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Land transport CO_2 emissions and climate change: evidence from Cyprus

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ABSTRACT

The land transport sector is one of the major emitters of CO_2 and one of the hardest sectors to decarbonise. This study employs an environmentally-extended input-output model to conduct an economy-wide assessment of CO_2 emissions in Cyprus, associated with a 22% increase in the final demand for the output of the sector by 2030. Model results indicate that the land transport sector creates the third highest (direct and indirect) CO_2 emissions within Cyprus economy; for every 1 million euro increase in the final demand of the sector's services and products, 407 additional tons of CO_2 are emitted. Considering that temperature in Cyprus is projected to increase by up to 4.5–5°C by the end of the century, our findings highlight the importance of the land transport sector in the transition of Cyprus to a low-carbon economy and the urgency of implementing in-sector cost-effective decarbonisation strategies.

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Land transport sector; CO_2 emissions; climate change; decarbonisation; environmentally-extended input-output analysis; eastern Mediterranean

1. Introduction

Rapid economic and population growth have contributed to the increasing demand for energy. The abundant use of fossil fuels (mainly coal and oil) to meet energy demands has adverse effects on climate and environment, such as global warming, sea level rise and ocean acidification, particularly related to the emission of carbon dioxide (CO_2), that is, the most important anthropogenic greenhouse gas (GHG). Air pollution from economic activity has imposed large health and economic burden on society (Lei and Ke 2018; Giannadaki et al. 2018). The Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) confirmed the assertion that the warming of our climate system is unequivocal and is associated with the increased anthropogenic GHG concentrations (IPCC 2013). More recent reports highlight the necessity of keeping the temperature rise to 1.5°C above preindustrial levels and reducing CO_2 emissions globally by 41–72% by 2050 and by 78–118% by 2100 with respect to 2010 levels in order to avoid the worst effects of climate change (IPCC 2018).

The Paris Agreement achieved at the 21st Conference of the Parties (COP) in Paris in 2015 signalled the intention of 195 member countries to combat climate change and contribute towards the mitigation of GHG emissions (UNFCCC 2019). The EU-28 and its Member States are committed to a binding objective for an overall economy-wide reduction of at least 40% of GHG levels by 2030 compared to 1990 (European Council 2014). This emission reduction target splits into the respective reduction sub-targets of 43% and 30% between the Emissions Trading System (ETS) and non-ETS sectors by 2030 compared to 2005 (European Council 2014). Cyprus' national targets for attaining

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the energy and climate objectives for 2030 include a reduction of GHG emissions in the ETS (i.e. electricity, cement and ceramics industries) and non-ETS (i.e. agriculture, transport, waste and other) sectors, compared to 2005, by 24.9% and 20.9%, respectively (Mesimeris et al. 2020).

The European Commission's proposal for a new European Green Deal includes a long-term strategy for moving to a net-zero GHG emissions economy by 2050, that is in line with the European Union's (EU) commitments to global climate action under the Paris Agreement (European Commission 2019a, 2019b). Mobility is one of the seven main strategic building blocks of European Commission's strategy to achieve EU's climate neutrality by mid-century.

Transport is one of the major and fast-growing emitters of CO_2 and one of the hardest sectors to decarbonise, given the continuing growth in demand for transport services and the rapid increase in demand for faster transport modes (Sims et al. 2014). Therefore, setting the transport sector on a low-carbon development pathway is necessary for mitigating climate change and stabilising global warming below 2°C (Lah 2017). Several studies have shown that the stronger the mitigation intensity, the more transport specific policies are required (Zhang, Fujimori, and Hanaoka 2018). However, it is widely acknowledged that current measures in most countries will not be sufficient to bring transport on to a 2°C pathway (Lah 2015). Two main barriers have prevented substantial reductions of CO_2 emissions in the transport sector, namely, incomplete international agreements and the high cost of clean technologies (Santos 2017).

In the EU-28, there is a general downward trend of GHG emissions during the 1990–2015 period. More precisely, GHG emissions in 2015 were decreased by 22% compared to 1990 levels (Eurostat 2017a). On the contrary, the emissions of the transport sector, which is the second most important source sector in the EU-28 (23% contribution in 2015), have been increased by 16% from 1990 to 2015. Within the sector, land transport is the biggest emitter accounting for 40% of all CO_2 emissions from transport (Eurostat 2018).

