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Evaluating the Fiscal and Technical Impacts of Decarbonizing all Road Transport Sectors at Regional Level

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Executive Summary

The global transition to electric vehicles is accelerating, but the full implications of widespread transport electrification remain only partially understood. The present study provides a comprehensive evaluation considering technical and fiscal dimensions of this transformation, focusing on a regional case in northern Italy. In the evaluated scenario by 2040, 88.4% of the regional vehicle fleet will be electric, increasing the annually electricity demand by 22.4% while reducing CO2 emissions by 87.6%. However, the study also quantifies a critical policy challenge: a 229 million euros reduction of tax income from fossil fuel consumption, just partially compensated by a 60 million euros increase in tax revenues from electricity sold for battery electric vehicles charging. The integrated analysis offers insights for policymakers in navigating the complex trade-offs of transport decarbonization.

1 Introduction

Electrification of transport is proceeding consistently in many countries of the world [1]. The global transition to Battery Electric Vehicles (BEVs) is accelerating, with peak values in countries like Norway [2], yet no country has achieved complete electrification across all transport sectors. While BEVs have demonstrated clear benefits through various cost-benefit analyses, such as the work of Massiani [3] and Baum et al. [4], the full implications of widespread transport electrification remain partially understood. Previous research has examined isolated aspects, such as the potential environmental benefits of an increase of BEV vehicles to replace fossil-fuelled vehicles circulating. Several studies demonstrate significant potential for CO2 emissions reduction through electrification, in some cases also listing how this reduction in the transport sector brings significant health benefits, like in the work of Beukers et al. [5]. Woody et al. [6] reports that battery electric vehicles (BEVs) have approximately 64% lower life cycle emissions than internal combustion engine vehicles (ICEVs) across sedans, SUVs, and pickup trucks from a technical perspective. Lie et al. [7] shows that implementing biofuel and electrified buses in Trondheim, Norway, reduced the overall carbon footprint by 37%, with potential for a further 52% reduction through full electrification. The potential results reachable in the transport sector are, however, interlinked with the power generation sector. Wert et al. [8] indicates that transportation electrification can lead to daily operational emissions reductions of up to 20-30% for all pollutants studied, outweighing the increase in emissions from the electric grid. Other studies confirmed that the effectiveness of electrification in reducing emissions varies depending on factors such as the carbon intensity of the electricity grid and charging patterns. Chen et al. [9] highlights that electric vehicles offer a route to decarbonization of transport, but only under the right electricity source and charging conditions, while Gustafsson et al. [10] emphasizes that energy carriers with high electricity dependence are not necessarily better than diesel from a well-to-wheel perspective, particularly in carbon-intense electricity systems.

For this reason, some studies in the literature have also analysed the increase in electricity and power required from the grid for charging vehicles. Bucher et al. [11] investigated the electricity requirements of electric vehicles (EVs) for a representative household in the United Kingdom, considering both present-day conditions and future projections. Similarly, Rosenberg et al. [12] estimated the expected annual growth in electricity demand in Norway up to the year 2050. A comparable study was conducted for the United States, analyzing projected scenarios through 2035 [13] In addition, the European Environment Agency [14] evaluated the overall electricity consumption associated with achieving an 80% market penetration of EVs within the European Union by 2050. These studies collectively underscore the anticipated rise in electricity demand resulting from large-scale EV adoption. In addition, Rotondo et al. [15] analysed the increase in electrical power required to the grid and also assessed the different hourly profile of the power requested from the grid for charging as a function of the type of vehicle and the charging strategy used.

