and barriers

The climate crisis is defined by its complexity and interrelationship between multiple factors in seemingly distant spheres. Because of this, threats and barriers can originate and appear in the same way from different places.

Regarding the fulfilment of the Roadmap objectives, the uncertainty lies in the pace and time needed to achieve the objectives.

Technically, the degree of development achieved seems to allow access to neutral city scenarios within the time horizons proposed in this Roadmap and, although there are uncertainties in some aspects (evolution in the development of batteries, adaptation of distribution networks, development of hydrogen technology, waste classification and treatment techniques, as well as the costs for their implementation, development of the markets for recovered materials, etc.), they do not seem to compromise the purpose.

In this area, success in achieving neutrality depends to a large extent on the **decarbonisation of the electricity mix**, which, if the established rates and milestones are not met, will slow down the whole process.

The adaptation of infrastructures, the transformation of the city's traffic fleet, the improvement of the energy efficiency of buildings, the extension of air conditioning systems based on clean energies or the improvement of waste collection and treatment processes must incorporate technical improvements and require long development periods that could alter the expected pace.

However, the greatest threats and barriers will be those related to social and economic aspects. The goal of a carbon neutral city cannot be achieved if there is no **public-private-social collaboration** in all aspects of the process. This urban development can only be understood in an inclusive society in a favourable and sustainable economic context.

The models of **governance** are also a key aspect. Climate action proposes comprehensive transformations that are sometimes difficult to develop in excessively rigid and compartmentalised administrative and organisational schemes and regulations whose design has not incorporated the climate variable.

A threat can also be posed by the **disconnection between scales**. Climate action in the city must be related to the metropolitan, regional and state context. Many urban activities and systems (mobility, food, energy, water, etc.) are strongly influenced by these other areas. Similarly, the process can be misdirected or slowed down if there is a lack **alignment in the policies of the different** administrations– – local, regional, national and European.

The **harmonization between policies** will be necessary not only in strategic and legal terms. The urban transformation that must be faced will require financial and budgetary policies and strategies that will have to be agile and efficient, for which **institutional coordination** is crucial.

The implementation of actions will require high investments, in some cases with direct economic returns and in a period of time that can be assumed by investors, but in many others this return will occur in the long term, as can be seen in the economic analysis, and will even be non-existent in purely economic terms, as in the case of many urban resilience actions. A favourable **economic context** and a wider focus when assessing returns will facilitate thus the implementation of measures.

The process towards climate neutrality requires a profound urban transformation, socially, economically and environmentally. The challenge lies in overcoming the inertia and immobile positions that hold back this evolution until we reach new paradigms and inertias which will naturally lead to a climate-neutral, economically prosperous and socially inclusive city. In a previous analysis of local barriers which affect climate action and potential improving actions, the following barriers were found.

*Table 5: Local barriers and measures concerning the Roadmap*

| Local barriers against the Roadmap | Measures |
|---|---|
| No climate criteria on urban regulations and planning | Revision of regulations and administrative management tools from a climate viewpoint.<br>Climate testing and innovation areas (regulation sandboxes) and change on regulations.<br>Awareness raising and training of urban planning and construction staff and professionals. |
| Lack of specific budget and funding tools for climate actions | Co-benefits economic assessment.<br>Private investment channelling tools. |
| Excessive segmentation on municipal framework and management which hinders comprehensive actions | Creating coordination areas and cross-sectional groups.<br>Scope change.<br>Inclusión de la variable climática en los diferentes ámbitos y planes municipales<br>Adding climate variables on different municipal scopes and planning. |
| Coordination problems among different administrations | Setting coordination boards and channels for different areas and resources. |
| Work inertia and routine. Difficult implementation of technical and planning innovations. | Creating work groups to share knowledge and training.<br>Developing training activities into municipal framework.<br>Boosting local, national and international networks and platforms. |

| | |
|---|---|
| Scarce risks and impact assessments tools. Economic assessment, impact on health, energy consumption, etc. | Developing monitoring tools for Climate Change effects - both risks and measures co-benefits. |
| Lack of knowledge among citizenship about climate risks and of mitigation and adaptation available actions. Difficult engagement of urban actors. | Providing information about climate change, focusing on relatable topics.<br>Facilitating shift towards new environments and habits.<br>Integrating population groups – especially the most vulnerable ones – on projects and initiatives against climate change. |