A large part of literature focuses on examining alternative approaches for reducing CO_2 emissions, including technological and managerial options for improving energy efficiency (Worrell, Price, and Martin 2001), deploying renewable energy, such as solar, wind and hydropower (Neuhoff 2005), increasing the usage of low carbon fuels, such as natural gas, hydrogen and nuclear power (Sims, Rogner, and Gregory 2003), and capturing and storage of CO_2 (Leung, Caramanna, and Maroto-Valer 2014). However, less work has been devoted to global warming mitigation and CO_2 emissions reduction at macroeconomic level (Cortés-Borda et al. 2015). Studying these relationships in the area of macroeconomics offers valuable information at both sectoral and spatial level. The environmental extension of macroeconomic models such as the environmentally-extended input-output analysis (EE-IOA) models has become a valuable tool for describing interdependency among economic sectors and CO_2 emissions throughout the world (Hawkins et al. 2015). Capturing both direct and indirect emissions of economic sectors from upstream production can provide an integrated estimate of the contribution of sectors to climate change mitigation policies (Suh 2006).

Given the importance of the transport sector in explaining the recent evolution of CO_2 emissions and considering that the increase in the final demand of several sectors typically leads to a significant increase in CO_2 emissions, a detailed analysis of the most-emitting transport system, that is, land transport, is of major relevance. This paper aims to assess the direct and indirect contribution of the land transport sector to CO_2 emissions, accounting for all monetary inter-industry transactions. Specifically, an EE-IOA model is applied to investigate the economy-wide effects of the growth of the land transport sector in the generation of CO_2 emissions in Cyprus. Our study focuses on Cyprus, an island located in the eastern Mediterranean climate change hot-spot (Giorgi 2006), where the current warming trends are well above the global and Northern Hemisphere land temperature trends (Zittis and Hadjinicolaou 2017), while significant decline in precipitation is observed since the beginning of the twentieth century (Zittis 2018). Considering that most of the climate projections suggest that the observed warming and drying in the region will be further intensified unless anthropogenic GHG emissions and concentrations are substantially decreased within the next decades (Lelieveld et al.

2016; Zittis et al. 2019), the design of smart decarbonisation strategies for the transport sector is of utmost importance. After this introductory section, the structure of the paper is as follows. The next section presents regional climate change projections for Cyprus as well as GDP and CO_2 emissions growth rates during the recent economic crisis and recovery periods. Section 3 outlines the methodology of the study and Section 4 presents the results of the analysis. The paper ends with the discussion of the results and conclusions drawn from the analysis.

2. Economic activity, CO_2 emissions and climate change projections for Cyprus

2.1. Economic growth and CO_2 emissions

The European economy experienced a period of the severe economic downturn during the last decade (Giannakis and Bruggeman 2017a). Cyprus entered in recession in 2012 experiencing large economic output and employment losses (Giannakis and Mamuneas 2018). The economic output was reducing for three consecutive years (2012–2014) with a total loss of 12% at current market prices, while the economic output of the land transport sector shrunk by 6% (Figure 1). During the economic downturn period, the CO_2 emissions in Cyprus reduced by 13%, while the CO_2 emissions of the land transport sector reduced by 31%. In the post-crisis period, i.e. from 2014 to 2016, the CO_2 emissions in Cyprus increased by 5.7% (Figure 2), which is the fourth highest increase in the EU-28. The highest increase in CO_2 emissions was recorded in Portugal (6.3%), while the highest decrease was registered in Malta (−28%); the CO_2 emissions in the EU-28 were marginally reduced by 0.6% (Eurostat 2018). The same period, the CO_2 emissions of the land transport sector in Cyprus increased by 17% (increase of 3.3% at EU-28 level).

Local projections for future sectoral CO_2 emissions are not currently available. However, we present here the global estimations of sectoral CO_2 emissions based on the Representative Concentration Pathways (RCP) scenarios (Figure 3). Specifically, we investigated three future pathways (RCP2.6, RCP4.5, RCP8.5) ranging from more optimistic to 'business-as-usual' estimations (see Box A1, Appendix 1). The data of global land transport CO_2 emissions were obtained from the RCP Database of the International Institute for Applied Systems Analysis (IIASA). Under all scenarios, land transport emissions are projected to increase up to 2030. Strong reduction of emissions is expected from 2030 onwards and until the end of the century for the strong mitigation pathway RCP2.6. By 2100, the emissions of the sector will not exceed 2 Gt of CO_2 equivalent at global level. Under the 'business-as-usual' pathway RCP8.5 an increase of emissions is expected at constant rates up to 2050; afterwards the CO_2 emissions growth rate slows down. According to the intermediate pathway RCP4.5, the emissions of the sector are projected to decrease from 2050 onwards and stabilise between 6 and 7 Gt CO_2 per year.