A third aspect, however, which has so far only been partially analysed in the scientific literature, concerns the economic and above all fiscal consequences of the change from fossil fuel to electric motor power for vehicles on the road in the future. As analyzed by Sterner [16], fuel taxation represents for some countries a basic revenue for the state, while in other countries it serves other purposes such as road maintenance. As shown by Parry et al. [17], this taxation has contributed to the transition towards more sustainable vehicles, especially BEV. However, this potential benefit can in the future create a rebound effect, as suggested by Anas et al. [18]. Reduced taxation revenues from electrified vehicle fleets could potentially impact government budgets and fiscal policies. As fossil fuel taxes contribute significantly to government revenues, a shift towards electric vehicles and a consequential reduction of the fossil fuel consumption may lead to a decrease in these tax collections, as analyzed by Balasoiu et al. [19]. This thematic has been inizailly analyzed by Tscharakschiev [20] in a theoretical model and subsequently taken into account for the case study of Mexico by Bonilla et al. [21], who firstly tried to evaluate the income reduction for a future scenario set in 2050. This tax revenue reduction could potentially affect the government's ability to fund public goods and services, necessitating alternative revenue sources or budget adjustments. Several studies analyzed possible innovative approaches to maintain funding for infrastructure and other public services. One potential solution is the implementation of new road taxes specifically designed for EVs, as noted in the study of Koniak et al. [22]. Even if this approach would help maintain a consistent revenue stream while also ensuring that EV owners contribute their fair share to road maintenance and infrastructure costs, it retains its possible effectiveness only for the purposes of a particular type of taxation.

While existing studies often address isolated aspects of transport electrification, an integrated analysis combining environmental, energetic, and fiscal dimensions remains limited. This study fills that gap by evaluating the comprehensive impact of full transport electrification in South Tyrol, a northern Italian region where the contribution of the transport sector to annual CO2 emissions is 46.5%, while the emissions from the power production sector represent the 5% of CO2 emissions, due to the high penetration of hydroelectric power production [23]. The analysis provided in this study includes not only passenger cars but also light commercial vehicles, heavy-duty trucks, and buses, offering a broader perspective. Moreover, it incorporates future scenarios to assess potential reductions in government revenue from fuel taxation, highlighting the long-term fiscal implications of the transition.

2 Materials & Methods

The study develops a fleet transition model based on 2021 baseline data from the ACI database [24] and subsequently corrected by eliminating vehicles registered in South Tyrol but destined for rent in other regions, as they do not circulate in the case study area considered [25]. The model projects the progressive electrification of the passenger vehicle fleet by combining current fleet composition data with projected new vehicle registrations. For passenger cars and commercial vans, future registration patterns are aligned with the Fitfor55 [26] emission reduction targets: 15% by 2025, 55% by 2030, and 100% by 2035. For heavy trucks and buses, the targets set by the European Union for heavy goods vehicles have been taken into account, with an emission reduction targets on new registration equal to 45% by 2030, 65% by 2035, and 90% by 2040 [27]. These targets were translated directly into electric vehicle adoption rates, with intermediate years calculated through linear interpolation. The total vehicle fleet size is assumed to remain constant, with the annual circulating fleet cf for each vehicle type (a) and year (t) calculated using equation (1).

$$cf_{a,t} = cf_{a,t-1} + new\ registrations_{a,t} - demolitions_{a,t} \quad (1)$$

Annual CO2 emissions are calculated using equation (2), which incorporates the number of vehicles by fuel type, an average yearly distance per vehicle, the energy demand of each fuel and fuel-specific emission factors.

$$CO_2\ emissions_{a,t}[kt_{CO2}] = cf_{a,t} * avg.distance\ travelled[km] * en.demand_a \left[\frac{kWh}{km}\right] * \ emission\ factor_a \left[\frac{kt_{CO2}}{kWh}\right] \quad (2)$$

The value of electricity demand for charging is instead calculated as in equation (3):

$$electricity\ demand_t = cf_{el,t} * avg.distance\ travelled[km] * en.demand_{el} \left[\frac{kWh}{km}\right] \quad (3)$$

Then, the fossil fuel consumption is calculated as in equation (4):

$$fuel\ consumption_{a,t} = cf_{a,t} * avg.distance\ travelled[km] * en.demand_a \left[\frac{kWh}{km}\right] * specific\ energy_a \left[\frac{L}{kWh}\right] \quad (4)$$

