ASSESSING THE COSTS AND BENEFITS OF THE SUSTAINABLE URBAN MOBILITY TRANSITION IN A EUROPEAN CITY

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Managing urban mobility is one of the most complex challenges facing city governments. Scarce resources make it necessary to adopt an integrated strategy, able to apply sustainable mobility policies evaluated in a scientific and measurable way and flexible enough to accommodate for future changes. In this context, this paper assesses the magnitude and the impacts of the transition to sustainable urban mobility, by providing the preliminary quantification of its costs and benefits in the city of Munich by 2030 and 2050. This example has been selected among the European cities considered within the 2021 EIT Urban Mobility study (Borgato et al., 2021).
The paper illustrates through transport, environmental and economic indicators the impacts of the mobility transition in three potential scenarios simulated with the MOMOS assessment tool. Additionally, the paper focuses on the effectiveness of sustainable policies' clusters. It provides an understanding of how intensively policies should be implemented to reach the Green Deal target and the EU objectives in the field of sustainable urban transport.
Results shows that in Munich – as in most of the European cities considered in the EIT Urban Mobility study – the Green Deal CO_2 emission reduction targets for the year 2050 (-90%, compared to 1990 levels) can be achieved in all three policy scenarios thanks to the implementation of sustainable policy measures as well as to an ambitious road vehicle fleet decarbonisation in line with the assumptions of the EU "Fit for 55" strategy. On the other hand, the 2030 target (-55%) can only be reached with drastic changes in people's mobility behaviour and very significant reduction of private motorized modes.

1. INTRODUCTION

The paper is based on the outcomes of the EIT Urban Mobility study on the Costs and Benefits of the Sustainable Urban Mobility Transition in European cities (Borgato et al., 2021). The study was built on the MOMOS[1] (Sustainable urban MObility Model) assessment tool that allowed to simulate the impacts of different mobility transition pathways on a range of indicators, including costs and environmental benefits, for different types of cities. Three potential scenarios, based on specific combination of policy measures, were designed and applied to 12 "city prototypes" to consider differences among the 779 EU27 cities above 50,000 inhabitants in terms

[1] MOMOS is a strategic model, developed in Excel and adaptable under several assumptions to different city circumstances in different European countries. The tool enables for a rapid identification, development, screening, and assessment of different measures and policy scenarios and of their expected impacts (http://www.trt.it/en/tools/momos).

of population size (small, medium, large) and geographic location area (Northern, Central/Western, Southern, Eastern Europe). Following the study's approach, this paper focuses on the preliminary results related to the city of Munich, selected as an example.

2. METHODOLOGY

2.1 Approach

The main goal of the overall study was to assess the costs of the sustainable urban mobility transition, its benefits, and the most cost-effective policies to accelerate this transition.

Three potential scenarios to achieve this target were designed combining 29 different sustainable transport policy measures: i) *Promote and Regulate*, mostly orienting transport demand towards more sustainable mobility behaviour through information, regulation, and promotion of innovative and shared mobility services; ii) *Plan and Build*, mainly focused on transport supply investments in technologies and infrastructures; iii) *Mixed*, combining policies from two previous scenarios and intensifying their reach.

2019 was the base year considered for the simulation of scenarios and projections were evaluated up to 2030 and 2050 using the MOMOS assessment tool. The impacts of the transition were estimated through key indicators from three domains: transport (modal split, car ownership), environment (CO_2 emissions, fatalities), and economy (city costs, revenues, and externalities), complemented by additional indicators.

The comparative analysis among the strategies allowed to understand the effectiveness of clusters of sustainable policies, in terms of costs/revenues and CO_2 emissions reductions. It also provided an understanding of how intensively policies should be implemented to reach the Green Deal target and the EU objectives in the field of sustainable urban transport.

2.2 City profile

The city of Munich is located in the south of Germany. With high quality of life and attractive labour market, it is the core of the Bavarian region. In 2019, the city had a population of 1.5 million[2]. From a transport perspective, Munich had a motorization rate[3] of 569 private cars per 1,000 inhabitants in 2019, slightly higher than the European average (555 private cars per 1,000 inhabitants in 2019). On the other hand, looking at available data on mode split (2008)[4], the demand for public transport was about 20%, against a 36% for private motorized modes. 28% of trips were made by foot while 14% were made by bike.