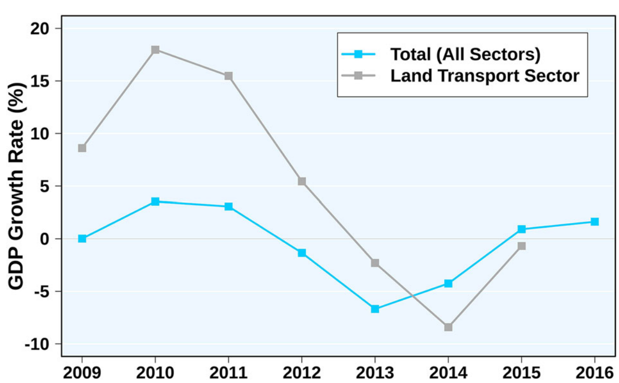

Figure 1. Total and land transport sector GDP growth rate in Cyprus, 2008–2016. Source: Eurostat (2017b).

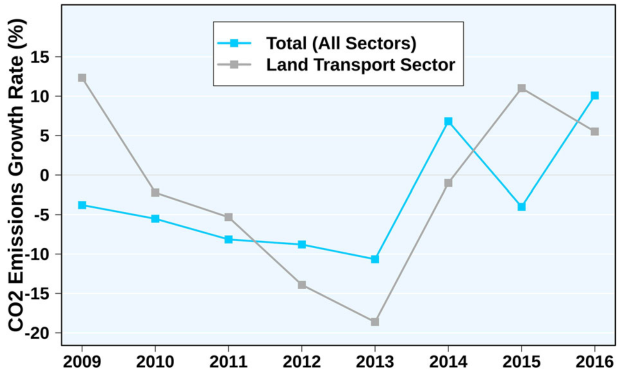

Figure 2. Total and land transport sector CO_2 emissions growth rate in Cyprus, 2008–2016. Source: Eurostat (2018).

2.2. Climate change projections for Cyprus

We employed a large number of regional climate projections for Cyprus derived from the European domain of the Coordinated Regional Downscaling Experiment (EURO-CORDEX) to assess the regional impacts of global warming and link future emission pathways with climate. Our ensemble consists of bias-adjusted output from 30 simulations in approximately 12-km horizontal resolution and is derived from different combinations of global/regional models (see Table A1, Appendix 1). We focus on near-surface temperature, an atmospheric variable that has a direct impact on humans and ecosystems, while it is also most straightforwardly affected by anthropogenic activities and changes of GHG concentrations in the atmosphere.

The projections of annual temperature averaged over Cyprus are summarised in Figure 4. The time-series consist of a common historical period (1951–2005) and future projections under the three RCP pathways previously described. The trends of temperature are in line with global projections of GHG concentrations. Temperature under all scenarios is projected to increase up to 2030s. During that decade the three pathways begin to differentiate. On one hand, RCP2.6 suggests a stabilisation of annual mean temperature over Cyprus to the level of 19°C (i.e. 1.5°C increase since mid-twentieth century); this pathway requires immediate actions and substantial decreases of GHG emissions and concentrations. One the other hand, the 'business-as-usual' RCP8.5 indicates that the mean annual temperature will reach 22°C (±1°C) by the end of the twenty-first century, that is, an increase of 4.5–5°C since 1950s. The results of the intermediate RCP4.5 pathway lie between RCP2.6 and RCP8.5 pathways.