# 11 Annexes and relevant information

Annex I.- Climate neutrality trend monitoring indicators

## Relevant information

- *Inventario de Gases de Efecto Invernadero de la Ciudad de Madrid* (*Greenhouse Gases Inventory from the City of Madrid*, 2019). Madrid City Council. 2021
- *The total economic case for decarbonisation in Madrid*. Material Economics. November 2020
- *Adaptación climática mediante soluciones basadas en la naturaleza: Madrid + Natural (Climatic adaptation through nature-based solutions: Madrid + Natural)* Madrid City Council 2020

Identified indicators for drivers and lines of action monitoring are as follow:

| **1.- General monitoring indicators** | | | |
|---|---|---|---|
| **Action** | **Indicator** | **Trend** | **Unit** |
| **General** | Total greenhouse gases (GHG) emissions | Available | kt $CO_2$eq |
| | Direct GHG emissions | Available | kt $CO_2$eq |
| | Indirect GHG emissions | Available | kt $CO_2$eq |
| | City emission intensity (emission/ud PIB) | Available | t $CO_2$eq/mill. € |
| | City energy intensity (Final energy consumption/ud PIB) | Available | tep/mill. € |
| **Residential** | Total greenhouse gases (GHG) emissions on residential sector | Available | kt $CO_2$eq |
| | Direct GHG emissions on residential sector | Available | kt $CO_2$eq |
| | Indirect GHG emissions on residential sector | Available | kt $CO_2$eq |
| **Services** | Total greenhouse gases (GHG) emissions on services sector | Available | kt $CO_2$eq |
| | Direct GHG emissions on services sector | Available | kt $CO_2$eq |
| | Indirect GHG emissions on services sector | Available | kt $CO_2$eq |

| | | | |
|---|---|---|---|
| **Transport** | Total greenhouse gases (GHG) emissions on transport sector | Available | kt $CO_2$eq |
| | Direct GHG emissions on transport sector | Available | kt $CO_2$eq |
| | Indirect GHG emissions on transport sector | Available | kt $CO_2$eq |
| **Industry** | Total greenhouse gases (GHG) emissions on industry sector | Available | kt $CO_2$eq |
| | Direct GHG emissions on industry sector | Available | kt $CO_2$eq |
| | Indirect GHG emissions on industry sector | Available | kt $CO_2$eq |
| **Sink accumulation** | $CO_2$ accumulation evolution (sinks) | Available | kt $CO_2$ |
| **Electricity** | Evolution of electrical emission factor (national level) | Available | kt $CO_2$/MWh |
| | Renewable electric generation | Available | ktep |
| | Electric energy contribution to total energy consumption | Available | % |
| **Thermal renewable energy** | Evolution of thermal renewable energy generation | Available | ktep |

| **2.- Residential sector:** Zero-emissions residential buildings | | | |
|---|---|---|---|
| **Action** | **Indicator** | **Trend** | **Unit** |
| **Reduce energy demand improving buildings isolation and energy efficiency** | Evolution of number of refurbished homes | In progress | Nº of homes |
| | Evolution of refurbished area | In progress | $m^2$ |
| **Shift to more efficient equipments and facilities** | Evolution of number of coal-fuelled boilers | Available | Nº of installations |
| | Evolution of natural gas consumption | Available | ktep |
| | Electric energy contribution to total energy consumption on residential and services sectors | Available | % |
| **Local actions for electric system decarbonization** | Ver 'General monitoring indicators' | - | - |