The provincial tax revenue is then calculated by multiplying the 2021 fuel cost [28] by 55%, which represents the proportion of fuel cost allocated to provincial taxes. For electric vehicles, the tax revenue is derived as per equation (5), assuming a tax cost tax_{cost} of 0.01 $\frac{€}{kWh}$ [29] and a cost charge of 0.28 $\frac{€}{kWh}$, with an IVA cost for public charging IVA_{pub} of 10% and equal to 22% for private charging IVA_{priv} [30], and assuming that the share of public charges CS_{pub} is 30%, while the share of private charges CS_{priv} is assumed to be 70% of total.

$$tax\ revenue_{el,t} = electricity\ demand_t * [tax_{cost} + cost_{charge} * (IVA_{pub} * CS_{pub} + IVA_{priv} * CS_{priv})] \quad (5)$$

The assumed values for the definition of the new registrations and the circulating fleet for the vehicle types considered are reported in Table *1*.

Table 1 – Main assumptions for the definition of the vehicle fleet for the different vehicle categories

	CARS	VANS	BUS	TRUCKS
Total Vehicles	330000	10000	750	1600
New Releases	33000	1000	62.5	200
Demolitions	33000	1000	62.5	200
Lifetime	10	10	12	8
Annual N km per car	11200	20000	55603	100000

The assumed values for consumptions and emissions are reported in Table 2, concerning all the vehicle considered in the study.

Table 2 - Assumed values for consumptions and emissions for the vehicle considered in the study.

	CONSUMPTIONS [kWh/100 km]				EMISSIONS [kgCO2/kWh]
FUEL TYPE	CARS	VANS	BUS	TRUCKS	ALL VEHICLES
Diesel	36.68	138.33	183.38	265.90	0.26972
Petrol	61.11	158.34	-	-	0.25017
LPG	44.32	-	-	-	0.22700
Methane	61.54	-	-	-	0.20200
Hybrid diesel	34.82	-	-	-	0.26972
Hybrid petrol	39.85	-	-	-	0.25017
Hybrid plug-in	32.00	-	-	-	0.02001
Hydrogen	28.92	-	316	253	0.00000
Electric Vehicles	13.61	20	140	180	0.00000

3 Results

This section presents the analysis in two main parts: first, examining vehicle fleet evolution and its impacts, followed by energy consumption patterns and their economic implications. The transition to electric vehicles in the scenario considered follows three distinct trajectories. For passenger cars, new vehicle registrations (Fig. 1-Top) show complete adoption of zero-emission vehicles by 2035, aligned with European emission constraints. However, the overall fleet composition (Fig. 1-Middle) transforms more gradually due to the continued operation of pre-2035 conventional vehicles, reaching a value of BEV circulating equal to 88.5% in 2040. This results in a 91.8% reduction of CO_2 emissions by 2040 (Fig. 1-Bottom) and an annual electricity demand increase of approximately 600 MWh.