Spatially, the projected warming is not uniform throughout Cyprus, regardless the small area of the island (Figure 5). The north-east part of the country is expected to warm more, a pattern that is

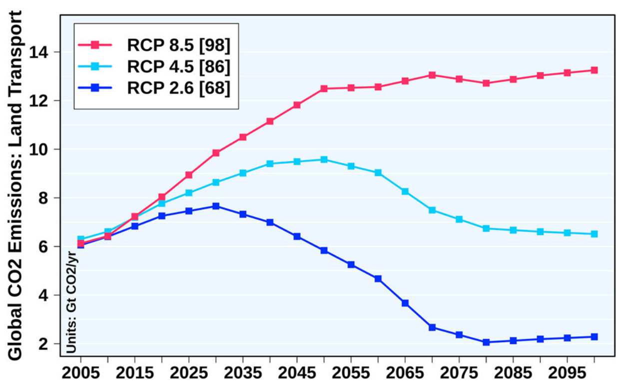

Figure 3. Annual time-series of projected of CO_2 emissions of the land transport sector at global level.

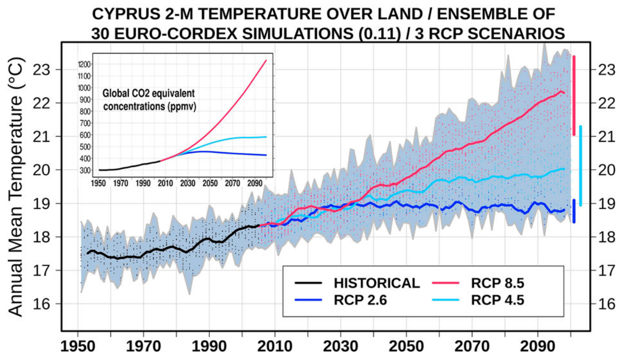

Figure 4. Annual time-series of projected temperature averaged over Cyprus and based on EURO-CORDEX regional climate simulations. The global CO_2 equivalent concentrations for three RCP pathways are superimposed.

more evident for the intermediate (RCP4.5) and 'business-as-usual' (RCP8.5) scenarios. Noteworthy, this region encompasses Nicosia, the capital and most populated city of the Republic of Cyprus. Additionally, the projected warming is unevenly distributed throughout the year and is found augmented during the already warm summer season (not shown).

3. Methodology

3.1. Input-output analysis

Input-output analysis (IOA) consists of a system of linear equations describing the distribution of the output of the sector among the rest sectors of the economy over a stated time period (Miller and Blair

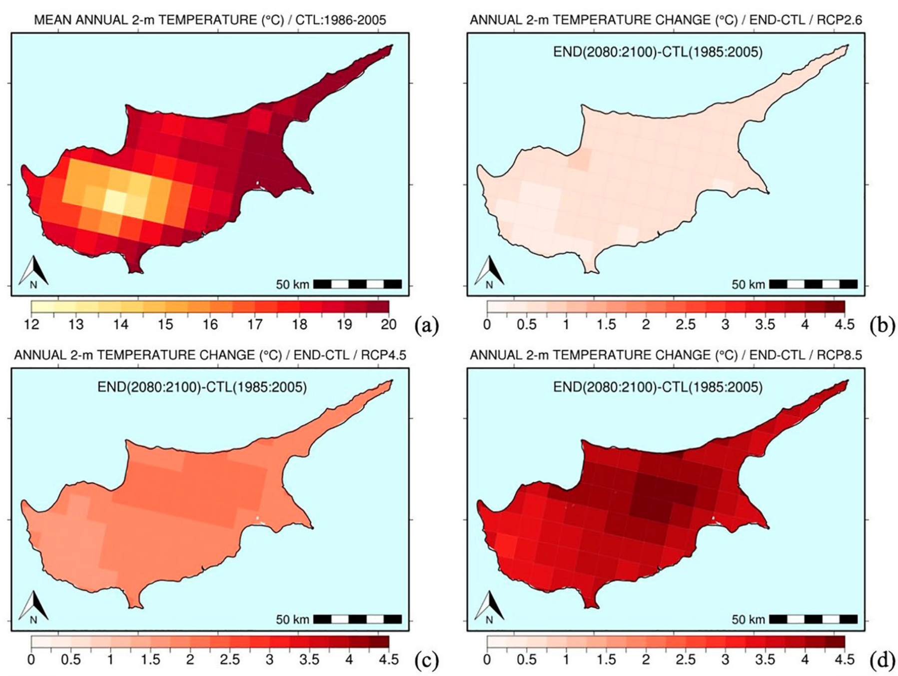

Figure 5. Mean annual 2-m temperature over Cyprus for the reference period 1985–2005 (a), and projected changes for the end of the twenty-first century (2080–2100) for three future pathways (b, c, d).

