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A Climate Neutrality Strategy for Cyprus

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Designing net-zero pathways through techno-economic assessments and enabling their implementation with the aid of behavioural insights

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ABSTRACT

This paper presents the findings of our model-based study on the transition of Cyprus to a net-zero economy. A climate-neutral Cyprus will be characterised by almost complete replacement of fossil fuels by electricity and renewable sources, full utilisation of waste and use of renewable hydrogen in transport and heavy industry. This will require serious public and private investments, which however can be beneficial for the economy and society. Still, important challenges lie ahead that call for swift policy action. Apart from long-term planning that must start today, effective implementation of green policies is key. In this context, the paper also provides a background on behavioural barriers that should be overcome, as the lack in understanding human behaviour is at the heart of the sustainability challenge. Drawing from our recent work for Cypriot authorities, we highlight directions in which policy-making in Cyprus can be enhanced, with special attention to energy poverty.

Keywords: *behavioural insights; carbon neutrality; climate policy; energy poverty; net-zero economy*

Introduction

Irrespective of occasional changes in the international economic and political landscape, global climate stabilisation remains an important policy priority in the wake of numerous natural disasters that are increasingly attributed to anthropogenic climate change. In line with the goals of the Paris climate agreement of 2015, whose attainment requires to eliminate the net emissions of greenhouse gases in the atmosphere in the coming decades, 142 countries of the world have pledged to achieve the transition to net-zero emission economies between 2050 and 2070. These countries correspond to 84% of the world population and 78% of global economic output[1]. In this context, and being a global pioneer in climate policy, the European Union has legally adopted the objective to achieve net-zero carbon emissions by 2050 in all Member states through the European Climate Law (Regulation (EU) 2021/1119).

Despite impressive progress in several zero-carbon technologies during the last years, the transition to climate neutrality requires changes in production and consumption systems of unprecedented scale and speed. Achieving such a goal in the next 25 years calls for substantial investments and is associated with uncertainties, costs, but also considerable benefits.

This paper sheds light on the challenges of the net-zero transition of the Republic of Cyprus, an island EU Member State, which is characterised by comparatively high greenhouse gas emissions per unit of economic output but at the same time is a service-based economy that – in an appropriate policy environment – can leapfrog to climate neutrality without serious socio-economic consequences that other industrialised nations are concerned about. We describe our model-based work that outlines the changes in the energy system required for the net-zero transition, the investment needs, and the macroeconomic and fiscal implications. We also focus on the social equity aspects of the transition, recognising that the lack in understanding human behaviour is at the heart of the sustainability challenge.

The rest of this paper is organised in three sections. Section 2 starts with an overview of the techno-economic modelling work that is employed in the literature to study net-zero transitions and continues with outlining the background knowledge about behavioural barriers that should be overcome to address the interaction between green policies and social equity. Section 3 describes our empirical work that highlights the important challenges to realise the net-zero transition in Cyprus. It starts by outlining the combination of mathematical tools used in our work and their novel aspects in comparison to the international state of the art that was reviewed in Section 2, and proceeds in Section 3.2 with a detailed outlook of the central net-zero scenario of this paper. At the same time, keeping in mind that planning the climate neutrality policies is not sufficient and effective implementation of these policies is crucial, Section 3.3 provides an analysis about a highly important issue of the transition – how to effectively address energy poverty, which is key for increasing social acceptance of decarbonisation policies. Finally, Section 4 concludes.

[1] See https://zerotracker.net/, last accessed on 23 May 2025.

Background

The implementation of energy system models to support the net-zero transition

Energy system models have been employed for several decades to assist in decision making and planning. They can be characterized as simplified representations of reality, comprised of mathematical equations, with the goal of comprehending complex interactions in a given energy system and providing policy insights (Huntington et al., 1982). Energy system models can provide answers to scientific problems that are policy relevant and can identify and steer effective investment decisions. At the same time, models cannot fully capture the real-world characteristics, while they are based on a series of assumptions with varying degrees of uncertainty. Thus, transparency of the analytical processes that lead to decisions to all interested stakeholders is crucial in ensuring social acceptance of the resulting policies and measures (Pfenninger, 2017).

Models are crucial in the policy design process, ensuring attainment of energy and climate goals. They are useful in informing decision makers of which policy instruments are effective and at what costs. Energy system models can broadly be distinguished between bottom-up technoeconomic models and top-down macroeconomic models (Herbst et al., 2012). Bottom-up models employ a high degree of detail in terms of technologies but typically do not offer any detailed insights on net impacts across the economy. On the other hand, top-down models represent the energy sector in aggregated sector-specific energy demand and supply and assess effects on the entire economy, but are not suitable for analysing potential technology deployment, due to insufficient detail in this regard (Gargiulo and Gallachóir, 2013). Certainly, policy makers are interested in details of both technical and economic aspects. Hence, macroeconomic and technoeconomic models are often employed in parallel. Similarly, in an effort to maximize the strengths and address the shortcoming of these two families of models, numerous examples of hybrid models exist in the literature (Bauer et al., 2008; Kumbaroğlu and Madlener, 2003; Martinsen, 2011; Merven et al., 2017; Schäfer and Jacoby, 2006).

Numerous modelling tools have been deployed over the last years, with variation in terms of spatial, temporal and sectoral representation (Chang et al., 2021). Furthermore, the use of models to guide policy making by national and regional governments is widespread, at least in developed countries and regions. For instance, the PRIMES suite of models has been at the centre of EU energy and climate policy at the level of the European Commission, providing analytical information on environmental, economic and social impacts by proposed policies (Capros et al., 2014; European Commission, 2016). The European Commission's Joint Research Centre has developed a separate modelling tool; the POTEnCIA (Policy-Oriented Tool for Energy and Climate Change Impact Assessment) model can be used for the assessment of EU energy policies (European Commission, 2015). Similarly, besides analysis at the regional level, the detailed quantitative and qualitative information required during the preparation of National Energy and Climate Plans (NECPs) encouraged the development and adoption of national-scale models by the relevant authorities of EU member states. The final versions of the NECPs were submitted to the European Commission at the end of 2019 and early 2020, while these have recently been revised to account for the more ambitious targets set by the European Green Deal (European Commission, 2025).

An overview of the NECPs submitted by EU member states shows that the underlying analyses employed a large variety of energy system models to assist with the various energy and environmental projections that had to be reported, as well as the economy-wide impact assessment on the proposed policies and measures. Nearly all countries use a combination of technoeconomic and macroeconomic models to provide valuable insights to policy makers. Even though other models have been utilised as well, optimisation models appear as the most commonly used subcategory of technoeconomic energy system models. The purpose of these models is to satisfy a specific objective function; frequently this is the minimisation of a particular system's cost (Herbst et al., 2012). On the other hand, in order to assist with the impact assessment of policy choices in the broader economy, Computable General Equilibrium (CGE) models are the most frequent choice, while some national authorities utilised Input-Output models. The former subcategory assumes that all markets are in perfect equilibrium and the implementation of policies preserves the equilibrium through price adjustments, while the latter captures the flow of goods and services across economic sectors and users in terms of value added and input/output coefficients (Herbst et al., 2012).

It is worth mentioning that some of the countries rely on an ensemble of models that can be tailored to provide detailed analysis for the different key sectors of the energy system. For instance, the Dutch NECP utilises fourteen different technoeconomic models either to analyse a specific sector or to post-process the outputs from the entire adopted toolkit (PBL, 2019). Similarly, besides the sector specific models, the Danish NECP utilises technology deployment models that represent existing investment and operating conditions of renewable energy technologies to simulate the profitability of these technologies and project capacity deployment outlooks for each of these (Danish Ministry of Climate, Energy and Utilities, 2019). The utilisation of a variable set of models to support even a single country's energy transition planning process indicates the necessity for policy makers to have access to a range of insights from numerous tools.

The potential of behavioural science to contribute to green transition policies

In recent decades, behavioural science has emerged as a transformative tool for improving public policy and addressing complex societal challenges, including climate change mitigation (e.g. Nielsen et al., 2024). The underlying principle is that if governments wish to encourage sustainable behaviours, they must first develop a more nuanced understanding of the factors that influence decision-making (Albarracin et al., 2024).

Human behaviour is a significant contributor to the sustainability challenge. A substantial proportion of the essential emissions cuts – as much as 62% in the case of the United Kingdom, according to the Climate Change Committee (Ivanova et al., 2020) – hinge on behavioural changes. These range from the adoption of green technologies, such as electric vehicles and enhancing energy efficiency in buildings, to lifestyle modifications including reduced consumption of red meat and dairy, increased reuse and repair and more active travel. However, the inherent challenges associated with climate change, such as its gradual nature, perceived uncertainty, psychological distance, and the discrepancy between beliefs, intentions, habits and norms, contribute to the difficulties in addressing it (Moleskis et al., 2024). For instance, people often discount future outcomes in favour of the present moment, and as a result tend to act in less environmentally-friendly ways, because they perceive these actions as less pleasurable, more costly and more time-consuming (Steg et al., 2014).

Conventionally, policymakers have utilised three primary instruments within their repertoire: (1) information provision through, for example, environmental labels on products and outreach campaigns; (2) economic incentives such as taxes, subsidies, and price adjustments; and (3) regulations like bans, rules, and industry standards. While the efficacy of these instruments in modifying consumption patterns is well-documented, a comprehensive understanding of the fundamental principles of human behaviour is also imperative (United Nations Environment Programme, 2017). In the absence of such understanding, policy approaches are likely to be based on unrealistic assumptions: a society characterised by deliberative decision-makers immune to cognitive biases and heuristics, who weigh the costs and benefits of their actions based on their own values and preferences in order to maximise their self-interest in the long run (Thaler, 2016).

In the realm of information provision, the conventional wisdom has long been that the comprehension of facts will inevitably result in optimal decision-making and that knowledge, in and of itself, will precipitate a shift toward s more environmentally-friendly behaviours. Consequently, policymakers frequently devise policies that place considerable emphasis on the dissemination of information. However, meta-analyses indicate that at least 80% of the factors influencing pro-environmental behaviours are not rooted in knowledge or awareness (Kollmuss & Agyeman, 2002). While informational interventions aim to alter beliefs, changing minds does not always translate to changing behaviour, especially when it comes to habitual behaviours (Webb & Sheeran, 2006). Research has demonstrated that ingrained habits are the most significant determinants of behavioural change, often exerting a greater influence than knowledge, skills, attitudes, beliefs and emotions (Albarracín et al., 2024), which results in a discrepancy between intentions and actions (Grimmer & Miles, 2017). A meta-analysis of studies on the impact of information provision on behavioural change shows that the effect of information is a mere 2-3% (Nisa et al., 2019).

This paucity of impact from information alone can be attributed to a number of factors. Habitual behaviours are not typically driven by values, as they no longer require deliberate thought or consideration (Verplanken & Wood, 2006). This occurs even in cases where the consequences are of personal significance. For instance, despite the widespread awareness of the health risks associated with behaviours such as overeating, excessive alcohol consumption, and physical inactivity, it is estimated that 63% of deaths worldwide are still due to diseases linked to these automatic behaviours, including cancer, cardiovascular disease, diabetes, and respiratory disease (Ash et al., 2012). This phenomenon can be further elucidated by the concept of information overload, which refers to the challenge of comprehending and effectively decision-making when confronted with an overabundance of information (Gross, 1964). A further common obstacle is that of lack of self-efficacy (the belief in our ability to make a positive difference), coupled with the fear-inducing approach adopted by information campaigns (Yang & Weber, 2019; Bloodhart et al., 2019; Chiang et al., 2019). Finally, inconvenience, in all its forms, is a most important obstacle. Numerous green options encounter significant challenges related to various frictions, encompassing economic and temporal considerations, the intricacy of the process, concerns regarding others' perceptions, and the probability of recall, among others, rendering tasks more effortful, potentially determining whether an action is undertaken or postponed indefinitely (Behavioural Insights Team, 2024).