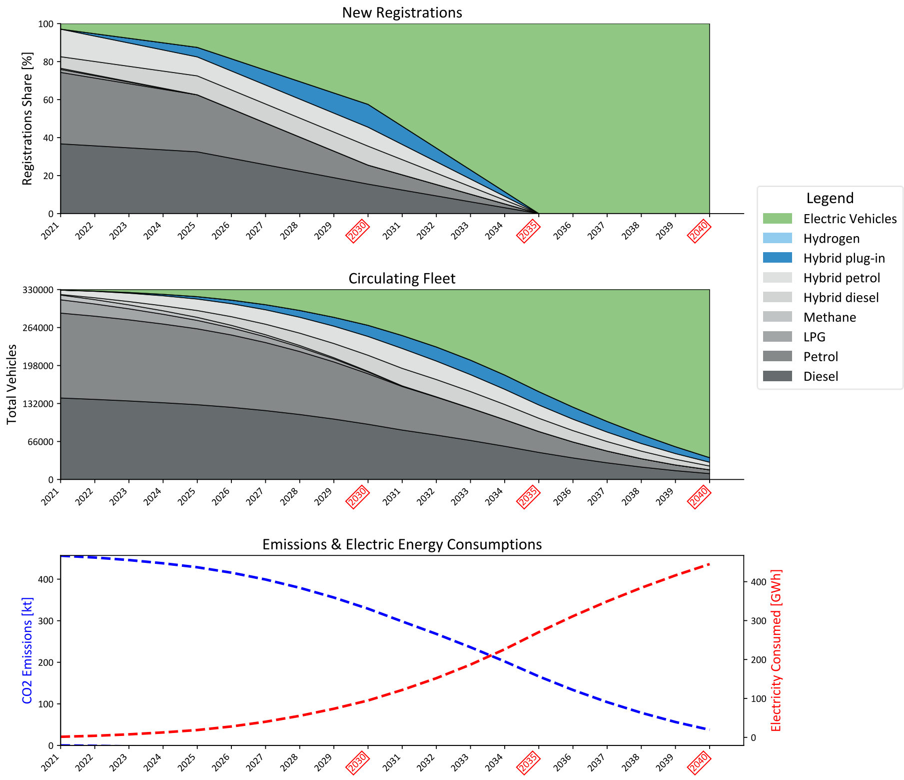

Fig. 1 – Progressive transition of the transport sector for passenger cars, considering the trend for new registration (Top), circulating fleet (Middle) and CO2 emissions & electric energy demand (Bottom)

Concerning instead the commercial vans sector, the inclusion of the same Fitfor55 directive, which also applies to passenger cars, causes a similar electrification process in the new registrations of commercial vehicles. The main difference is related to the less diversified motorisation of the fleet. Initially powered mostly by diesel, this will reach 87.6% by 2040 (Fig. 2-Mid). The electrification of the vehicle fleet in this case allows a reduction of CO2 emissions by 90% compared to 2021 values, with a dual increase of 35.4 GWh of electricity required from the grid (Fig. 2-Bottom).

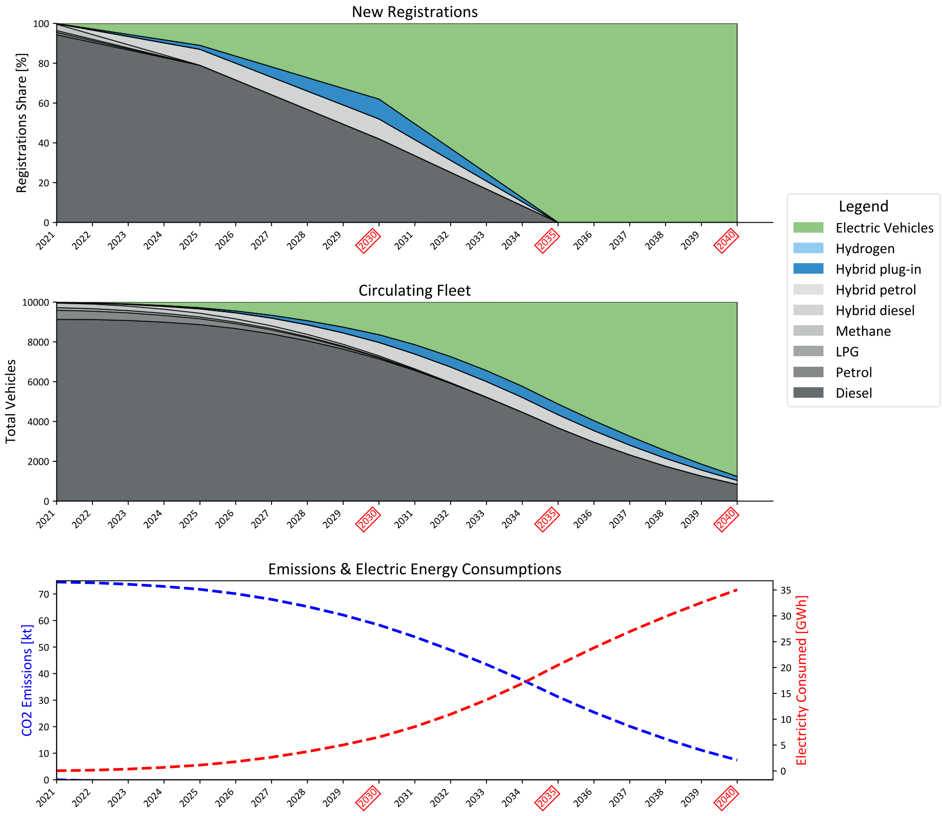

Fig. 2 - Progressive transition of the transport sector for commercial vans, considering the trend for new registration (Top), circulating fleet (Middle) and CO2 emissions & electric energy demand (Bottom)