2009), and it has been widely applied for policy impact evaluation and technical change analysis (Giannakis, Efstratoglou, and Psaltopoulos 2014; Giannakis and Bruggeman 2017b). Below, we briefly review the IO methodology, while in Section 3.2 we introduce the basic concepts of the EE-IOA.

For an economy with n sectors, the i sector distributes its output through sales to the other sectors and final demand as follows:

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \tag{1}$$

Where x_i is the total output of sector i; x_{ij} describes interindustry sales by sector i to all sectors j $(i, j = 1, \ldots, n)$; y_i is the final demand for sector $i's$ product.

The technical coefficients a_{ij} represent the value of the output from sector i that is required to produce one unit of output in sector j, and are calculated as follows:

$$a_{ij} = x_{ij}/x_j \tag{2}$$

Equation (1) can be written in matrix notation as follows:

$$X = AX + Y \tag{3}$$

$$X = (I - A)^{-1}Y \tag{4}$$

where $(I - A)^{-1}$ is the Leontief inverse or the total (direct and indirect) requirements matrix.

3.2. Environmentally-extended input-output analysis

The IOA framework has been incrementally applied to investigate the interaction of the economy with the environment (Leontief 1970; Giannakis et al. 2019).

The extension of IOA models to EE-IOA models involves the addition of an exogenous vector of pollution intensity, here denoted as $D = [d_i]$, that is, CO_2 emissions (e_i) per unit of each sector's output (x_i) calculated as follows (Miller and Blair 2009):

$$d_i = \frac{e_i}{x_i} \tag{5}$$

The total (direct and indirect) CO_2 emissions (E) can be calculated as follows:

$$E = D(I - A)^{-1}Y \tag{6}$$

3.3. Data and application of the EE-IOA model

The RAS technique, a widely used method for updating IOA tables was used to update the latest available 2010 symmetric IOA table to 2016 (for more information see Miller and Blair 2009; Giannakis and Mamuneas 2018). The initial scheme of 65 sectors of economic activity was aggregated into 22 economic sectors (see Table A2, Appendix 2). The 2010 IOA table for Cyprus was obtained by the Statistical Service of Cyprus (Cystat 2017). The sectoral CO_2 emission data were obtained by the Eurostat (Eurostat 2018). Although the well-known assumptions of the EE-IOA technique, i.e. linearity, homogeneity, proportionality, and uncertainties in source data (Wiedmann 2009), EE-IOA has been extensively used for assessing the overall contribution of economic sectors to greenhouse gases emissions (Morán and del Río González 2007; Alcántara and Padilla 2009; Dias et al. 2014; Cortés-Borda et al. 2015).

In this study, we used the long-term outlook of the EU Reference Scenario 2016, that is, one of the European Commission's key analysis tools in the areas of energy, transport and GHG emissions, to estimate the growth rate of the land transport sector in Cyprus towards 2030 (Capros et al. 2016). Specifically, we performed an economy-wide assessment of CO_2 emissions in Cyprus, associated with a 22% increase in the final demand for the output of the land transport sector from 2016 to 2030 (hereafter LandTrans22 scenario).

4. Results

The IOA multiplier analysis identified the most important economic sectors with regards to their capacity to generate economic output throughout the economy (Table 1). The food manufacturing sector creates the highest direct and indirect effects on the output of the Cypriot economy (1.83), that is, for a 1 million increase in the final demand for the products of the sector, the total output of the economy will be increased by 1.83 million Euro. Significant backward linkages are created also by the construction (1.76) and the water transport (1.76) sectors. On the other hand, service sectors such as education (1.14) and public administration (1.22) create low multiplier effects. The output multiplier for the land transport sector is relatively low (11^{th} in rank) indicating weak backward linkages with the rest sectors of the economy.

The EE-IOA multiplier analysis identified the contribution of the twenty-two sectors of economic activity in the generation (direct and indirect) of CO_2 emissions (Table 1). The Electricity, gas and water sector (2,028) and the Metal and non-metal products sector (1,785) are the most important (direct and indirect) CO_2 emitters. The model results confirm the large contribution of the land transport sector activities in the generation of CO_2 emissions. The meaning of the land transport multiplier (3rd in rank) is that for every 1 million Euro increase in the final demand for the products and services of the sector, 407 additional tons of CO_2 will be emitted. We have to note that contrary to the land transport sector, the water transport (shipping) and air transport sectors emit relatively low CO_2 emissions (15th and 22nd in rank, respectively), although they create high economic multiplier effects with the rest sectors of the economy (3rd and 4th in rank respectively). Service sectors such as Health (21), Education (20) and Public administration (19), similar to the economic analysis, generate low (direct and indirect) CO_2 emissions.