2.3 Input data

The MOMOS assessment tool needs several input data to represent the city's characteristics at base year, reproducing different circumstances related to its socio-

[2] Source: Eurostat, Statistisches Bundesamt Deutschland
[3] Source: ACEA database
[4] Source: EPOMM database

demographic aspects as well as mobility features (public transport infrastructure, innovative services, parking, traffic management solutions, etc.). Almost half of all data collected were publicly available through desk research (sources include, for example, reports of public transport operators, service provider websites, national statistics databases, previous sectorial studies, etc.). The remaining data were estimated considering either similar contexts (e.g., a city with similar characteristics for which such data is available) or through assumptions and professional judgement.
That said, the application to the context of Munich is considered as a preliminary testing, while the production of a more updated and realistic picture would only be possible through a tailored collaboration with local authorities and operators willing to share input data that could better describe the city's initial situation and parameters.

Table 1 - List of collected data inputs (either publicly available or estimated)

Group	Input data
Urban Characteristics	City type, population structure/distribution/growth, average income, etc.
Urban Mobility Characteristics	Motorization rate, modal split, congestion rate, traffic flows, logistic flows, private vehicles fleet composition, etc.
Public Transport Characteristics	Average ticket price, network length, average speed, offer, fleet composition, etc.
Park & Ride	Capacity, extension, frequency, etc.
Infrastructure and Traffic Management	Parking price, parking stalls, bike path length, PT priority lane length, electric charging points, hydrogen charging points, etc.
Car Sharing	Users, vehicles, price, etc.
Bike Sharing	Bicycles, price, etc.
Vehicle Access Regulation	Limited traffic zones, pedestrian areas, etc.
Traffic Calming Measures	Share of urban area with traffic calming regulation, etc.
Road vehicle fleet composition	Vehicle fleet

2.4 Design of the scenarios

Within this study a scenario was intended as a set of urban transport measures implemented over time with different ranges of intensity. There is not a unique solution to realize a sustainable mobility transition: the selection of policies, but also their temporal implementation and the intensity of their application play a key role in determining the impacts. Three scenarios were designed, to explore how a city can reach the Green Deal target both in 2030 and 2050 and investigating the effects on mobility, environment and economy based on different approaches (demand-oriented vs supply oriented) obtained through the combination of 29 transport policy measures. By including regulations and behavioural incentives as well as the provision of infrastructures and service, the three scenarios generate changes in urban mobility and mode shifts in individuals' choices (with related acceptability

issues). More in details, the following scenarios (including policies reported in Table 2) were simulated.
S1 – Promote and Regulate. This scenario is designed to deliver results in the short term through information, regulation, and promotion of innovative shared mobility services.

S2 – Plan and Build. With a focus on investments in technology and infrastructure, this scenario is expected to produce long-term results.

S3 – Mixed. Within this scenario, the policies from the previous two scenarios are combined and intensified, with the aim of reaching the EU Green Deal target both in 2030 and 2050.

Table 2 - Policy measures in the scenarios: Promote and Regulate (S1), Plan and build (S2), Mixed (S3)

Policy Group	Policy Measure	S1	S2	S3
Shared Mobility and Demand Management	Sustainable travel information and promotion	X		X
	Mobility as a Service	X		X
	Bike sharing	X		X
	Micro mobility	X		X
	Carsharing	X		X
	Delivery and servicing plan	X		X
	Teleworking	X		X
Innovative Services	Autonomous vehicles		X	X
	Demand-responsive transport		X	X
	Intelligent Transport Systems		X	X
Green Public Transport and Logistics Fleets & Charging Infrastructure	Electric energy refuelling infrastructure	X	X	X
	Hydrogen energy refuelling infrastructure	X	X	X
	Green public fleet	X	X	X
	Green logistics fleet	X	X	X
Pricing Schemes	Congestion and pollution charging	X		X
	Parking pricing	X		X
	Public transport integrated ticketing and tariff schemes	X		X
Transport Infrastructure	Bus network and facilities		X	X
	Tram network and facilities		X	
	Walking and cycling networks and facilities		X	X
	Park and ride		X	X
	Metro network facilities and light rail		X	
	Urban Delivery Centres and city logistics facilities		X	X
Traffic Management and Control	Legal and regulatory framework of urban freight transport	X		X
	Legal and regulatory framework of new mobility services	X		X
	Prioritizing Public Transport		X	
	Access regulation and street space reallocation	X		X
	Traffic calming measures	X		X
	Pedestrian Areas	X		X