Regarding the bus sector, the less stringent directive on the reduction of CO2 emissions from new registrations, combined with the longer useful life of buses compared to the other types of vehicles shown so far, implies a slower electrification of the circulating fleet (Fig. 3-Mid), for which 57.9% electric vehicles and 13.5% hydrogen vehicles will be reached in 2040, allowing a 70.6% reduction in CO2 emissions against an increase in the electrical energy required to recharge these vehicles of 59.1 GWh (Fig. 3-Bottom).

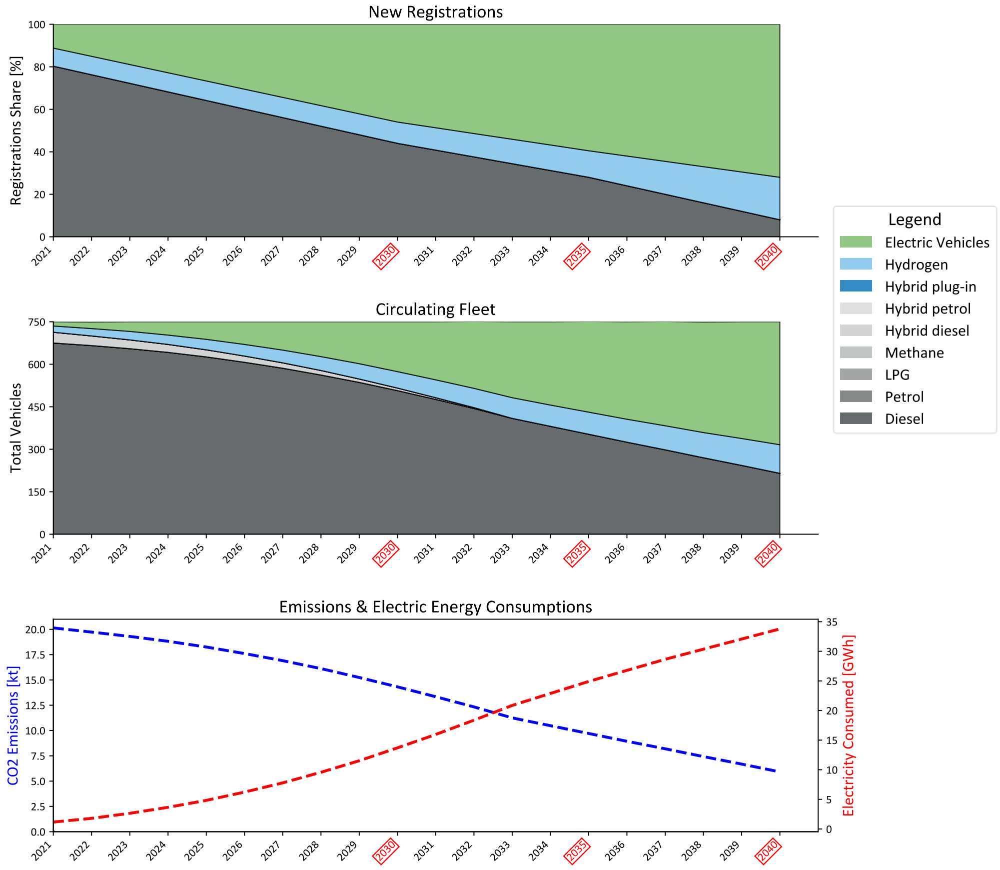

Fig. 3 - Progressive transition of the transport sector for public buses, considering the trend for new registration (Top), circulating fleet (Middle) and CO2 emissions & electric energy demand (Bottom)