A correlation analysis between the economic output and CO_2 multipliers indicated a weak negative association (−0.21), which reveals that the production sectors in Cyprus can create strong

Table 1. Economic output multipliers and CO_2 multipliers for the economic sectors of Cyprus (2016).

Sectors of Economic Activity	Output Multipliers (M€/M€)	Rank	CO_2 Multipliers (tn/M€)	Rank
Agriculture	1.54	8	77	11
Mining	1.67	5	165	6
Food Manufacturing	1.83	1	69	12
Textile	1.38	12	37	16
Wood and Paper	1.44	10	58	13
Chemical and Plastic Products	1.33	16	292	4
Metal and non-metal products	1.37	13	1785	2
Machinery and equipment	1.27	19	45	14
Electricity, gas and water	1.30	18	2028	1
Construction	1.76	2	79	9
Trade	1.35	14	106	8
Accommodation and Food Services	1.50	9	35	17
Land transport	1.39	11	407	3
Water transport	1.76	3	44	15
Air transport	1.70	4	1	22
Warehousing, postal and courier activities	1.66	6	28	18
Banking – Financing	1.60	7	190	5
Real Estate	1.23	20	79	10
Public administration	1.22	21	27	19
Education	1.14	22	6	20
Health	1.33	15	5	21
Other Services	1.30	17	160	7

economic backward linkages in the economy and invigorate economic growth without substantially increasing their CO_2 emissions.

The 22% increase in the final demand for the output of the land transport sector by 2030 (LandTrans22 scenario), assuming no change in technology (a_{ij}), results in an overall (direct and indirect) increase of CO_2 emissions by 37,538 tons, which corresponds to 24% increase of sector's emissions relative to 2016 levels. The projections of the land transport sector CO_2 emissions at global level (see Figure 3) indicate an increase of the emissions of the sector by 12% by 2030 under the most ambitious mitigation pathway (RCP2.6). Carbon dioxide equivalent emissions are expected to increase under the intermediate RCP4.5 and the 'business-as-usual' RCP8.5 by 20% and 36%, respectively. These estimates, considering the differences in the basic assumptions of the drivers of the scenarios, e.g. technological changes and economic trends, indicate the robustness of our analysis.

5. Discussion

In this study, we performed an empirical analysis of the contribution of the land transport sector to CO_2 emissions generation at macroeconomic level. The results of the EE-IOA model indicate the large direct and indirect CO_2 emissions of the land transport sector in Cyprus as well as the relatively low economic backward linkages with the rest sectors of the economy. On the contrary, shipping and air transport sector create high backward linkages and multiplier effects with the rest sectors of the economy with relatively low CO_2 emissions. Giannakis and Mamuneas (2018) found that the transportation sector and the food manufacturing industry are the sectors with the highest backward linkages in the Cypriot economy overtime, i.e. in both economic growth and crisis periods. The electricity, gas and water sector and the metal and non-metal products sector create the highest direct and indirect CO_2 emissions in Cyprus followed by the land transport sector. Our findings are aligned with the results of Morán and del Río González (2007) study, who found with the use of EE-IOA that the sectors with the highest CO_2 emitting power in Spain are electricity, non-metallic and metallic products, chemical industry and terrestrial transport. Similar results for Spain are reported by Alcántara and Padilla (2006). The analysis of the energy-related GHG emissions of the Mexican economy revealed that the largest emissions come from the road transport sector (Chatellier-Lorentzen and Sheinbaum-Parado 2017). Specifically, a 1% increase in the final demand of the sector would lead to a 333% increase of total CO_2 emissions. Dias et al. (2014) found in the municipality of Aveiro that the land transport and transport by pipelines sector have the highest (direct and indirect) contribution on GHG emissions, i.e. 22% of total emissions. The large (direct and indirect) contribution of the transport sector in the generation of carbon emissions is also reported for the economy of Beijing in China (Ge et al. 2016; Shao et al. 2016).