In order to enhance communication, behavioural science helps policymakers to consider the content of their messages in addition to the framing, formatting and timing of these communications. By leveraging some of the cognitive biases that hinder citizens in making suboptimal choices, policymakers can design communication with these in mind. For instance, the simplification of information and the establishment of tangible consequences in relation to sustainable practices have been demonstrated to be effective in capturing people's attention. This is analogous to the heightened impact of observing the effects of an illness on a particular individual as opposed to merely being exposed to statistical data. Furthermore, invoking pride rather than guilt has been shown to yield more favourable outcomes in encouraging (or discouraging) specific behaviours (Patrick et al., 2009). The credibility of the messenger is also a significant factor in the persuasiveness of the message. Research has shown that people are more likely to take a message seriously if the messenger is perceived to have formal or informal authority, is similar to the audience, and evokes positive emotions (Webb & Sheeran, 2006; Durantini et al., 2006; Hayns-Worthington, 2018). A notable example of this phenomenon can be seen in the influence of David Attenborough on his audience. The manner in which information is presented, or framed, is also of significance, in the sense that individuals are more responsive to information depicting potential losses (in terms of something they currently own or enjoy) than to information highlighting potential gains of the same magnitude (Kahneman & Tversky, 1984).

A second policy tool comes in the form of monetary (dis)incentives. Conventionally, policymakers have presumed that individuals exhibit sensitivity and responsiveness to incentives, particularly those of a financial nature. Consequently, incentives are extensively employed by governments to regulate behaviours deemed undesirable (e.g., taxes on cigarettes) and to encourage behaviours that enhance well-being (e.g., tax relief on pensions). The efficacy of such measures is evident in specific domains of life, wherein they serve to recalibrate the costs and benefits involved in decision-making processes. However, it is important to note that they are not universally applicable or effective in all contexts. The costs associated with incentive programmes can, on occasion, render them prohibitively expensive, and the utilisation of economic incentives can result in unintended consequences.

The underlying reasons for this phenomenon are multifaceted. Firstly, financial incentives can frequently be both costly and ineffective. A seminal example is provided by researchers Chetty et al. (2014), who demonstrate the low value for money of incentive policies to increase retirement savings. Their research indicates that for every dollar spent by the government on subsidies, there is a 1 cent increase in total savings. Conversely, cost-free behaviourally-informed policies that take into account the power of default options, such as automatic employer contributions to retirement accounts, have been shown to increase savings by a significant margin (Chetty et al., 2014). Secondly, financial incentives have the capacity to diminish intrinsic motivation. Studies demonstrate that the introduction of incentives, such as subsidies or other forms of financial rewards, for activities that individuals already find pleasurable, results in diminished intrinsic motivation to engage in those same activities (e.g. Deci, 1971; Lepper et al., 1973). Thirdly, financial disincentives (or penalties) have the potential to amplify undesirable behaviours by shifting perceptions. This phenomenon is exemplified by a study conducted at an Israeli nursery, which highlights the potential for unintended consequences (Gneezy & Rustuchini, 2000). In addressing the issue of tardiness among parents, the nursery resorted to the implementation of financial penalties with the objective of reducing tardiness and optimising operational efficiency. However, this intervention led to an increase in the number of tardy parents, rather than a decline, which was attributed to a shift in parental perception regarding lateness: rather than perceiving it as a social ill that caused inconvenience and embarrassment, many parents now viewed it as an additional service that they were legitimately paying for.

Furthermore, traditional policy-making neglects the untapped potential in leveraging behavioural and cognitive phenomena, such as people's general propensity to loss aversion and the allure of prizes and lotteries, because of how people form valuations, which is through reference points (Kahneman & Tversky, 2013). For instance, a body of research spanning various sectors, from blue-collar workers to educators, has demonstrated that individuals tend to exhibit enhanced performance when they receive a bonus at the commencement of the year with the understanding that it will be withdrawn if they fail to meet the stipulated performance standards, as opposed to receiving the performance-based bonus at the year's end (e.g., Fryer et al., 2012).

As a third option for achieving change, governments may elect to implement hard measures, such as regulations, mandates and bans, which compel citizens and corporations to adopt or avoid certain behaviours. However, the efficacy of such measures can be hindered by impractical enforcement, stemming from citizens' reluctance to relinquish fundamental liberties. Another reason why regulation can fail to have an effect may lie in its design. Complex language, lack of clarity, lengthy texts, bureaucratic structures, frequent changes, accessibility issues and insufficient guidance can result in people ignoring rules (Hunt, 2023).

The behavioural science approach helps to design regulation and accompany it with softer interventions, so that the resulting combination helps people self-regulate rather than rebel or ignore it. One such example is how the state of Texas solved their problem with litter in 1986. Up to then, despite spending $20 million annually on trash removal, highways were increasingly littered. The authorities decided to seek a marketing campaign to help tackle the issue. This led to the creation of the 'Don't mess with Texas' campaign that drastically reduced littering (by 54% in one year), and continues today, featuring many famous Texans, including Willie Nelson and Matthew McConaughey (Nodjimbadem, 2017). The tremendous success of the campaign lies in how it harnesses people's social identity, sense of duty and pride, leveraging a powerful intrinsic motivator—residents' desire to protect and honour their state. It also helped to shift social norms by making littering socially unacceptable. Importantly, the slogan was simple, memorable, and direct, making it easy to understand and recall, and it was delivered by then-influencers such as popular athletes and other celebrities.

A fourth policy option that has become available to policy-makers through behavioural science is choice architecture. This term refers to the careful design of how choices are presented, and it embodies a broader shift from traditional regulation to behaviourally-informed policies. In this capacity, policymakers assume the role of 'choice architects', meticulously designing the context, process, and environment in which individuals formulate decisions. Through purposeful design, they leverage predictable patterns of cognitive thinking to guide people's choices. In essence, this creates an environment in which one is free to choose, but certain decisions are more cognitively taxing than others. This approach is commonly referred to as the concept of *nudge* (Thaler & Sunstein, 2021). As a stand-alone policy option, a nudge retains freedom of choice (it is liberty-preserving as opposed to regulation) and does not alter economic incentives.

The implementation of these four behaviourally-informed policy tools has the potential to significantly enhance the policy-making process in Cyprus towards the net-zero transition. To illustrate this, we describe an example based on our recently published case study that focuses specifically on energy poverty, which was conducted as part of this LSE HO funded project (Moleskis et al., 2025).

Empirical Results for Cyprus

The Policy Landscape

Cyprus is located in one of the world's most vulnerable regions to climate change (Republic of Cyprus, 2022). At the same time, being a European Union Member State, the country is committed to the EU's ambitious climate policy goals that are included in the European Green Deal and have been adopted in the European Climate Law. According to the latter, the Republic of Cyprus must contribute to achieving the EU-wide target of reduction of greenhouse gas emissions by 55% in 2030 compared to 1990 and net zero greenhouse gas emissions by 2050. It is well documented that Cyprus is still characterised by very large dependence on imported fossil fuels and high greenhouse gas emissions per capita; this calls for swift action towards decarbonisation and diversification of energy supply, which can also improve the country's energy security and affordability. These remarks are reflected in all recent EU policy documents about Cyprus (see e.g. Council of the European Union, 2024).

Since 2021, the country has secured very substantial EU funds of more than 2 billion Euros for its green transition, from the National Recovery and Resilience Plan (RRP), the extra 'REPowerEU' chapter of the revised RRP, the European Structural and Investment Funds, the Just Transition Fund, and the Connecting Europe Facility. Still, decarbonisation of the Cypriot economy is evolving slowly. According to the revision of the National Energy and Climate Plan (NECP) of December 2024 (Republic of Cyprus, 2024), and in line with analysis of the European Environment Agency (2024), meeting the legally binding 2030 emission reduction targets is unlikely because there is not enough time for all green energy investments to be implemented.

Against this background, Section 3.2 of this paper provides techno-economic assessments that lay out pathways to the net-zero transition of Cyprus by 2050, keeping in mind the intermediate decarbonisation target of 2030 foreseen in EU legislation. Some of these assessments have been used by Cypriot authorities in their NECP. After presenting the trajectory to 2050, we explore the impact of these decarbonisation targets on the Cypriot economy – the investment needs and the fiscal and broader economic effects. As the investments and economic impacts have largely been addressed in the NECP and the relevant study is publicly available, this paper pays special attention to the post-2030 challenges on the way to a carbon-neutral economy.

Beyond designing a decarbonisation strategy, however, the road to its implementation is full of challenges. The net-zero transition in such a short time frame (from 2025 to 2050) is not a 'business-as-usual' endeavour. Apart from investments, technological readiness, and financing barriers, the uptake of green technologies and the change in behaviour is difficult, especially in vulnerable parts of the population that may lack the financial means and the mental willingness to overcome intermediate barriers and adopt green technologies and greener habits. In this regard and based on the review presented in Section 2.2. above, Section 3.3 proposes practical policy changes inspired by behavioural insights.

A model based assessment of the challenges of the net-zero transition

This section describes the analysis conducted for assessing the energy, environmental and economic aspects of the transition of Cyprus to a net-zero economy. We start by outlining the analytical tools used in this assessment, then highlight the main results and provide insights into the economic challenges and opportunities of the transition.

Modelling Tools

For the support of national energy and climate planning efforts in Cyprus, we have developed over the years a set of models to assess different dimensions of energy policies and how those affect the evolution of the energy system and the broader economy. These models, developed on the basis of the state-of-the-art reviewed in Section 2.1 above, are updated at least every year and are run for numerous scenarios in line with policy questions that must be addressed. The combined utilisation of these models provides long-term projections of energy demand and supply, greenhouse gas emissions, economic activity, employment, and cost of living impacts. The mathematical specifications of these models are included in the Appendix of this paper.

The different models and their interconnections are presented in Figure 1. First, an energy demand forecast model provides final energy demand projections for all sectors except road transport. Then, a cost-optimisation model uses these projections to provide a cost-optimal energy and technology mix that satisfies that final energy demand and simultaneously provides projections on electric vehicle penetration and the subsequent electricity demand in land transport. Optimisation is carried out for all years up to 2050 and can include different constraints in different years (e.g. constraints about maximum emissions, minimum renewable energy penetration, etc). Information from both these models is further provided to a macroeconomic input-output model and a consumer demand model to analyse impacts on economic output, employment, and social equity.

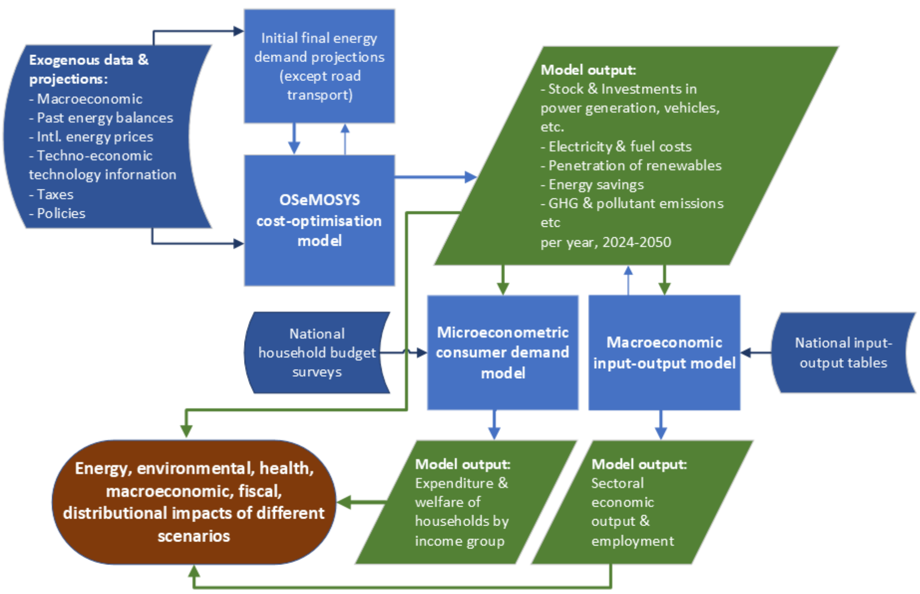

Figure 1. Modelling tools used for the preparation and impact assessment of national energy and climate plans of Cyprus up to 2050.

As a first step, an energy demand forecast model developed for Cyprus is applied to project final energy consumption across the economy (Zachariadis and Taibi, 2015). The energy forecast model has been used to support official energy planning efforts of national authorities in the recent past and is mathematically described in detail in a relevant publication by the International Renewable Energy Agency (2015). Utilising energy balances and other statistics for the recent past supplied by the Statistical Service of the Republic of Cyprus and other sources, an outlook to 2050 is provided. The main energy-consuming sectors of the economy are separately modelled, namely: agriculture, households, non-metallic minerals industry, other industry, and services.