The packages of policies were defined by considering the EIT Urban Mobility strategic objectives, as well as the targets of the Green Deal and of the EU Smart and Sustainable Mobility Strategy. However, each city has its own vision and specific roadmap towards sustainable mobility transition (e.g., some policies could be preferred than others, local incentives might favour the development of infrastructure rather than the promotion of innovative services, etc.). Therefore, a collaboration with local authorities would be necessary to tailor the city's transition simulation according to its own vision and path towards the future.

As a complementary input, some exogenous assumptions and trend were required by the model for estimating future projections. Concerning the evolution of vehicle technology composition, the base trend adopted in this study follows the assumptions related to the EU Reference Scenario 2020[5] (estimating for cars in 2050 about 53% of innovative fuels). Conversely, the three potential scenarios were simulated with a very ambitious penetration of innovative vehicle technologies, building on the assumptions of the EU 'Fit for 55' strategy[6] (European Commission, 2021) (assuming for cars in 2050 about 96% of innovative fuels).

3 RESULTS

The simulation of the three scenarios showed that, to reach the Green Deal CO_2 emission reduction target, a large reduction in the private motorized transport share is needed. Personal habits would require drastic adaptations especially in the short term (e.g., consistent reduction in private car use, large increase in active modes and shared mobility), to complement the required vehicle fleet evolution towards cleaner and more sustainable technologies. In 2030, the objective is reached only by the *Mixed* scenario, as the EC target requires at this stage a very high reduction of CO_2 emissions in a short period of time. Instead, in 2050, all the scenarios, although implementing different policies, can reach the target.

3.1 Transport indicators

One of the most important indicators to evaluate sustainable mobility transition is **Modal Split,** showing changes according to the implemented policies. As shown in Figure 1Figure 1, Private Motorized modes are reduced in all scenarios, with the biggest reduction in the *Mixed scenario*, already declining consistently in the short term in 2030.

[5] EU Reference Scenario 2020: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en
[6] EU 'Fit for 55' strategy: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541