Concerning the heavy duty vehicle sector, the slower electrification for the new registrations in the first years considered (Fig. 4 – Top), together with the starting fleet largely composed of fossil-fuelled vehicles (Fig. 4 – Mid), implies a slower electrification of the circulating fleet, even with the same emission reduction targets as for buses. Considering the year 2040, the transition towards less pollutant heavy trucks allows a -72.2% reduction of CO_2 emissions, with an increase of 174.8 GWh for charging electric vehicles and for the production of hydrogen for the fuel cell vehicles (Fig. 4 – Bottom)

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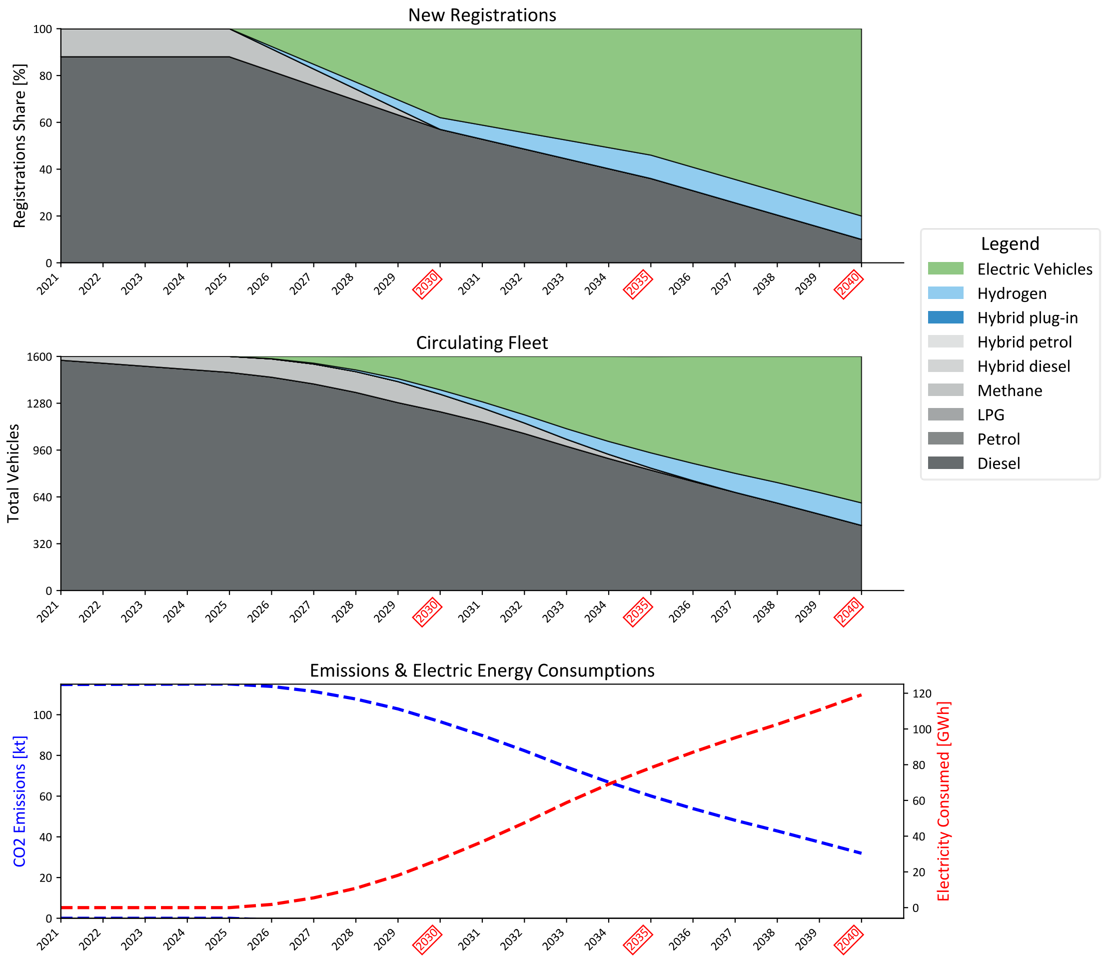