Demand growth for the various energy forms is driven by exogenously defined macroeconomic assumptions obtained from the Ministry of Finance, technology costs and fuel prices, while it is subject to income and short-term and long-term price elasticities; these vary across the different sectors of the economy and are based on national econometric analyses and data from the international literature. The model also computes fuel shares in each sector, depending on technology costs, the penetration potential of various technologies and technical constraints for the uptake of new technologies, and allows computing future final energy consumption by sector and fuel.

The forecast model provides final energy consumption projections for all sectors except road transport. These projections are used as input in the OSeMOSYS cost-optimisation model. Road transport projections are conducted in OSeMOSYS because OSeMOSYS has a more detailed techno-economic representation of road vehicles and can therefore perform more granular and reliable projections and policy simulations for this sector.

Apart from input to OSeMOSYS, the demand forecast model also provides estimates of the annual expenditure of households by energy commodity; these are used as input for further economic assessments of macroeconomic, employment and social equity impacts of energy and climate policies.

The model employed in the second step of the analysis is developed within the Open-Source Energy Modelling System (OSeMOSYS), which is a long-term cost-optimisation energy system model (Howells et al., 2011). OSeMOSYS has been used in numerous studies with focus ranging from a global, regional and national scale (e.g. Gardumi et al., 2018). It is a bottom-up technoeconomic model that is demand-driven. The choice of technologies and energy mix is based on the adopted technoeconomic assumptions (e.g. fuel costs, technology costs, resource availability, emission limits). The model's objective function is the minimisation of the total discounted system cost over the entire modelling horizon subject to several constraints.

For this study, an existing model of the Cyprus electricity supply system was adopted that includes the transport and heating and cooling sectors (Taliotis et al., 2020), using code enhancements that allow consideration of short-term grid constraints (i.e. ramping characteristics, minimum stable operation levels and the need for operational reserves – see Welsch et al., 2014; 2015). The OSeMOSYS model of Cyprus has a modelling horizon until 2050, with annual resolution in terms of technology investments. Furthermore, in order to be able to capture intra-annual variations in demand and supply of electricity, each year is broken down into 96 time-steps. Specifically, the year is split into 8 seasons, which are represented by the average day of each season. These are in turn split into 12 time-steps to capture the intra-day variability in electricity demand and supply. The selection of the seasons and the day parts aims at capturing as much as possible the variability in electricity demand, without increasing too much the temporal resolution of the model, which would have a direct adverse effect on the computational effort needed when optimising the model.

The next tool is a macroeconomic input-output model (IO). IO analysis is a quantitative technique for studying the interdependence of production sectors in an economy over a stated time period (Miller and Blair, 2009) and has been extensively applied for policy impact evaluation, technical change analysis and forecasting. We have developed a continuous semi-dynamic demand-driven IO model with disequilibrium adjustment processes and applied it to assess the macroeconomic impacts of a decarbonisation scenario in comparison to a baseline scenario. The initial static equilibrium conditions of the model were based on the latest available IO table of Cyprus for the year 2019, which includes 65 sectors of economic activity. The national table was aggregated into 20 sectors of economic activity. Although IO tables of years 2020 and 2021 were available, they were intentionally not used in this analysis because of the irregular developments in economic activity in those years due to the pandemic.

The rationale of linking an energy optimisation model with an IO model is that a specific decarbonisation scenario will involve additional and/or different types of investments in comparison to a baseline scenario, thus generating different macroeconomic impact. The projected annual expenditures, including capital investments and operation and maintenance costs, from the OSeMOSYS model are introduced in the IO model to reflect changes in the investment demand of the specific sectors. These expenditures are classified in eight categories, namely: (a) industry, (b) power generation technologies, (c) electricity storage technologies, (d) gas infrastructure, (e) public transport, (f) private transport, (g) waste, and (h) buildings (i.e. energy efficiency measures, heat pumps, solar water heaters etc.). The shares of spending for the development and operation of all interventions under the two scenarios to the various sectors of economic activity have been allocated based on information obtained from the relevant literature (e.g. Tourkolias et al., 2009; Markaki et al., 2013), as well as on experience from the development and operation of actual projects in Cyprus.
Finally, we use a consumer demand model, specifically developed for Cyprus in collaboration with the Economics Research Centre of the University of Cyprus (Pashardes et al., 2014), to assess the impact of decarbonisation policies on the cost of living by household income group. This approach is based on the fact that price changes differ across goods, hence their effect can vary between households due to preference heterogeneity. In the case of energy, the unit cost is made from the prices of items such as electricity, gasoline, gas, heating oil, solid fuels and renewable sources. To the extent that these items do not increase proportionately in price and their shares in consumption vary across households due to preference heterogeneity, then the unit cost of energy also varies across households. For example, households without a car are not affected by a change in automotive fuel prices, whereas multi-car households may see a considerable increase in their cost of living if fuel prices rise.

Thus, Pashardes et al. (2014) constructed a consumer-theory-based measure of the unit cost of composite goods commonly used for empirical demand analysis, and used the variation in this cost across households to estimate a demand system from a limited household expenditure surveys. They applied the method to estimate the price elasticity of household demand for energy in the context of an integrable complete demand system using data drawn from three household expenditure surveys conducted in Cyprus in 1996, 2003 and 2009 by the Statistical Service of Cyprus. Then they simulated the welfare effects of price increases assumed to result from the adoption of EU's 2020 energy and climate package on households grouped by income, location and demographic characteristics. The model was re-estimated in 2019, using in addition the data from the household expenditure survey of year 2015, and was used in the first NECP of Cyprus.
The assumptions used in these models concerning macroeconomic developments, technological progress and potential of different technologies, evolution of energy prices as well as carbon prices are described in detail in Annex 11 (pp. 262-283) of the revised National Energy and Climate Plan (Republic of Cyprus, 2024).

It is worth noting that Cyprus is among the EU member states that utilise both technoeconomic and macroeconomic models to provide detailed energy, environmental and economic projections for the NECP; not all countries in the EU have adopted such a methodology. Furthermore, the utilisation of

OSeMOSYS as the core energy system model makes Cyprus the first country in the EU to adopt a fully open-source modelling framework to produce its official energy projections.

Results: An outlook to 2050

As regards *final energy demand*, Figure 2 shows the projected fuel mix up to 2050. Liquid fuels (oil products), which currently account for more than half of this demand, are replaced to a large extent by 2040 and almost fully by 2050 from electricity, renewable energy sources and biomass.

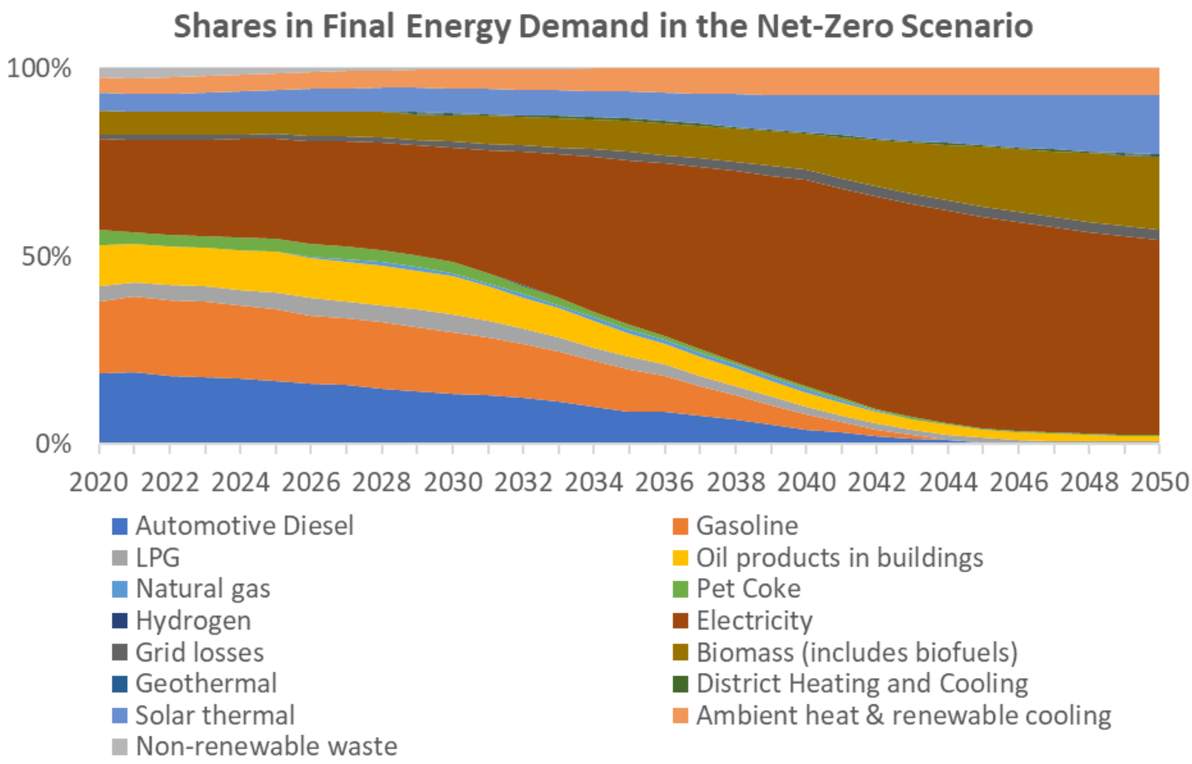

Figure 2: Fuel shares in final energy demand in Cyprus up to 2050.

In the *heating and cooling* sectors (industry, buildings, agriculture), the use of very small quantities of petroleum products remains even in 2050 because it was considered that the full path of the transition to climate neutrality starts from 2031, hence some systems installed before 2030 and having a lifetime of more than 20 years remain in operation (no mandatory replacement of all equipment before the end of its lifetime was imposed).

In the *transport* sector, the transformation starts before 2030 with the gradual electrification mainly of light vehicles and buses and accelerates over the next decades with the gradual phase-out of internal combustion engines and hybrid vehicles (see Figure 3). Heavy trucks are the last category of vehicles to be electrified, while the market also includes a small number of passenger cars and heavy hydrogen (fuel cell) vehicles. Because not all old vehicles were considered mandatory to be scrapped, and although from 2035 according to the recently adopted EU legislation all new cars will have to be zero-emission ones, nevertheless in 2050 there are about 3,700 plug-in hybrid vehicles remaining on the market. This is because a small number of vehicles purchased before 2035 may remain on the road in 2050 in the absence of mandatory withdrawal, and because some used vehicles purchased after 2035 will not be zero-emission and will still be on the road in 2050.

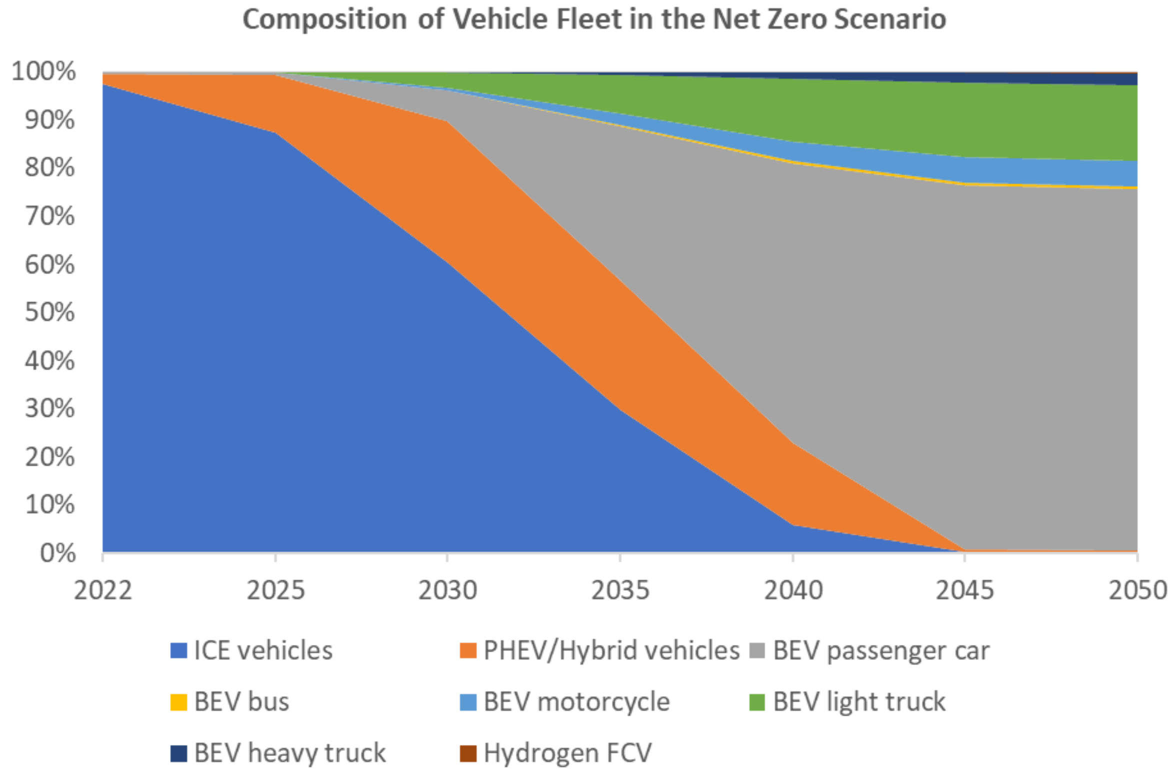

Figure 3: Evolution of market shares of different vehicle technologies in the Net-Zero scenario. Source: OSeMOSYS Cyprus model.