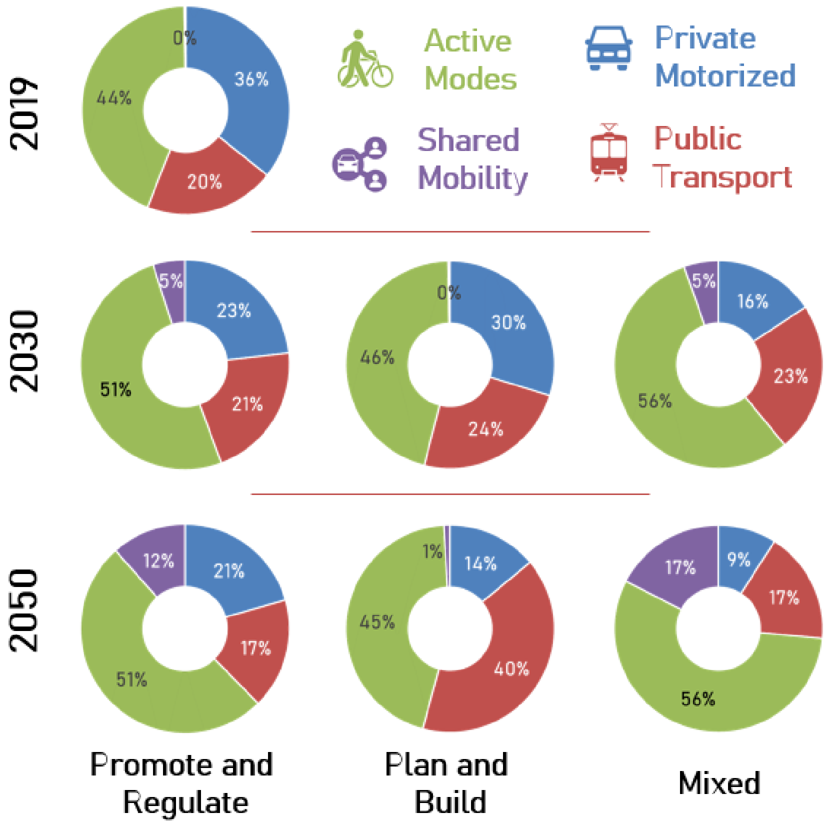

Figure 1 – Aggregated Modal Split of the three policy scenarios for 2019, 2030, and 2050

In the *Promote and Regulate* Scenario the reduction of Private Motorized modes by 2050 (21% of mode share) is achieved through policies supporting the shift toward active modes and shared mobility (resulting respectively in 51% and 12% of mode shares); e.g., traffic calming measures, pedestrian areas, and street space reallocation, as well as promotion of bike sharing and sustainable travel information.
Instead, the *Plan and Build* Scenario aims to replace private motorized trips with the use of public transportation. Here, the highest value of public transport share is reached at 2050 (40% against 17% in the *Promote and Regulate* Scenario and in the *Mixed* one). This impact is achieved through several policies, assuming also the implementation of DRT (Demand-Responsive Transport), in addition to the implementation of new public transport lines and the improvement in the public transport frequency.
Finally, the *Mixed scenario* results in significant short-term increase in both active mobility and public transport, complemented with a significant penetration of car sharing by 2050 (supported also by the introduction of autonomous shared vehicles). In this case, the short-term increases in active mobility and public transport are reached thanks to the timing and intensity of the policy measures deployed already in the first decade of simulation, discouraging the use of cars on one hand (e.g., congestion charging, remote working, or higher parking prices) and supporting active modes on the other hand.

Together with mode split, **car ownership** is also considered as a key indicator of sustainable mobility (Figure 2). In line with the reduction of private car use, the largest reduction is reached in the Mixed scenario (-32% in 2030 and -49% in 2050). Such reduction is not possible without a drastic change in personal mobility habits. As expected, the *Plan and Build* scenario, based on long-term urban policies such as the implementation of new metro lines, shows the smallest reduction in the car ownership in 2030.

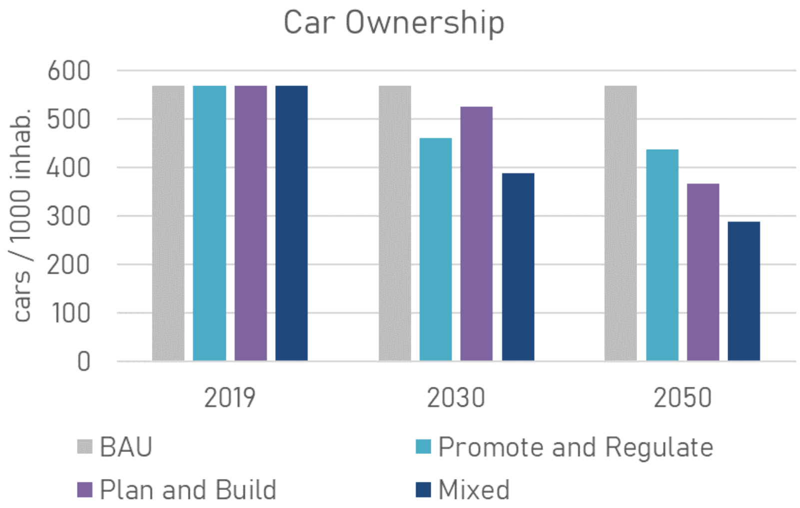

Figure 2 – Car Ownership in the Business-as-usual Scenario and in the three project scenarios

3.2 Environmental and safety indicators

The main environmental indicator is the amount of **CO_2 emissions** from urban mobility (Figure 3), representing the core objective of the EU Green Deal with the reduction of -55% by 2030 and -90% by 2050, compared to 1990 levels.