| **3.- Zero-emissions transport sector** | | | |
|---|---|---|---|
| **Action** | **Indicator** | **Trend** | **Unit** |
| **Reducing travel/private transport demand** | Evolution of traffic volume | Available | Miles of vehicles/day |
| | Evolution of private vehicle use | Available | Millions of vehicles·km/year |
| | Evolution of teleworking | In progress | In progress |
| | Evolution of new low-emission areas (ZBE) | In progress | $m^2$ |
| | Evolution of percentage of restricted parking service areas (SER) | In progress | $m^2$ SER/total built-up $m^2$ |
| **Modal shift from private vehicle towards other modes / intermodality** | Evolution of pedestrian mobility (working days; Saturdays, Sundays and public holidays) | Available | Miles of persons/day |
| | Evolution of public transport mobility | Available | Nº of users (millions/year) |
| | Evolution of cycling mobility (nº of BiciMAD stations) | Available | Nº of stations |
| | Evolution of cycling mobility (BiciMAD usage) | Available | Miles of uses/year |
| | Evolution of zero-emission carsharing/carpooling | In progress | Nº of vehicles/year |
| **Fleet electrification and renovation. Service optimization (Public transport and urban freight transport)** | Evolution of zero-emission vehicle registration compared to total of registrations | Available | % |
| | Evolution of zero-emission taxis compared to total of taxis | Available | % |
| | Evolution of zero-emission buses compared to total of buses | Available | % |

| | | | |
|---|---|---|---|
| | Evolution of DGT environmental badges on vehicle fleet (private vehicles) | Available | Nº of private vehicles (miles) |
| | Evolution of DGT environmental badges on new registrations (private vehicles) | Available | Nº of private vehicles |
| | Evolution of DGT environmental badges on vehicle fleet (motorcycles) | Available | Nº of motorcycles |
| | Evolution of DGT environmental badges on new registrations (motorcycles) | Available | Nº of motorcycles |
| | Evolution of municipal fleet zero-emission vehicles | Available | % ZERO |
| **Reducing emissions on aviation sector** | Evolution of aviation fuel consumption (kerosene on landing-taking off) | Available | ktep |
| | Evolution of total flights per year | Available | Miles of flights/year |

| **4.- Services sector:** Zero-emissions buildings and facilities from services, commercial and institutional sectors | | | |
|---|---|---|---|
| **Action** | **Indicator** | **Trend** | **Unit** |
| **Reducing energy demand by building isolation and boosting energy efficiency** | Evolution of energy consumption of a sample of municipal facilities | In progress | Energy consumption/$m^2$ |
| **Shift to more efficient equipment and facilities** | Evolution of number of heat pumps | In progress | Nº of installations |
| | Evolution of consumption of street lighting | Available | kWh |
| | Evolution of number of street lights (city, monuments, roads, and tunnels longer than 200 m) | Available | Nº of street lights |
| | Evolution of consumption of street lighting in relation to number of street lights | Available | kWh/nº of street lights |
| | Evolution of power of street lighting (city, monuments, roads, and tunnels longer than 200 m) | Available | kWh |
| **Local actions for electric system decarbonization** | Evolution of municipal solar energy power. | Available | kWp |
| | Evolution of solar energy generation on municipal building and facilities | Available | MWh |

| **5.- Waste sector:** Reducing waste impact | | | |
|---|---|---|---|
| **Action** | **Indicator** | **Trend** | **Unit** |
| **Reducing waste generation** | Evolution of generation rate per capita | Available | kg/(inhabitant·year) |
| **Raising recovery rates on residential, services and municipal sectors.** | Raise in recovery rates on residential, services and municipal sectors | Available | % |
| **Organic waste collection and treatment** | Evolution of selective collection of organic waste | Available | t/year |
| | Evolution of biogas from biomethanization related to biomethanization organic waste | Available | $Nm^3/t$ |
| | Evolution of biomethane injected into gas network related to total of biogas | Available | $Nm^3$ biomethane/$Nm^3$ biogas |

| **6.- Industry and other sectors :** Emission reduction in other sectors | | | |
|---|---|---|---|
| **Action** | **Indicator** | **Trend** | **Unit** |
| **Reducing the impact of solvent and refrigerant gases** | Evolution of fluorinated gases emissions | Available | t |
| **Reduction of industrial sector emissions** | Evolution of final energy consumption on the industrial sector | Available | ktep |
| | Electric energy contribution to final energy consumption total on the industrial sector | Available | % |
| **Naturalised areas and reforested city** | Evolution of tree canopy | In progress | In progress |
| | Evolution of green areas | In progress | % |

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