Our findings reveal the importance of the land transport sector in the transition of Cyprus to a low-carbon economy and highlight the urgency of taking in-sector action. The government of Cyprus has outlined several key strategies in the 'Cyprus' Integrated National Energy and Climate Plan' to reduce GHG emissions from the road transport sector, the most important of which are investments for the development of infrastructure and services to support the electrification of the sector and the shift towards public transport modes (Mesimeris et al. 2020). However, we have to note here that the planned policies and measures foreseen in the National Energy and Climate Plan are not expected to fully meet the legally binding target of the Effort Sharing Regulation (2018/842/EU), i.e. to reduce the non-ETS GHG emissions by 24% in 2030 (Zachariadis et al. 2019). In view of the declared political commitment of the EU for a climate-neutral economy by 2050, more ambitious emission abatement policies and measures are needed to fill the abovementioned non-ETS emissions abatement gap and reach carbon neutrality.

Financial and institutional barriers including the high investment costs to develop low-emissions transport systems, the low turnover of stock and the low impact of a carbon price on petroleum fuels, impede the uptake of low-carbon technology (Sims et al. 2014). For example, the high cost is one of the main obstacles for the transition to electric drive vehicles, which can be decreased however as scale increases (Greene, Park, and Liu 2014). Until the cost of the clean technologies reduces enough to become economically attractive, subsidies and taxes are needed (Santos 2017). Sims et al. (2014) support that subsidies and taxes need to be decided on environmental criteria rather than on economic efficiency criteria, and the Paris Agreement has shown the way for these environmental oriented subsidies and taxes to become politically feasible.

Technological policy interventions such as deep electrification in the transport sector create the largest positive effects on emission reduction, but cannot alone achieve the decarbonisation targets due to their longer-term performance (Zhang, Fujimori, and Hanaoka 2018). Brand, Cluzel, and Anable (2017) showed for the UK that the mass market electrification of the car market cannot alone achieve deep cuts in carbon emissions. Social transformations such as behavioural change could be effective supplementary policy tools for a transition to low-carbon economy (Creutzig et al. 2016). Changing people's behaviour towards preferring public transport, low fuel consumption vehicles (e.g. hybrid) or non-motorised vehicles (e.g. bikes) can lead to important reductions of GHG emissions (Dias et al. 2014). Therefore, an integrated approach that combines technological and social transformations is needed for developing an energy-efficient decarbonised transport system (Tran et al. 2012; Zhang, Fujimori, and Hanaoka 2018).

The projected increase of temperature in Cyprus and specifically in the main urban centres during summers, highlights the urgency for steering our cities towards a path of low-carbon mobility. Public transport in Cyprus has a great potential for increase as a very low share of citizens living in cities use public transport modes. Specifically, Cyprus has one of the highest car ownership rate in the world, that is, 742 cars per 1000 persons (Mesimeris et al. 2020). It has been estimated that less than 20% of the total transportation in Cyprus, measured in passenger-kilometres is performed by buses with the rest being carried out by passenger cars (Eurostat 2017c). The formulation of a Sustainable Urban Mobility Plan (SUMP) for Limassol, that is, the second largest urban area of the country, revealed that urban dwellers, although the perception of the car as the preferred mode of transport is deep-seated in the Cypriot society, are willing to move towards greener transport modes provided that several preconditions such as high quality public transport services, coherent and safe bicycle network, bicycle renting system, parking restrictions, are met (PWD 2019). A recent study in the built-up area of the centre of Limassol revealed the benefits of reducing car use in favour of public transport modes; a decrease in car use from 92% (current levels) to 70% towards public transport modes would result in a 20% reduction of CO_2 emissions (Giannakis et al. 2018).

The macroeconomic assessment of the contribution of economic sectors to CO_2 emissions generation highlight the need of encouraging the development of economic activities that can at the same time be economically viable and environmentally sustainable. On the contrary, traditional sectors of economic activity, such as land transport, which create relatively low economic backward linkages but high GHG emissions, should be adapted towards a more environmentally-friendly context. Future research on citizens' satisfaction with public transport modes through questionnaire surveys could improve our understanding of citizens' needs and expectations. This will allow the formulation of specific recommendations for enhancing the shift towards public transport modes.