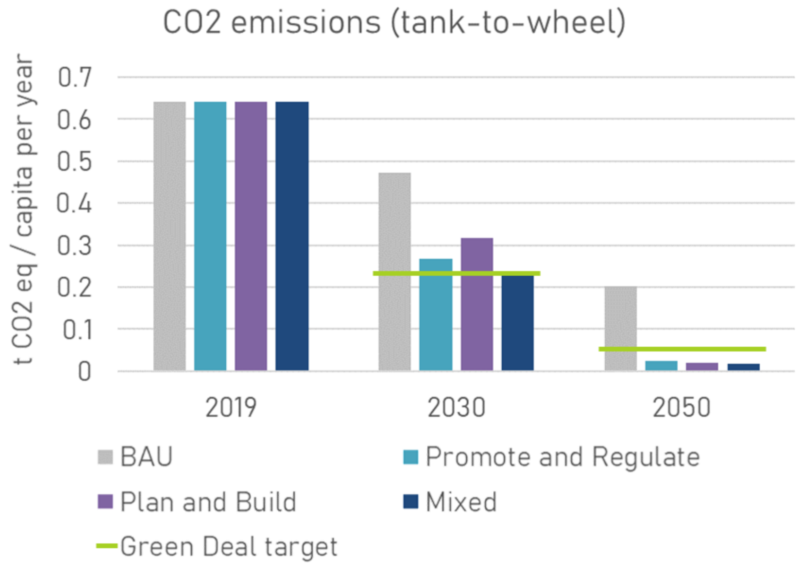

Figure 3 – CO_2 emission (thank-to-wheel) from transport in 2019, 2030, and 2050. Green Deal target highlighted in green.

Referring to the base year of the project, due to the increase of emissions between 1990 and 2019, the target percentages of reduction become -64% in 2030, and -92% in 2050 implying a significant reduction especially in the short-term.
Indeed, neither *Promote and Regulate* nor *Plan and Build* scenarios achieve such target in 2030, that is reached only by the *Mixed* scenario, resulting from its large changes in personal mobility habits (e.g., drastic reduction in private car use).
It's important to mention that the *Business-as-usual* (BAU) scenario includes already the car fleet evolution assumed in the EU Reference scenario 2020. This is why, as it can be noted in Figure 3, the BAU scenario presents a large decrease in the CO_2 emissions, although not sufficient to achieve the Green Deal target.
Along with the CO_2 emissions, **fatalities** represent another important indicator for evaluating the transition toward sustainable urban mobility (Figure 4).

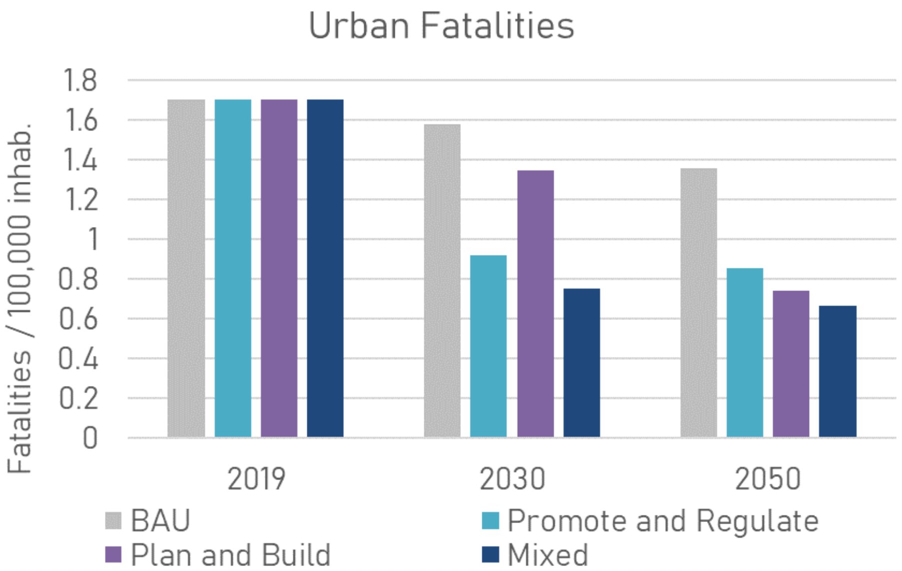

Figure 4 - Urban fatalities of the three policy scenarios for 2019, 2030, and 2050