Fig. 4 - Progressive transition of the transport sector for heavy duty trucks, considering the trend for new registration (Top), circulating fleet (Middle) and CO_2 emissions & electric energy demand (Bottom)

Table 3 therefore shows the values for the different vehicles considered and the total value of CO_2 emission reduction within the transport sector, as well as the increase in electricity required from the grid. This transition would cause a 22.4% increase in the energy consumed annually in South Tyrol, as a result of an additional demand of 714 GWh.

Table 3 – Emissions reduction and yearly energy consumption for each vehicle type considered

VEHICLE	Emissions 2021 [kt CO2]	Emissions 2040 [kt CO2]	Emissions REDUCTION	Energy Consumption 2021 [GWh]	Energy Consumption 2040 [GWh]
CARS	456.44	37.51	-91.8 %	1.51	445.18
VANS	74.51	7.42	-90.0 %	0.04	35.04
BUS	20.14	5.91	-70.6 %	6.69	59.14
TRUCKS	114.82	31.91	-72.2 %	0.00	174.78
TOTAL	**665.91**	**82.76**	**-87.6 %**	**8.24**	**714.14**

The energy consumption analysis reveals significant efficiency gains through electrification. For the vehicles considered in this study, Fig. 5-Top compares the thermal energy consumption of Internal Combustion Engines (ICE) with the electrical energy consumption of BEVs. The superior efficiency of electric motors leads to substantially lower overall energy consumption by 2040, when BEVs dominate the fleet. This transition manifests in two key effects: first, a marked decrease in fossil fuel consumption from 2021 to 2040 (Fig. 5-Mid), delivering environmental benefits through reduced CO_2 emissions; second, a corresponding change in revenues through taxes (Fig. 5-Bottom). For buses and trucks, projected tax revenues in 2040 are less reduced, compared to 2021 levels. This outcome is primarily attributable to the adoption of hydrogen-powered vehicles, whose efficiency advantages over conventional fossil fuel vehicles are less pronounced, and whose operating costs are elevated due to the substantially higher price of hydrogen relative to electricity Summing al the impacts for the different vehicles, revenues from fossil fuel taxation in 2040 would decrease by approximately 230 million euros, compared to an increase in revenues from electricity taxation of 60 million euros.