The energy consumption of road transport is determined by the composition of the vehicle fleet mentioned above and by technological developments in terms of vehicle energy efficiency. Essentially, in 2050 there is little gasoline consumption left (due to the few plug-in hybrids remaining in circulation) and the corresponding biofuels blended with gasoline. In addition to the widespread deployment of electric vehicles, leading to increased electricity consumption, it is assumed that trams may enter into service, at least in the capital city of Nicosia, before 2040, in line with national plans. Thus, electricity accounts for 57% of energy demand in road transport in 2040, and 99% in 2050.
In aviation, the penetration of sustainable aviation fuels (e.g. biofuels) starts gradually after 2025, while in the next decade the use of 'electro-fuels' (e-fuels) is also foreseen, i.e. hydrocarbons produced from green hydrogen and carbon captured from some source. Hence by 2050 clean fuels account for more than 70% of the sector's energy consumption, as required by the recently adopted European Regulation (EU) 2023/2405 "ReFuelEU Aviation".

With regard to *power generation*, as a result of the intense electrification in all final energy demand sectors as mentioned above, higher electricity demand is expected by 2050, more than double the amount consumed in the country in 2021. This increased demand, combined with the requirement for zero emissions in 2050, is leading to major changes in the power system, both in installed capacity and in the mix of power generation implemented each year until 2050.

Existing thermal power plants will all be decommissioned by 2050, while new combined cycle thermal power plants burning natural gas are projected to be in operation, with about 220 MW entering the system in 2025 and an additional 649 MW with carbon capture and storage (CCS) technology from

2029 onwards. Photovoltaic installed capacity increases steeply to 3200 MW by 2050, while significant installations of other renewables – 500 MW of concentrated solar thermal plants, which becomes a cost-effective technology but its expansion is limited by land requirements, 450 MW of onshore wind farms, 350 MW of offshore/floating wind farms and 126 MW of new biogas/biomass plants. In total, renewable anergy (RES) plants are projected to reach a capacity of more than 4.5 GW by 2050.

At the same time, despite the assumed operation of electricity interconnection in 2030, there is a need for additional storage technologies, with battery installations reaching 188 MW (752 MWh) in 2050. The need for additional storage arises because it is assumed that the capacity of the Interconnector remains at 1000 MW as currently planned, while as mentioned the installed capacity of variable renewables exceeds 4000 MW.

As a result of the installed capacity projections, the electricity generation mix in 2050 changes drastically compared to today, but does not reach full RES use, as illustrated in Figure 4. 76% of the electricity generation is provided by RES in 2050, and the rest by combined cycle gas plants with CCS technology. It should be noted, however, that the implementation of CCS in Cyprus with an investment cost as proposed by the European Commission (adopted in this scenario) is uncertain, because it is not known whether there are suitable locations in Cyprus for carbon dioxide storage. In case storage would have to be done in other countries, thus the captured carbon dioxide would have to be transported elsewhere, the cost of the technology would increase significantly and may not be viable for Cyprus.

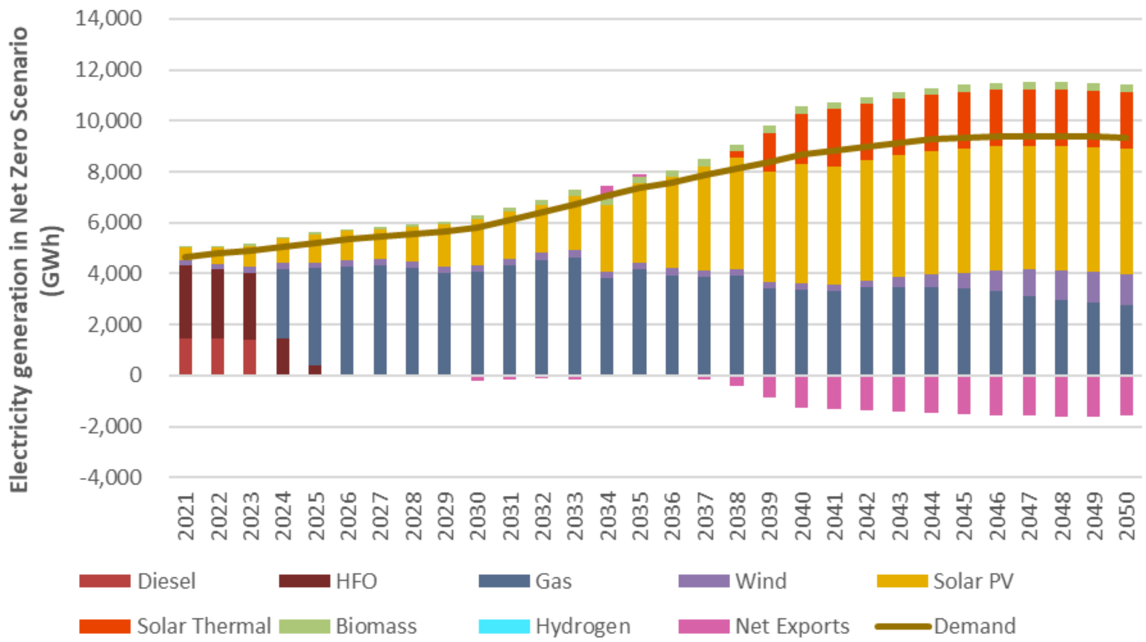

Figure 4: Power generation mix up to 2050 according to the central Net-Zero Scenario. Source: OSeMOSYS-Cyprus model.

It is also noteworthy that the Net-Zero Scenario foresees substantial electricity exports after 2038 thanks to the interconnections to be implemented. These exports reach almost 1600 GWh per year in the period 2045-2050, corresponding to 13-14% of the entire power generation in Cyprus. However, these projections must be treated with caution because they strongly depend on power generation

costs in interconnected countries and the way that electricity markets will operate in Cyprus and Europe.
The above summarises the results of the central Net-Zero Scenario that we considered. Further sensitivity analysis of an earlier central scenario are outlined in Zachariadis and Taliotis (2023).

Investment outlook

It is evident that the transition to a climate-neutral economy will require significant investment over the next three decades, across all sectors of the economy. In a previous detailed report (Zachariadis and Taliotis, 2023), we presented an estimate of the public and private investment needed up to 2050 to enable the path to decarbonisation, both as total amounts and as additional amounts compared to the Scenario With Existing Measures (WEM) of the revised NECP. WEM serves as the current "Business as Usual" scenario as it includes the policies that had already been adopted at EU and national level by 2023-24.

A first finding of our analysis is that total investments for the period 2031-2050 for the implementation of the Net-Zero Emissions (NZE) scenario amount to 81 billion Euros (at constant 2022 prices), which corresponds to 8.8% of the GDP of this 20-year period. The total investment levels are similar in both the WEM and the NZE scenario, but the structure of investment is different: Achieving climate neutrality requires significantly higher investments (in the order of 6 billion Euros'2022) in electricity generation, energy upgrades of buildings and industrial plants, and sustainable mobility. These are, however, offset by significantly lower investments in motor vehicles (around 5.5 billion Euros less in net-zero compared to WEM). Considering in addition the investments that will be needed in the aviation and shipping sectors, mainly for the production and distribution of zero-emission fuels, the cost could rise to 83 billion Euros'2022 or 9% of the 2031-2050 GDP.

When one considers investment needs, it should be noted that by 'investment' we refer to spending on infrastructure, equipment and consumer durables that use energy. Some of this expenditure does not fall under the definition of investment as included in the National Accounts ('gross fixed capital formation'). Household expenditure on private passenger cars as well as on energy-consuming household equipment is included in the National Accounts as 'private consumption'. Thus, if we exclude expenditure on private vehicles, the amount of the necessary investments becomes 41 billion Euros, or 2 billion Euros per year on average (Figure 5). For comparison, it is noted that according to the National Accounts of Cyprus of the last five years, gross fixed capital formation was around 4-5 billion Euros (whereas it had fallen to 2-3 billion Euros per year during the financial crisis period 2012-2015). This is an indication that the required public and private investments to achieve climate neutrality are within the capacity of the Cypriot economy but should be a priority for much of the economic activity in the coming years.

A second finding is that, when focusing on public investment to achieve net-zero in the energy system only, we estimate this to be close to 6 billion Euros'2022, which correspond to 0.64% of the period's GDP. If one considers additionally the required non-energy investments in the agri-food sector and waste management, as well as some investments in public infrastructure for clean aviation and shipping fuels, it is expected that public investments for climate neutrality should absorb close to 1% of GDP each year until 2050. This corresponds to 4-4.5 billion Euros per decade, which is at least 50% higher than the amount of public funds allocated to climate action in the current decade 2021-2030. The above assumes that major infrastructure investments for natural gas and the electricity interconnection with Greece will have been completed by 2030. In case of expansion or upgrades of this infrastructure post-2030, additional investments must be considered for the period 2031-2050.

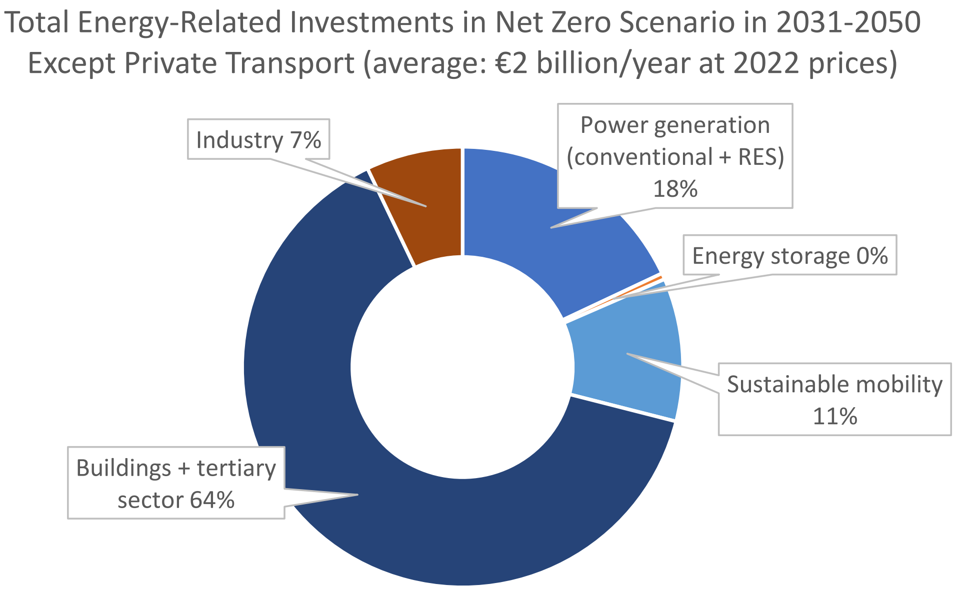

Figure 5: Allocation of investments towards a net-zero economy by sector. Source: OSeMOSYS Cyprus model and additional authors' calculations.