As it could be expected, the *Plan and Build* scenario, focused on long-term policies, leads to the lowest reduction in 2030 (-21%), while *Promote and Regulate* and *Mixed* scenarios present a reduction of -46% and -56% respectively in 2030. The main drivers for the fatality reductions in these two scenarios are traffic management and control measures, such as traffic calming (with 30 km/h speed limits) and pedestrian areas. In the long term, in 2050, urban fatalities are reduced similarly among the three scenarios, ranging from -61% for the *Mixed* scenario and -50% in the *Promote and Regulate scenario*. In the *Plan and Build scenario,* the reduction in fatalities by mid-century is mostly due to the expansion of cycling and walking infrastructure. It's important to highlight that a decrease of -20% in urban fatalities by 2050 is estimated in the *Business-as-usual* scenario, where no specific policies are assumed, but technological improvement is foreseen (e.g., sensors for accident detection) for the vehicle fleet and combined with already on-going safety policies.

3.3 Economy indicators

The MOMOS tool allows to estimate economic impacts in terms of total revenues, total costs, and external cost savings (Figure 5). Since it needs more public transport investments than the other scenarios, the *Plan and Build* scenario in 2050 is the least advantageous under all the three economic aspects. On the contrary, the *Promote and Regulate* and *Mixed* scenarios show similar performances, with better results reached by the latter in terms of net balance. For this scenario, revenues come from public transport ticketing, congestion charging and parking policies while costs are essentially those needed to implement and maintain the mobility services, such as Public Transport infrastructures and shared mobility services.

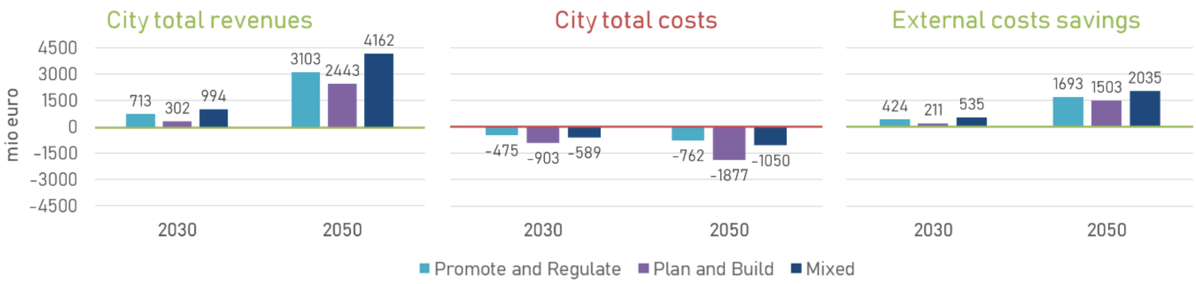

Figure 5 - Economic results components of the three scenarios in 2030 and 2050

External costs of transport are monetized, including and CO_2 emissions, air pollutant emissions (NOx, VOC, CO and $PM_{2.5}$), noise and accidents (considering fatalities and injured people), estimated applying the monetary values reported by the European Commission handbook of 2019[7]. In particular, for climate change costs the central estimation of the Handbook has been used, taking into account different values for the short – medium run (100 €/tCO_2 equivalent until 2030) and for the long run (269 €/tCO_2 equivalent from 2040). Adding revenues and externalities and subtracting the costs of the implemented policies, the Net Balance of each scenario is estimated (Figure 6).

In 2030, only the *Plan and Build* scenario has a negative net balance, while for the other two scenarios it is always positive. The reason is that the *Plan and Build* scenario includes investments in new infrastructures, that are highly expensive, and obtain benefits only in the long-term (2050), where it shows a positive net balance, although much lower than the other two.