6. Conclusions

The results of the macroeconomic analysis highlight the large direct and indirect CO_2 emissions of the land transport sector in Cyprus and provide national policy makers and urban planners with quantitative information for formulating sustainable transport policies to mitigate climate change and stabilise global warming below 2°C. Specifically, a projected 22% increase in the final demand for the output of the land transport sector by 2030 results in an overall (direct and indirect) increase of CO_2 emissions by 37,538 tons, which corresponds to 24% increase of sector's emissions relative to 2016 levels. Considering the projected temperature increase for Cyprus, that is, up to 4.5–5°C by the end of the century, the need of investing in clean technologies for the mobility sector is of utmost importance. The land transport is one of the hardest sectors to decarbonise, thus subsidies and taxes are needed to make the low-carbon technology economically attractive. Cities in Cyprus are currently trying to recover from a car-dominated regime in urban planning design by re-allocating road space for public transport and non-motorized vehicles. Our findings highlight the need for a better integration of environmental, energy and transport policies that could further lead to reduced CO_2 emissions in Cyprus.

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Appendices

Appendix 1

Table A1. Description of the ensemble set of regional climate simulations used.

Global Model	Regional Model	Modelling Centre	RCP2.6	RCP4.5	RCP8.5
CNRM-CM5 (r1)	CCLM	CLM Community		X	X
CNRM-CM5 (r1)	RCA4	SMHI		X	X
EC-EARTH (r12)	CCLM	CLM Community		X	X
EC-EARTH (r12)	RCA4	SMHI	X	X	X
EC-EARTH (r1)	RACMO22E	KNMI		X	X
EC-EARTH (r3)	HIRHAM5	DMI		X	X
HadGEM2-ES (r1)	CCLM	CLM Community		X	X
HadGEM2-ES (r1)	RACMO22E	KNMI		X	X
HadGEM2-ES (r1)	RCA4	SMHI		X	X
IPSL CM5A-MR (r1)	RCA4	SMHI			X
MPI-ESM-LR (r1)	RCA4	SMHI		X	X
MPI-ESM-LR (r1)	CCLM	CLM Community		X	X
MPI-ESM-LR (r1)	REMO	MPI-CSC	X	X	X
MPI-ESM-LR (r2)	REMO	MPI-CSC	X	X	X

Box A1. Description of representative concentration pathways.

RCP2.6: The RCP2.6 is developed by the IMAGE modeling team of the Netherlands Environmental Assessment Agency (van Vuuren et al. 2007). The emission pathway is representative for scenarios in the literature leading to very low greenhouse gas concentration levels. It is a so-called 'peak' scenario: its radiative forcing level first reaches a value around 3.1 W/m^2 mid-century, returning to 2.6 W/m^2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially over time.

RCP4.5: It is developed by the MiniCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (Clarke et al. 2007). It is a stabilisation scenario where total radiative forcing is stabilised before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions. It is often considered as an intermediate scenario.

RCP8.5: The RCP 8.5 is developed by the MESSAGE modeling team and the IIASA Integrated Assessment Framework at the International Institute for Applies Systems Analysis (IIASA), Austria (Riahi, Grübler, and Nakicenovic 2007). The RCP8.5 is characterised by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels. It is often considered as a 'business-as-usual' scenario.

Source: http://www.iiasa.ac.at/

Appendix 2

Table A2. NACE codes of Cyprus input-output table economic sectors, 2016.

n/n	Sector	Description NACE*
G1	Agriculture	A01, A02, A03
G2	Mining	B
G3	Food Manufacturing	C10, C11, C12
G4	Textile	C13, C15
G5	Wood and Paper	C16, C17, C18
G6	Chemical and Plastic Products	C19, C20, C21, C22
G7	Metal and non-metal products	C23–C25
G8	Machinery and equipment	C26–C33
G9	Electricity, gas and water	D35, E36, E37–39
G10	Construction	F
G11	Trade	G45-G47
G12	Accommodation and Food Services	I
G13	Land transport	H49
G14	Water transport	H50
G15	Air transport	H51
G16	Warehousing, postal and courier activities	H52-H53
G17	Banking – Financing	K64-K66
G18	Real Estate	L68
G19	Public administration	O84

(*Continued*)

Table A2. Continued.

n/n	Sector	Description NACE*
G20	Education	P85
G21	Health	Q
G22	Other Services	J58, J59, J60, J61, J62–63, M69–70, M71, M72, M73, M74, M75, N, RS, T, U

Source: Eurostat (2008).
*NACE: Statistical classification of economic activities in the European Union.