Figure 6 shows the difference in investment and fuel costs in the period 2031-2050 between the Net-Zero scenario and the scenario With Existing Measures. Essentially, this figure compares the cost of (largely imported) investments and the cost of fuel imports. Note that fuel costs do not include excise duties and VAT, as these are amounts that remain in the national economy. In electricity generation, increased investments of more than 1 billion Euros are foreseen over the 20-year period, with a negligible difference in fuel costs (assuming that the modern natural gas plant will remain in operation in the NZE scenario, in which case the increased efficiency compared to the WEM scenario is offset by the increased electricity needs in NZE). In buildings and industry, higher investments of the order of 4 billion Euros are foreseen, which yield fuel cost savings of 2 billion Euros. In road transport, which includes both public and private transport modes, both investments and fuel costs are lower in the NZE scenario by about 6 billion Euros.

In total, implementation of the NZE scenario requires higher investments of 508 million Euros'2022 and yields 4 billion Euros'2022 lower fuel costs up to 2050. This means that, even if important side-benefits (like improved air quality) are not considered, these investments are beneficial for the national economy and society.

Note that, in order to have comparable sectoral calculations, Figure 6 shows the total investment costs regardless of the lifetime and the time at which each investment is made. For the same reason, the costs are presented undiscounted. This may overstate the benefits of investments because fuel cost savings are spread over more years into the future and will be lower if discounted. On the other hand, these benefits are underestimated in this calculation because some investments will generate fuel savings well beyond 2050 – which are ignored here. Therefore, our overall conclusion that these investments pay off is valid.

Evidently, the above estimates of costs and capital investment up to 2050 are inevitably subject to uncertainties. On the one hand, costs may be underestimated, given that there is equipment that will have high replacement costs in order to achieve near-zero emissions in all sectors of the economy. On the other hand, the strong economic and political push in Europe towards innovative zero-emission technologies (renewable energy, electric vehicles, green hydrogen, etc.) may lead to lower costs of achieving climate neutrality than estimated in this study. It has to be recalled that key renewable energy technologies have experienced dramatic cost reductions over the last 20 years, which had not been predicted by international agencies and organisations even some years before.

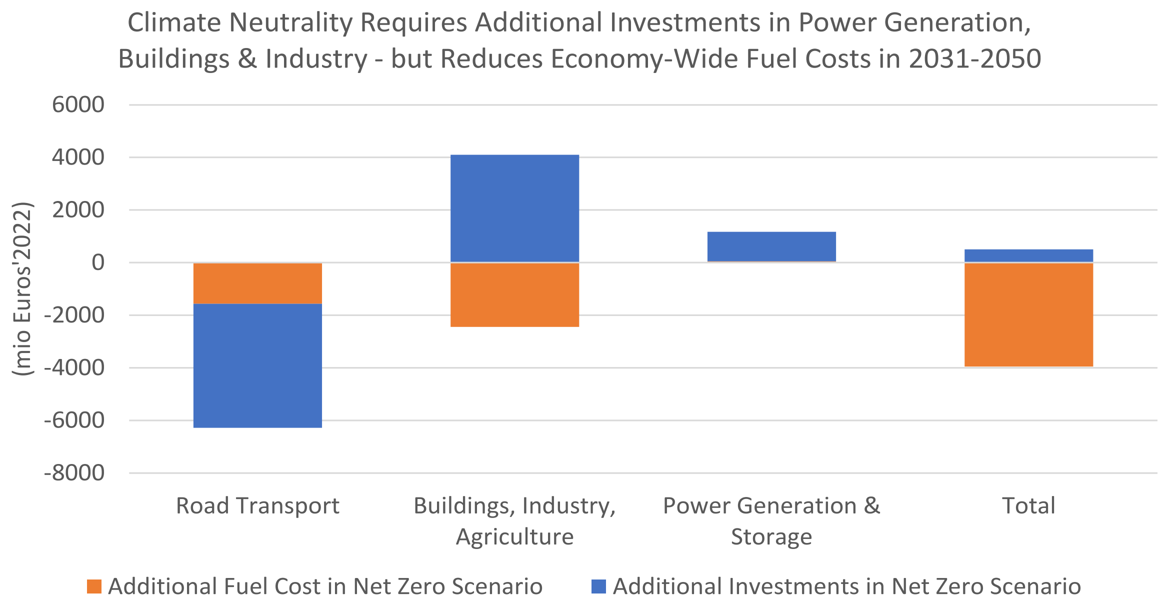

Figure 6: Additional investment and fuel costs in the NZE scenario compared to the WEM scenario. Source: OSeMOSYS Cyprus model.

Economic implications of the transition

Section 3.2.2. described the key features of the energy system as required to achieve the net-zero transition by 2050 and Section 3.2.3. focused on the investment needs. Based on the above, as well as on insights from our IO model simulations and consultation with economic experts, the following aspects are worth mentioning as regards the macroeconomic implications.

Inflationary pressures of the transition is always a concern for economic policymakers. From a macroeconomic perspective, the key feature of a climate-neutral economy will be increased capital investment and reduced operating costs. All key technologies (renewables, energy storage, electric vehicles, electrolytes for renewable hydrogen production) have higher investment costs than conventional current technologies, but much lower operating costs. Thus the Cypriot economy, like other economies across the world moving towards the green transition, will have to spend more on investment in green technologies and much less on importing fuel for its vehicles and factories. Such a development creates inflationary pressures. In order to realise these investments, very substantial public and private resources will need to be allocated in specific directions, which will not necessarily improve short-term welfare. For example, a more expensive electric car will provide the same services to the household as a conventional car, but at a higher initial cost. So would a renewable energy system with storage, compared to a conventional electricity or steam generation system in industry.

If the resources available for these investments are given, they will be allocated to fewer and more expensive initial investments, which shifts the supply curve to the left. With constant demand, this alone raises prices. If more resources are made available, e.g. by redirecting public and private resources from other sectors, the demand for these investments increases at the same time, also because of legally binding obligations to reduce emissions and/or because of financial incentives that the state may give to households and firms. Thus, upward pressure on prices will be stronger. Inflationary pressures will be directed both towards raw materials and equipment (even more so due to the increased global demand for such equipment in view of the simultaneous green transition in many developed economies) and towards the service sector, where increased works such as insulation, photovoltaic installation, etc., will be demanded from companies with limited labour capacity. In addition, if more resources are made available not by redirecting resources from other sectors but by borrowing, there will be both inflationary pressures and a strain on public and private debt.

At the same time, however, one should not underestimate the inflationary pressures created by the current economic model in an economy like Cyprus, which relies so heavily on fuel imports. The uncontrolled fluctuations in international fuel prices affect the operating costs of the economy and leave very little room for reaction, since the equipment using these fuels cannot be replaced in the short term. This creates a chain effect on prices. The response against such pressures is often financial support for households and businesses, which puts a strain on public finances, as explained below, but at the expense of growth prospects and possibly deteriorating public debt.

As far as the trade balance is concerned, the impact of the green transition is not clear. On the one hand, fuel imports will fall sharply, but on the other hand, imports of equipment for green investment will increase. Thus, the trade deficit in the petroleum product import sector will be drastically improved. At the same time, the value of vehicle imports may be slightly reduced by a reduction in the growth rate of the vehicle fleet, together with a reduction in the price differential between conventional and electric vehicles from 2030 onwards. Hence, this may also lead to a slight improvement in the balance in the medium term. As regards other green technologies, imports of solar panels, wind turbines, batteries and equipment for upgrading the electricity grid will increase, which worsens the trade balance.

With this in mind, one can estimate that the green transition is likely to start with a negative impact on the trade balance sheet due to the initial need for large import-dependent investments, but later the impact may be positive due to the large reduction in the need for imports of fuels and energy-intensive equipment.

In this direction, choices made by government policy are also important. An example is the building sector, since buildings in Cyprus are energy intensive because before 2008 there were no legislative obligations on energy efficiency. Restricting the construction of new buildings, by withdrawing any relevant incentives, and correspondingly introducing stronger incentives for the use of existing buildings, including dormant buildings, would both help reduce emissions from the building sector, but would also prevent further deterioration in the current accounts balance.

More generally, it should be pointed out that in order to avoid negative developments in the balance, the necessary investments (over 80 billion Euros as mentioned above) would have to replace other prescribed public and private investments that are not in line with the green transition. Otherwise, increased investment would create an even larger current account deficit and make it difficult to finance from external resources.

A further concern is the impact of the transition on productivity, for which no positive development is to be expected in the short term. The increased need for green investment may take resources away from areas where productivity can grow faster. With the implementation of investments, a clear increase in productivity in the use of energy and other natural resources is expected, as investments in energy saving, waste recovery and electrification will increase the energy efficiency of the whole economy. However, until most of these investments are implemented, the impact on overall productivity is uncertain.

Overall, economic growth prospects are uncertain. As shown in the previous Section 3.2.3 above, the Cypriot economy could save around 4 billion Euros (at 2022 prices) over the 2031-2050 period, or 0.4-0.5% of GDP each year, from the measures to be taken for climate neutrality. The savings will allow these resources to circulate in the economy in the form of increased investment and consumption and stimulate the country's economic activity. However, due to the uncertainty over the long time horizon and the difference between the period when most investments will be made and the period when the largest savings will occur, it is difficult to make more detailed estimates. There is also uncertainty, which is not addressed by standard macroeconomic models, about changes in the relative prices of the affected products/industries, the capital/labour ratio in the affected sectors and the change in the cost of production and its impact on the competitiveness of domestic products.

As GDP is significantly affected by the trade balance, the impact of the green transition on imports and exports (which is uncertain and may start negatively and turn positive, as mentioned above) will lead to corresponding changes in economic growth. In order not to adversely affect the balance of payments and ultimately GDP, it should be ensured that the necessary additional investments in buildings, equipment, etc. substitute for existing non-green investments, rather than amounting to further investments that lead to increased imports. The positive impact on the economy can be reinforced as long as more domestic production can be achieved for green products and services. To the extent that Cypriot companies can actively be engaged in the green sectors mentioned above, domestic value added and thus the country's growth potential will increase. Therefore, the development of domestic industry in green sectors should be a national priority.

Another positive aspect is the reduction of uncertainty about energy costs in the economy. While currently fluctuations in international oil prices create inflationary pressures and uncertainty and have a significant impact on the operating costs of businesses, households and the public sector, the green transition can reduce operating costs significantly and thereby reduce uncertainty, with a favourable impact on growth prospects.

Economic growth is of course also dependent on the fiscal outlook. The path towards climate neutrality poses new challenges for fiscal stability. On the one hand, increased public spending will be necessary to meet the increased investment needs mentioned above, to finance public investments towards achieving the zero-emission target (e.g. in electricity grids, energy upgrades of public buildings, integration of renewable energy in the public sector, etc.); to provide partial financial support for private investment (e.g. grants for zero-emission vehicles and energy upgrades for homes and businesses); and to directly support vulnerable households and businesses that cannot finance green investments and may be exposed to increased energy costs.

On the other hand, the evolution of public revenues is subject to important uncertainties. First, Emissions Trading Systems (ETS) are being extended and will already cover all aviation and shipping emissions within the EU and part of the emissions from travel outside the EU before 2030. All emission allowances will be sold in auctions and will constitute public revenue, all of which will be earmarked for climate action. By 2030, annual revenues of around €150-200 million are expected. This amount is negligible (less than 5%) compared to the total tax revenues of the Republic of Cyprus, which ranged between 4 and 6 billion Euros in recent years. In the period after 2030, an increased price of ETS allowances is expected on the one hand, but on the other hand the available allowances will decrease as the whole of Europe transitions to zero carbon emissions. It is likely that allowances in the existing ETS will fall to near zero already in 2040. Therefore, ETSs are not a reliable long-term source of public revenue.

A second uncertainty on the fiscal front is that, while the introduction of a carbon tax (equivalent to an additional excise tax on fossil fuels) is a possible development and may be a source of revenue, at the same time such taxes have a political cost, resulting in increasing social pressure for 'fiscal neutrality' - i.e. the additional revenues from such a tax being returned to households and businesses either in a horizontal or targeted way. It is therefore doubtful whether a carbon tax can increase overall public revenues.