[7] Handbook on the external costs of transport - Version 2019 – 1.1 (Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities

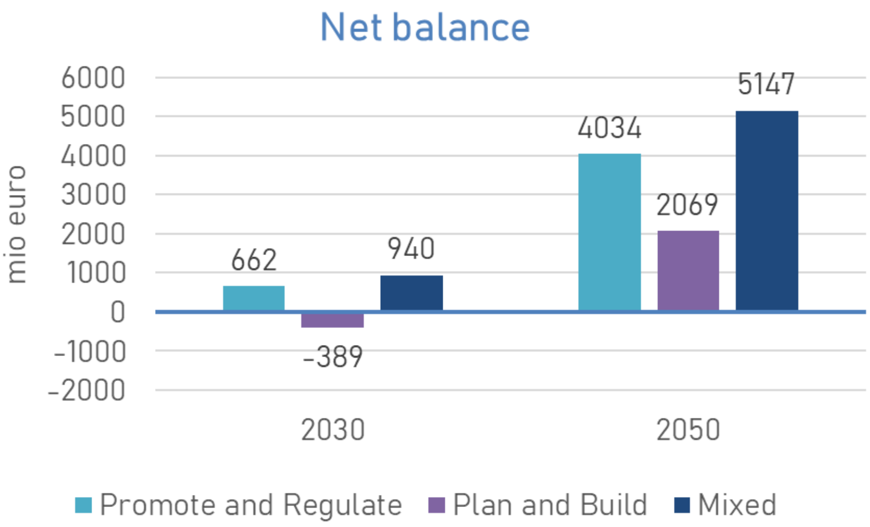

Figure 6 - Economic Net Balance of the three scenarios in 2030 and 2050

From a different perspective, economic outcomes were analysed to explore the effectiveness of five different policy groups with respect to CO_2 emissions reduction: *Shared Mobility and Demand Management, Innovative Services, Pricing Schemes, Transport Infrastructure* and *Traffic Management and Control*.