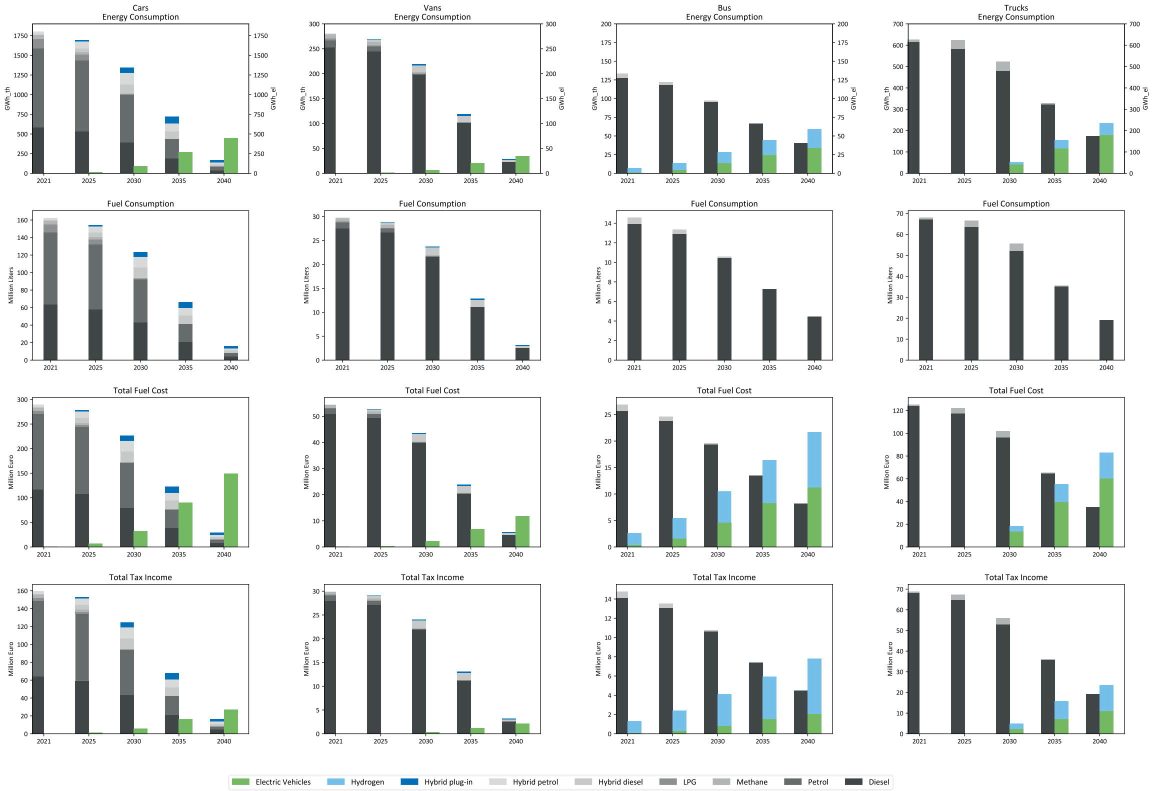

Fig. 5 - Techno-economic consequences of the fleet electrification for passenger cars (first column), commercial vans (second), buses (third) and heavy duty trucks (fourth), including the trend of energy consumption (Top), the fossil fuel consumption reduction (Middle) and the consequential reduction of income from fuel taxation (Bottom)

4 Conclusions

This study contributes to the existing literature by providing a comprehensive analysis of transport sector electrification that integrates both technical and fiscal perspectives. The analysis of South Tyrol's transition to electric vehicles reveals several significant findings. By 2040, following European Union sales targets, the region's vehicle fleet will achieve 88.4% electrification, representing one of the most comprehensive regional electrification scenarios modeled in the literature. This transition will increase annual electricity demand by 22.4%, consistent with projections by Rosenberg et al. [12] for comparable regions. However, our analysis extends beyond energy demand to quantify a substantial reduction of 583 kt of on-site CO_2 emissions (-87.6%).

Our findings demonstrate that the effectiveness of this emissions reduction is particularly significant in South Tyrol due to the region's high penetration of renewable electricity generation, confirming the importance of grid carbon intensity emphasized by Chen et al. [9] and Gustafsson et al. [10]. The concentrated reduction of local emissions will likely deliver substantial indirect socioeconomic benefits through improved air quality and reduced health impacts, as suggested by Buekers et al. [31].

The fiscal analysis presented here addresses a critical research gap identified in the introduction. Unlike previous theoretical models, like the work of Tscharakschiev [20], or single-sector analyses, like the work of Bonilla et al. [21], our study provides a comprehensive quantification of the fiscal implications across all road transport sectors. By 2040, while tax revenues from electricity will increase by 60 million euros, revenues from fossil fuel taxation will decrease by 229 million euros representing a net reduction of 169 million euros. This substantial fiscal impact significantly exceeds preliminary estimates in previous studies and presents a major policy challenge requiring careful consideration. Our findings suggest that the direct transfer of tax revenues from fossil fuels to electricity consumption may be insufficient to maintain fiscal stability. The magnitude of the revenue gap identified here necessitates the development of alternative fiscal frameworks specifically designed to support rapid transport electrification while maintaining public revenue streams.

This study advances the understanding of transport electrification by providing an integrated assessment of environmental, energetic, and fiscal dimensions across all vehicle categories. The comprehensive approach reveals complex trade-offs that must be navigated to achieve successful decarbonization of the transport sector. Future research should build on these findings to develop and evaluate specific policy mechanisms that can address the identified fiscal challenges while sustaining the transport electrification.

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Presenter Biography

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