In addition, taxing carbon emissions in road transport may accelerate the erosion of the tax base and reduce public revenues more quickly. Prior to the advent of electrification, the demand for motor fuels was very price inelastic because there were not many alternatives to gasoline and diesel vehicles, hence a carbon tax could generate significant revenue for several years. Today, however, as electromobility is developing faster, the switch to vehicles that do not burn liquid fuels can deprive the government of significant tax revenues. For this reason, consideration should be given to gradually shifting the tax burden of vehicles towards energy consumption rather than emissions, especially in the form of annual circulation fees (vehicle excise duties). Since electric vehicles have lower running costs than conventional ones, the use of such energy-based fees can ensure stability of vehicle tax revenues without overburdening taxpayers.

The trend towards taxation of aviation and marine fuels, while currently not progressing in the context of the discussed revision of the European Energy Taxation Directive, will nevertheless remain, as these sectors will have to participate in the global climate neutrality effort. Such taxes can provide significant additional public revenue, especially as these sectors are among the hardest to carbonise and are expected to remain dependent on conventional fuels for many years to come. However, especially in the tourism sector, there is a risk of possible cost increases due to higher air ticket prices, hence such pan-European taxes will probably have to be combined with compensatory measures. Therefore, again the budgetary benefit is uncertain.

In parallel with the above challenges related to climate change mitigation policies, public spending for mitigating adverse impacts of climate change (e.g. compensation for fires, droughts, etc.) and public investment for climate change adaptation (e.g. for coastal protection, restructuring of agricultural crops, etc.) is expected to increase.

The above is an indication that the green transition may lead to negative fiscal consequences if timely measures are not taken to safeguard the fiscal balance. One such type of measures has already been mentioned – shifting the tax base of road transport from fuel use to energy use and annual vehicle use. Other possible actions would be to redirect public investment and subsidies from sectors that do not contribute to – or even contradict – the green transition towards green sectors, to implement the investments shown in Figure 5. Such sectors could be road construction and agricultural subsidies (for crops, water use, equipment, etc.), some of which are provided without environmental requirements.

It should be noted, however, that today's 'business-as-usual', with high dependence on fuel imports and large fluctuations in international prices, also creates fiscal pressure. Recent experience with the support measures implemented in 2022-23 shows that the continuation of the current situation does not guarantee at all that fiscal performance will be better without the green transition. We cite as an example the calculations made by the UK Office for Budget Responsibility (2023), which estimated how much the UK's public finances would be affected by continued dependence on fossil fuels, assuming that a similar temporary crisis in gas prices to that of 2022 may occur once every decade. Taking into account the inflationary pressures created by a sharp increase in energy costs, the increase in public spending involved and the need for financial relief for households and businesses, it has been estimated that the UK public debt will increase by 13% of GDP in 2050, more than the estimated debt burden of the green transition measures.

The outlook for employment is a further concern for policymakers. As in other developed countries with a strong contribution of the tertiary sector to GDP, the number of jobs affected by the green transition is relatively limited. As Figure 7 shows, even if the entire sectors of the relatively energy-intensive Cypriot industry and the sale of fuel, vehicles and spare parts are assumed to be affected, these comprise 31,000 jobs or about 7% of total employment, which amounted to about 432,000 in 2021. If the indirectly affected jobs in the sectors supplying goods and services to the above sectors are taken into account, as calculated from our economic input-output model, an additional 24,000 jobs or 5.5% of the total are affected. It is also possible that employment in the tourism sector may be affected if, for example, environmental requirements from aviation make Cyprus a less attractive tourist destination, but it is too early to draw such conclusions.

As a result, the jobs that can be affected quantitatively or qualitatively amount to less than 13% of total employment and come from sectors that contribute less than 10% to total GDP. It should also be stressed that, due to the gradual transition to climate neutrality and because Cyprus has very little really energy-intensive industry, most of the above-mentioned jobs are not substantially at risk, but may require retraining of part of the employed workforce.

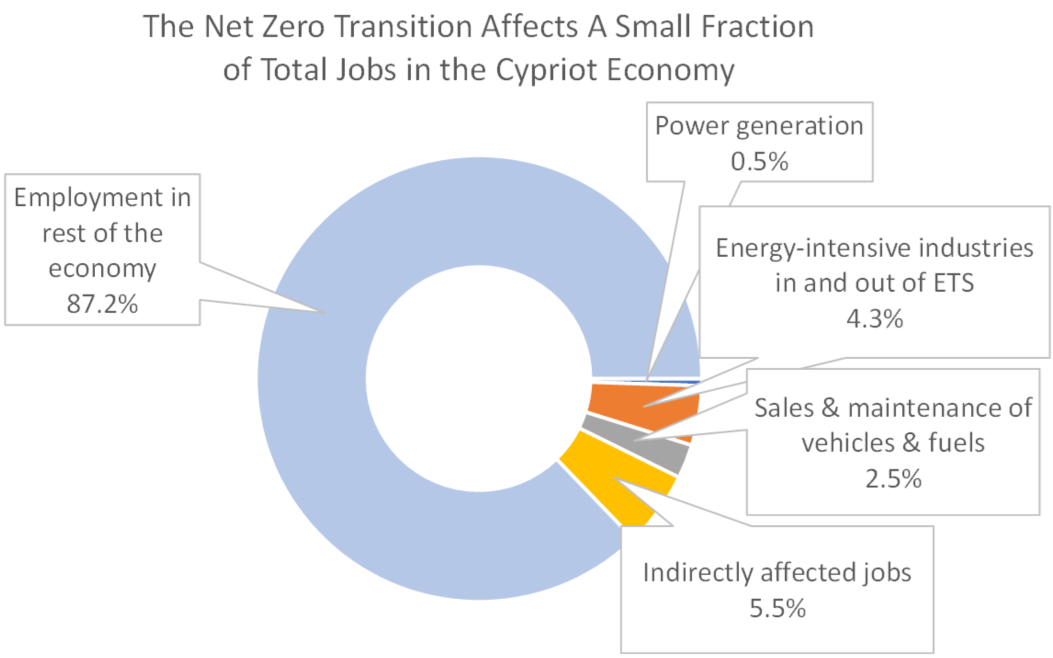

Figure 7: Jobs potentially affected by the transition to climate neutrality. Data source. Indirect jobs are calculated from the Cyprus Institute's input-output model of the Cyprus economy (Taliotis et al., 2020).

Addressing social equity challenges of the transition through behavioural insights

A highly important aspect of the zero-carbon transition is the impact on social equity. As the EU accelerates the scale and pace of its climate policies, the immediate and long-term socio-economic effects are becoming increasingly apparent, especially among vulnerable groups (Fuest et al., 2024). One particular challenge – probably the most important one associated with the path to carbon neutrality – is energy poverty, conceptually defined as the incapacity to meet essential energy needs due to economic constraints or infrastructural inadequacies (Viola, 2021). Energy poverty is a pervasive issue within the EU, particularly in Southern European countries, where a significant proportion of households (15% - 19% in the case of Cyprus) struggle to secure adequate energy services (Santamouris et al., 2009; European Commission, 2024). To alleviate energy poverty, Cyprus has already started implementing several measures, as outlined in the draft revised National Energy and Climate Plan (Republic of Cyprus, 2023; Kyprianou & Serghides, 2020; Andreou & Koutsampelas, 2022).

This section highlights some of the relevant challenges by concentrating on a specific but typical case study from Cyprus. We focus on the most recent Grant Scheme in Cyprus, titled 'Encouraging the Use of Renewable Energy Sources and Energy Saving in Residential Buildings 2024-2025', which was announced in January 2024, with a total budget of €90,000,000, to remain open until December 2025. By providing financial incentives, this Grant Scheme aims to encourage the utilisation of renewable energy sources (photovoltaic panels) and energy saving measures (roof insulation) in existing residential buildings owned by natural persons. While targeting the entire population, this Scheme has specific provisions for vulnerable households for installing photovoltaics (a grant of €1,250 per kW, with a maximum grant ceiling of €6,250) and roof insulation (75% grant and a maximum grant amount of €3,750 or €37.50 per sq.m.) (RES Fund, 2024).

Despite the attractive features of the Scheme, policy-makers are likely to encounter substantial difficulties in ensuring effective dissemination of financial aid and high application rates from vulnerable households. Empirical research indicates that multiple barriers, including cumbersome application procedures and inadequate outreach significantly hinder participation in such programs worldwide (Bertrand et al., 2006; Currie, 2004). In the case of Cyprus, unofficial information from energy authorities indicates that previous government efforts to support households in energy poverty resulted in less than half of the intended participants applying for funding, leaving more than 55% of vulnerable households unaided.

Reusing the conventional approach is unlikely to work. On top of the usual challenges of poor outreach, ineffective communication and complex, bureaucratic processes that often hinder the uptake of grant schemes (Currie, 2004), policy-makers must also consider the growing evidence from behavioural science regarding the unique obstacles faced by vulnerable groups. Notably, prolonged financial stress can significantly impact people's decision-making capacities. Recent studies show that individuals experiencing poverty and income instability tend to exhibit compromised cognitive function, including impaired forward thinking and problem-solving skills (Mani et al., 2013). The cognitive capacity it takes to constantly worry about budgeting has been shown to lead to outcomes such as forgetfulness, impulsive spending, anxiety, distraction, and failure to plan ahead, all of which contribute to worse long-term decisions (e.g., Shah et al., 2012; Spears, 2011; Tomm & Zhao, 2018). Of particular importance is the evidence that households in financial distress often struggle with long-term planning, focusing instead on immediate needs. While this is a rational response to financial constraints, it can lead to long-term harm and underutilisation of available grants. Forward thinking is crucial to investing in energy efficiency measures because it involves expending resources in the present (money and time) for a higher return in the future. However, the absence of such planning, driven by pressing short-term needs, often results in missed opportunities to leverage available grant schemes.

To address this challenge, we undertook an in-depth analysis of this Scheme and employed behavioural journey mapping to delineate four critical stages in the application process (awareness, consideration, decision-making, and action) and respective potential barriers, both structural and behavioural, within each step. For instance, for the second step, *Consideration*, the decision-maker is confronted with barriers such as tunnelling, which can cause people to focus on immediate concerns, thus neglecting needs that are further away in the future. The messenger effect is also set to play a significant role in whether people will consider the Scheme. This means that the credibility, trustworthiness, and overall perception of a message is significantly influenced by the characteristics of the person delivering it, such as their expertise, authority, attractiveness, and relatability. Moreover, the presence of hassle factors, like public servants not answering phonelines and website links leading to generic homepages, signal an unsupportive environment, discouraging citizens from choosing to seek more information. Another hassle factor is the need to relocate until the energy efficiency renovations are completed, which may appear daunting in the face of constrained financial resources. Further, the provision of too much information can lead to overload. Cyprus's Grant Scheme bundles funding for all households with that for vulnerable households. As such, from the perspective of a vulnerable household, there's a lot of irrelevant information that they need to sift through before finding out what is relevant to them. Hassle factors and information overload can easily lead to procrastination and indefinite delay in applying to the Scheme.

Diving deeper, devoting sufficient time to comprehend the intricacies of the Scheme, may not guarantee an adequate grasp of its implications, particularly if the language employed is characterised by technical complexity and ambiguity. In order to gain a clear understanding of the value that the Scheme can offer to their household, two further obstacles must be overcome. Firstly, the use of complex and unclear language, reminiscent of EU regulations, can hinder comprehension. Secondly, the sequence of information presented in the document does not align with the interests of a vulnerable household but rather reflects the priorities of a government. Secondly, there is ambiguity. The benefits are not clearly delineated, and no examples, case studies or statistics are provided. The eligibility criteria are also not straightforward. Those who may be interested are required to ascertain and comprehend two distinct types of information regarding eligibility criteria: firstly, socio-economic criteria established by the Ministry of Energy, Commerce and Industry; and secondly, technical information necessary for the identification of the relevant category (e.g. total electricity consumption in the past year, the time that the building permit is issued).

Taken together, these structural and behavioural barriers have been shown within the behavioural science literature to deter applications and sabotage policy efforts for financial support. The identification of these barriers has resulted in the formulation of a series of practical recommendations for Cypriot policymakers, designed to assist in the overcoming of these barriers and the enhancement of the volume of applications received.