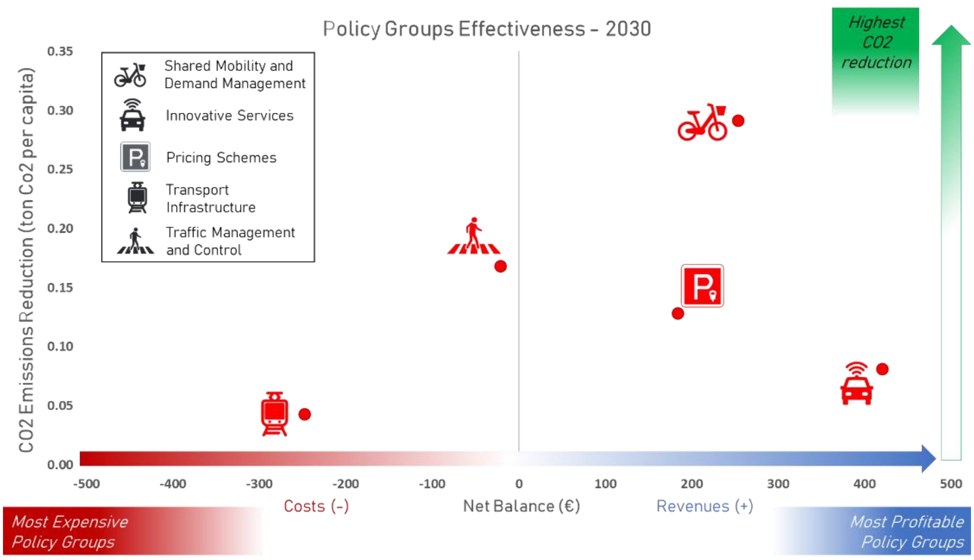

Figure 7 - Policy group effectiveness for the "Large City" prototype in 2030

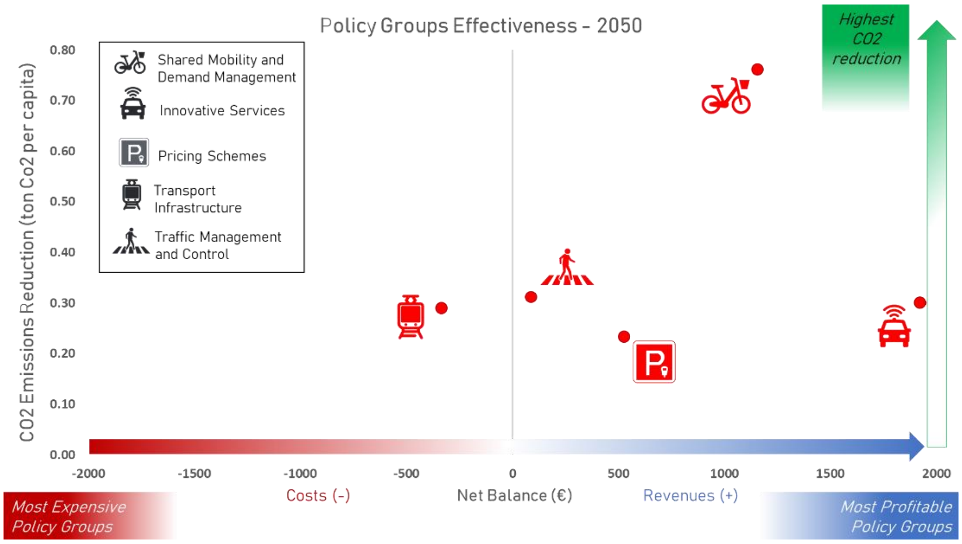

Figure 8 - Policy group effectiveness for the "Large City" prototype in 2050

Within the overall study, the effectiveness analysis was performed for the year 2030 (Figure 7) and 2050 (Figure 8) for the prototype cluster of Central/Western EU large cities, the one Munich is belonging to. The diagram shows the net balance on the x-axis and the CO_2 emissions reduction on the y-axis. In both 2030 and 2050, the *Shared Mobility and Demand Management* policy group provides the higher reduction in terms of CO_2 emissions combined with positive impacts in terms of revenues, while the *Transport Infrastructure* policy group is the most expensive with limited greenhouse gases reduction. The *Innovative Services* provides the higher revenues, although CO_2 emissions reduction is limited in 2030 and comparable to pricing scheme and traffic management in 2050.

4 CONCLUSIONS

The use of the MOMOS assessment tool to simulate three potential scenarios of the sustainable urban mobility transition provided a quantification of the associated costs and benefits. The focus of the paper is the city of **Munich (DE)**, selected among the European cities considered within the 2021 EIT Urban Mobility study.

The **EU Green Deal target** was taken into consideration to evaluate the three modelled policy scenarios. In all scenarios, the CO_2 reduction target can be achieved in 2050, while in 2030 only the *Mixed* scenario can reach this ambitious goal. Therefore, this scenario provides an example of the effort needed to face the challenge of greenhouse gases emissions reduction within a decade. Since large changes in personal mobility behavior are necessarily required to complement the impacts of a renewed and cleaner vehicle fleet, only through boosted planning and regulating measures it is possible to achieve the EU Green Deal CO_2 reduction target in the short term.

The achievement of the target related to greenhouse gas emissions has been complemented with the analysis of the related costs and benefits, evaluated with the net balance indicator. The indicator is negative only for the *Plan and Build* scenario in 2030, due to the burden of initial investments required, while the other two scenarios have always a positive net balance for the city of Munich. the *Mixed* Scenario turns out to lead to the highest value, thanks to high revenue generation and high external cost savings derived from the scenario's positive externalities. The *Promote and Regulate* Scenario instead, presents an interesting compromise in case the initial investments needed in the *Mixed* Scenario couldn't be afforded.

It is important to note that the results presented in this paper for the city of Munich were performed based on literature data publicly available, whereas a collaboration with the public administration could lead to a more accurate design and analysis. In addition, policy measures could be better tailored to the city context and vision toward sustainable urban mobility. In this sense, the three potential scenarios presented are mainly illustrative, but other combinations of policy measures could be better adapted to the urban context of Munich to simulate the sustainability pathways, also depending on the most relevant aspects from the perspective of the public administration. An additional layer of accuracy could therefore be gained with a closer collaboration with local authorities and policy makers.

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