Specifically, the replacement of monologue-style presentations with discussion sessions within relatively small, newly formed groups among the targeted population has been demonstrated to assist in the reshaping of social norms and the alleviation of the stigma associated with participating in such schemes (Bertrand et al., 2006). This, in turn, has been shown to increase positive word-of-mouth recommendations. To assist with the process of gaining people's attention and overcoming tunnelling, policy-makers may wish to consider the concept of loss aversion. This can be achieved by clearly presenting the cost of non-participation in the Scheme alongside examples of future savings that would be lost, rather than the savings that would be gained (Kahneman & Tversky, 2013).

Another effective strategy is to harness the power of social proof and in-group identity by communicating the examples of individuals who have already applied to the Scheme. It is important to select those who bear similarities to the targeted population, such as the problems they face and the city or village they live in (Cialdini & Trost, 1998). While it is acknowledged that certain inconveniences cannot be entirely eliminated, it is recommended that where feasible, seemingly minor alterations be implemented to facilitate a more straightforward and less uncertain application process for individuals. A pragmatic, cost-effective solution that has been effective in mitigating information overload is the "passport page", which provides an executive summary of the key points that would be of interest to the intended audience (Behavioural Insights Team, 2015). Furthermore, the provision of assistance to vulnerable households in the initial stages of the application process (e.g., through the pre-filling or pre-populating of certain information) can be efficacious in enhancing the completion of application forms.

In conclusion, as this case study demonstrates, the integration of behavioural science into policy design is fundamental for augmenting the effectiveness of climate neutrality policies through strategic modifications and behaviourally-informed design. More detailed insights are available in the full paper (Moleskis et al., 2025).

Conclusions

This paper has presented the main findings of our model-based study on the transition of Cyprus to a net-zero economy, with an emphasis on the energy system of the country, the necessary investments, and the fiscal and macroeconomic implications of this transition. A climate-neutral Cyprus in 2050, as required by the European Climate Law, will be characterised by almost complete independence from fossil fuels and replacement by electricity and renewable sources, full utilisation of waste and use of renewable hydrogen in transport and heavy industry, depending on developments in the respective technologies. This will require serious investment from the public and private sectors. Public investment should absorb close to 1% of GDP each year until 2050, twice as much as public funds currently provide for climate action.

These investments can be beneficial for the economy and society and in the medium term can free up resources that can be reinvested in the economy. As the UK Climate Change Committee (2025) noted, *"The most significant impacts of the Net Zero transition on the [UK] economy as a whole are likely to be felt through increased resilience to economic shocks, both from climate change itself and from fossil fuel price shocks."* We expect this also to be the case in Cyprus, and more broadly in the whole of Europe due to its importance on fossil fuel imports.

However, important challenges lie ahead that call for swift policy action. In order to put the country on a climate-neutral path, all public policies should, already today, be aligned to orient investments towards the net-zero emissions target in 2050. Delays in the green transition will be more costly to the Cypriot society. Therefore, effective implementation of green policies is key. In this context, the paper has also provided a background on behavioural barriers that should be overcome, as the lack in understanding human behaviour is at the heart of the sustainability challenge. We provided an overview of why and how the behavioural element (from sticky habits to cognitive biases), when ignored, hinders traditional policy-making efforts. Drawing from our recent work for Cypriot authorities, we discuss the behavioural array of forces capable of driving change when applied judicially. Our findings highlight three directions in which policy-making in Cyprus can be enhanced: improved understanding of the drivers behind local behaviours before designing policies, targeted communications design for changing habits and overcoming problems with existing policies with behavioural science methods.

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APPENDIX
Brief description of the models employed in this study

A1. Introduction

As part of the support provided to national energy and climate planning efforts, a set of models has been developed to assess different dimensions of energy policies and how those affect the evolution of the energy system and the broader economy. The combined utilisation of these models provides long-term projections of energy demand and supply and greenhouse gas emissions (see Figure 1 in Section 3.2.1 of the main text). First, an energy demand forecast model provides final energy demand projections for all sectors except road transport. Then, a cost-optimisation model uses these projections to provide a cost-optimal energy and technology mix that satisfies that final energy demand, and simultaneously provides projections on electric vehicle penetration and the subsequent electricity demand in land transport. Information from both of these models is further provided to a macroeconomic input-output model and a consumer demand model to analyse impacts on economic output, employment, and social equity.

A2. Energy Demand Forecast Model

At the initial step of the analysis, an energy demand forecast model developed for Cyprus is applied to project final energy consumption across the economy (Zachariadis and Taibi, 2015). The energy forecast model has been used to support official energy planning efforts of national authorities in the recent past and is mathematically described in detail in a relevant publication by the International Renewable Energy Agency (2015). Utilising energy balances and other statistics for the period 2015-2023 supplied by the Statistical Service of the Republic of Cyprus and other sources, an outlook to 2050 is provided. The main energy-consuming sectors of the economy are separately modelled, namely: agriculture, households, non-metallic minerals industry, other industry, and services (see Table A1). Demand growth for the various energy forms is driven by exogenously defined macroeconomic assumptions obtained from the Ministry of Finance, technology costs and fuel prices, while it is subject to income and short-term and long-term price elasticities; these vary across the different sectors of the economy and are based on national econometric analyses and data from the international literature. The forecast model provides final energy consumption projections for all sectors except road transport. These projections are used as input in the OSeMOSYS cost-optimisation model. Road transport projections are conducted in OSeMOSYS because, as explained in Section A3.2 below, OSeMOSYS has a more detailed techno-economic representation of road vehicles and can therefore perform more granular and reliable projections and policy simulations for this sector.

Apart from input to OSeMOSYS, the demand forecast model also provides estimates of the annual expenditure of households by energy commodity; these are used as input for further economic assessments of macroeconomic, employment and social equity impacts of energy and climate policies.

The forecast model calculates future annual energy consumption in each one of the above-mentioned major economic sectors of Cyprus as a function of future macroeconomic variables and energy prices. It also calculates fuel shares in each sector, depending on technology costs (investment, operation, maintenance and fuel costs), the penetration potential of various technologies and technical constraints for the uptake of new technologies, and allows computing future final energy consumption by sector and fuel.

Final energy demand, by economic sector and year, is the sum of a) demand for substitutable energy and b) demand of non-substitutable electricity. The former denotes all final energy forms that are used in various sectors and uses (including a fraction of electricity consumption), which may be substituted by other energy forms in the future. The latter denotes use of electricity in appliances and for lighting purposes, where electricity does not compete with other fuels and therefore all energy needs for these uses will continue to be covered by electricity in the foreseeable future; non-substitutable electricity follows its own dynamic path in the model.

Table A1: List of economic sectors covered in the energy demand model and the corresponding economic activity variable.

Sector	Activity variable
Agriculture	Value added of agriculture, forestry and fishing
Cement industry	Value added of cement industry
Other industry	Value added of all industry except cement industry
Households	Private consumption
Services	Value added of service sector
Aviation	Gross Domestic Product

The fuels/energy forms considered in the model are: gasoline, automotive diesel, aviation kerosene, gas oil, light fuel oil, heavy fuel oil, liquefied petroleum gas (LPG), pet coke, biomass, biofuels, electricity, solar energy, geothermal energy and hydrogen. Obviously, not all fuels are relevant for all economic sectors – for example, pet coke has historically been used only in the cement industry in Cyprus.

Due to the recursive form of the model's equations, a forecast can start from any year t – the base year – using energy, macroeconomic and price data from official sources, and proceed year by year until 2040 with the use of the formulae described above. When data for a more recent year t' becomes available, that year can become the base year, and the forecast starts from year $t'+1$ onwards. This makes it easy to update national energy forecasts when new base year data are available.

The model's full mathematical specification is provided in International Renewable Energy Agency (2015).

A3. OSeMOSYS Cost-Optimisation Model

A3.1 Basic equations

The model employed in the second step of the analysis is developed within the Open-Source Energy Modelling System (OSeMOSYS), which is a long-term cost-optimisation energy system model. OSeMOSYS has been used in numerous studies with focus ranging from a global, regional and national scale (Gardumi et al., 2018; Peña Balderrama et al., 2018; Sridharan et al., 2019). It is a bottom-up technoeconomic model that is demand-driven, which means the exogenously defined demand has to be met, no matter the cost. The choice of technologies and energy mix is based on the adopted technoeconomic assumptions (e.g. fuel costs, technology costs, resource availability, emission limits). The model's objective function is the minimisation of the total discounted system cost over the entire modelling horizon. The algebraic formulation of the objective function, as described in the original

OSeMOSYS code publication (Howells et al., 2011), is provided below along with the relevant cost function equations.

OBJECTIVE

minimize $\sum_{y,t,r}$ $TotalDiscountedCost_{y,t,r}$ (OBJ)

COSTS

TOTAL DISCOUNTED COSTS

$\forall_{y,t,r}$ $TotalDiscountedCost_{y,t,r}$ = $DiscountedOperatingCost_{y,t,r}$+$DiscountedCapitalInvestment_{y,t,r}$ + $DiscountedTechnologyEmissionsPenalty_{y,t,r}$- $DiscountedSalvageValue_{y,t,r}$ (TDC1)

OPERATING COSTS

$\forall_{y,l,t,r}$ $VariableOperatingCost_{y,l,t,r}$ = $\sum_m RateOfActivity_{y,l,t,m,r}$***$VariableCost_{y,t,m,r}$*** (OC1)

$\forall_{y,t,r}$ $AnnualVariableOperatingCost_{y,t,r}$ = $\sum_l VariableOperatingCost_{y,l,t,r}$ (OC2)

$\forall_{y,t,r}$ $AnnualFixedOperatingCost_{y,t,r}$ = $TotalCapacityAnnual_{y,t,r}$***$FixedCost_{y,t,r}$*** (OC3)

$\forall_{y,t,r}$ $OperatingCost_{y,t,r}$ = $AnnualFixedOperatingCost_{y,t,r}$ + $AnnualVariableOperatingCost_{y,t,r}$ (OC4)

$\forall_{y,t,r}$ $DiscountedOperatingCost_{y,t,}r$ = $OperatingCost_{y,t,r}$/((1+**$DiscountRate_{t,r}$**)^(y-**StartYear**+0.5) (OC5)

CAPITAL COSTS

$\forall_{y,t,r}$ $CapitalInvestment_{y,t,r}$ = **$CapitalCost_{y,t,r}$** * $NewCapacity_{y,t,r}$ (CC1)

$\forall_{y,t,r}$ $DiscountedCapitalInvestment_{y,t,r}$ = $CapitalInvestment_{y,t,r}$/((1+**$DiscountRate_{t,r}$**)^(y-**StartYear**)) (CC2)

SALVAGE VALUE

$\forall_{t,r,y:\,(y\,+\,OperationalLifet,r)<\,StartYear\,+\,card(YEAR)}$ $SalvageValue_{y,t,r}$ = 0 (SV1)

$\forall_{t,r,y:\,(y\,+\,OperationalLifet,r)\geq\,StartYear\,+\,card(YEAR)}$ $SalvageValue_{y,t,r}$ = $NewCapacity_{y,t,r}$* $CapitalCost_{y,t,r}$*((1-((((1+**$DiscountRate_{t,r}$**)^(**StartYear**+card(**YEAR**) - y))-1) /((1+**$DiscountRate_{t,r}$**)^**$OperationalLife_{t,r}$**-1))) (SV2)

$\forall_{y,t,r}$ $DiscountedSalvageValue_{y,t,r}$ = $SalvageValue_{y,t,r}$/((1+**$DiscountRate_{t,r}$**)^(1+card(**YEAR**))) (SV3)

where

y the specific year within the modelling horizon (i.e. 2024-2050).

t the specific technology considered in each equation.

r the region within the OSeMOSYS model; i.e. Cyprus, in this particular case.

l the time-slice, defining a specific part within each year.

m mode of operation, defining wherever necessary different modes of operation for each technology. For instance, in batteries the first mode charges and the second mode discharges the battery.

An existing model of the Cyprus electricity supply system is adopted that includes the transport and heating and cooling sectors (Taliotis et al., 2020), using code enhancements that allow consideration of short-term grid constraints (i.e. ramping characteristics, minimum stable operation levels and the need for operational reserves – Welsch et al., 2014; 2015). An example of these code enhancements is shown below. In this equation (defined as R28 in the code), the online capacity in a time slice which is linked to another time slice is reduced up to its defined maximum. The online capacity of the other time slice must be larger than this reduced capacity. This equation is used to capture the ramping characteristics of thermal power plants.

$$\forall_{y,l,ll,t,f,r}:$$

$$\boldsymbol{ElectricityForTransmissionTag}_{f,r} = 1\ \&\ \boldsymbol{TimeSliceLinkTag}_{l,ll,r} \neq 0:$$
$$OnlineCapacity_{y,ll,t,r} * (1 - \boldsymbol{MaxOnlineCapReduction}_{y,t,r}) *$$
$$\boldsymbol{TimeSliceLinkTag}_{l,ll,r} \leq OnlineCapacity_{y,l,t,r} \qquad \text{(R28)}$$

where

ll This also defines a timeslice and is used if independent indices are required

f Fuel (e.g. electricity, coal, gas etc.)

ElectricityForTransmissionTag

Defines the fuel chosen to represent electricity generated by power plants. Equals 1 for electricity and 0 for all other fuels.

OnlineCapacity

The capacity of all power plants which form part of the same technology category and are currently generating electricity.

TimeSliceLinkTag

Links time slices with each other to limit generation and online capacity reductions. Can as well be used to link future to past time slices to limit the capacity reduction in one time slice based on a future online capacity.

MaxOnlineCapacityReduction

Maximum reduction of the online capacity of a technology from one time slice to another. Entered as percentages of the online capacity.

A3.2. Temporal Variability

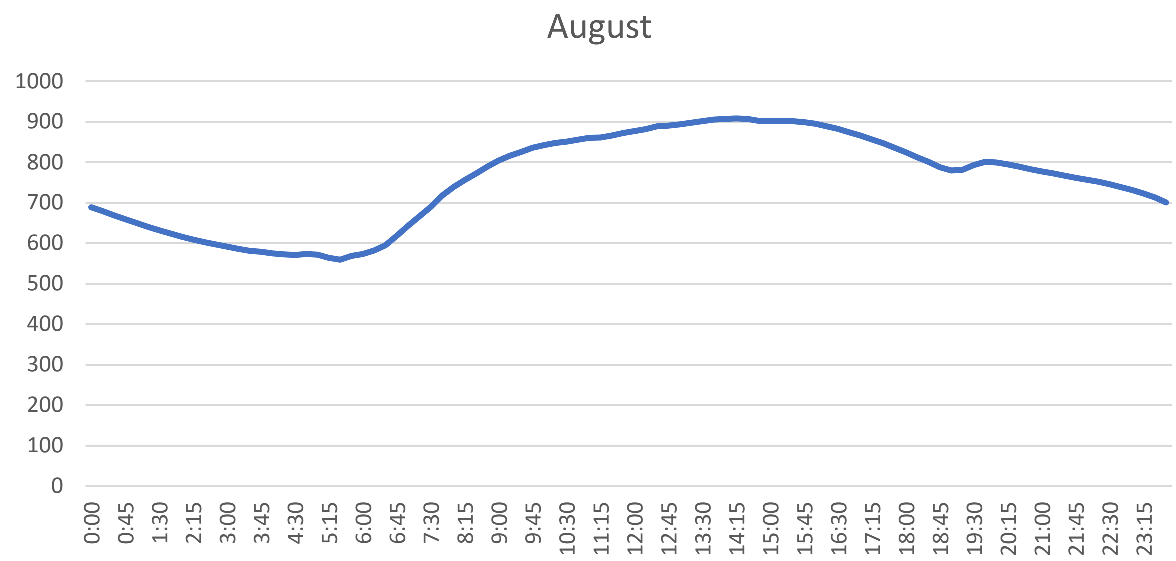
Seasonal and Daily Breakdown

The OSeMOSYS model of Cyprus has a modelling horizon until 2050, with annual resolution in terms of technology investments. Furthermore, in order to be able to capture intra-annual variations in demand and supply of electricity, each year is broken down into 96 time-steps. Specifically, the year is split into 8 seasons, which are represented by the average day of each season. These are in turn split into 12 time-steps to capture the intra-day variability in electricity demand and supply. The selection of the seasons and the day parts aims at capturing as much as possible the variability in electricity demand, without increasing too much the temporal resolution of the model, which would have a direct adverse effect on the computational effort needed when optimising the model. Table A1 indicates the seasonal and daily temporal breakdown adopted in the model.

Table A1. Temporal resolution adopted in the OSeMOSYS model of Cyprus.

Seasonal Breakdown		Daily Breakdown			
Season	**Months**	**Day part**	**Start Hour**	**End Hour**	**Duration (hours)**
1	January-February	**1**	00:00	01:00	1
2	March-May	**2**	01:00	06:00	5
3	June	**3**	06:00	07:00	1
4	July	**4**	07:00	08:00	1
5	August	**5**	08:00	11:00	3
6	September	**6**	11:00	12:00	1
7	October-November	**7**	12:00	13:00	1
8	December	**8**	13:00	17:00	4
---	---	**9**	17:00	19:00	2
---	---	**10**	19:00	20:00	1
---	---	**11**	20:00	22:00	2
---	---	**12**	22:00	24:00	2

The previous version of the OSeMOSYS model of Cyprus that informed the first NECP of Cyprus used the 2017 load variability data, as provided by the Transmission System Operator of Cyprus (TSO-Cy) on their website, in order to represent the seasonal and daily variability in electricity demand. However, this has been updated with data for 2019, which were provided by the TSO-Cy. Examples of days for two of the selected seasons are shown in Figure A; these were used to inform the variability of the identified seasons and day parts. Due to the COVID-19 pandemic, it was agreed that electricity demand in 2020 and 2021 was not representative of normal conditions, while crucial economic sectors, such as tourism, were affected in 2022 by the war in Ukraine; hence data from 2019 was selected.



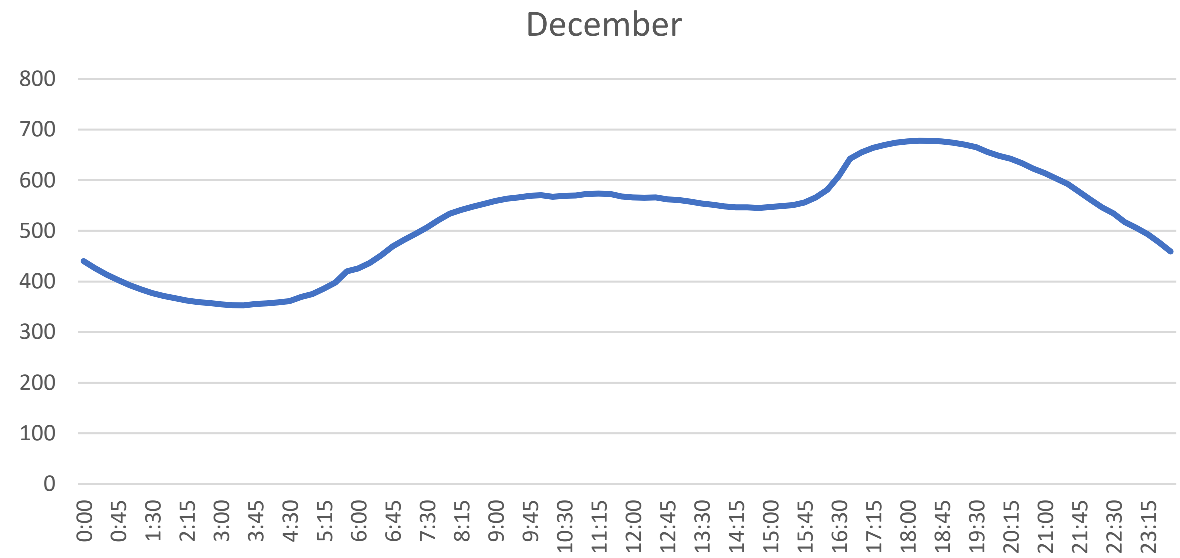


Figure A2. Electricity load profile for identified seasons 5 (August) and 8 (December), using 2019 data.

Electricity demand profile by customer category

As mentioned above, the potential adoption of energy efficiency measures will be considered in the scenarios to be assessed. However, these measures may vary in terms of ambition in each sector of the economy. For instance, improvements in the thermal insulation of existing residential buildings may occur at a larger pace than energy efficiency improvements in the services or industrial sectors. In this sense, the final electricity demand projected on an annual basis for each of these sectors by the energy demand forecast model will be affected accordingly. Additionally, the seasonal and daily load profile will be affected for the portion of the demand, in which energy efficiency measures are implemented, thus changing the overall shape of the load profile. Such changes could be captured if the electricity demand profile by customer category was available. However, since these are not accessible, the overall load profile is used instead.

Charging profile of electric vehicles

The rising importance of electric vehicles in the future will have a direct effect both on the level of electricity consumption and the daily profile of this demand. Hence, as the number of electric vehicles increases, the total electricity profile is expected to shift accordingly. Due to the low number of electric vehicles in the existing vehicle fleet and in the absence of relevant data about the charging behaviour in Cyprus, assumptions about the charging profile are necessary.

Even though the first NECP of Cyprus adopted a charging profile from a UK-focused study, this is deemed as inaccurate and has been updated for the NECP revision. For this purpose, relevant assumptions from the latest Ten-Year Development Plan of the ENTSO-E are used (*Figure A3*) (see ENTSO-E and ENTSOG, 2020). Based on discussions with officers of the TSO-Cy and Ministry of Energy, Commerce and Industry (MECI), this revised profile is deemed more representative of the charging behaviour of electric vehicle owners in Cyprus.

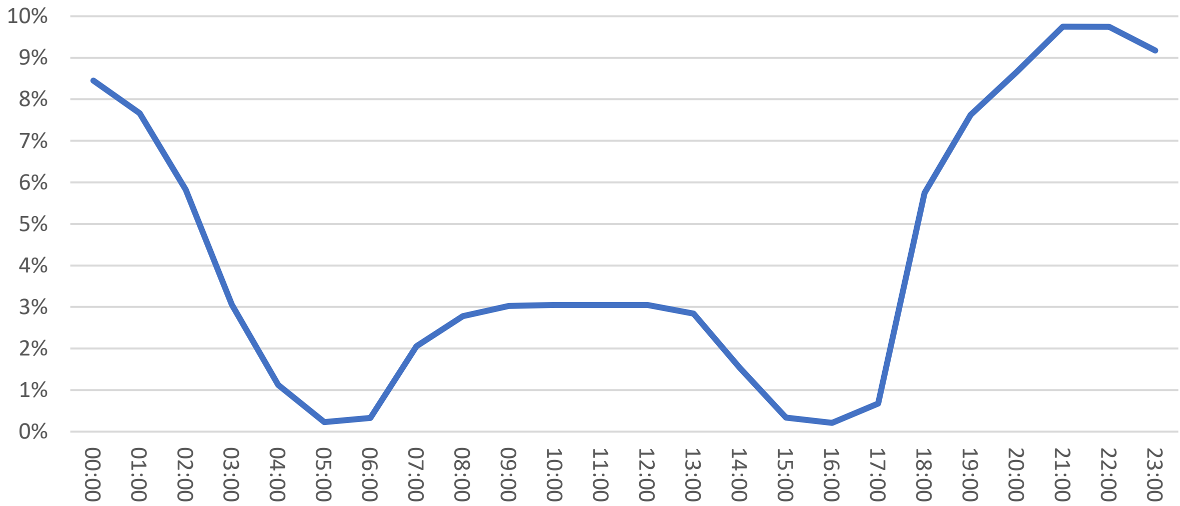


Figure A3. Electric vehicle charging profile in a typical day.

A4. Economic Input-Output Model

Input-output (IO) analysis is a quantitative technique for studying the interdependence of production sectors in an economy over a stated time period (Miller and Blair, 2009), and it has been extensively applied for policy impact evaluation, technical change analysis and forecasting (Giannakis and Bruggeman, 2017).

The static version of the IO model can be formulated by the equation (1):

$$X = AX + Y \qquad (1)$$

where, X is an $n \times 1$ vector of production in each sector of economic activity; Y is the final demand for each sector's product; A is a (nxn) matrix of technical coefficients a_{ij} that denotes the total output from sector i that is required to produce one unit of output in sector j as follows:

$$a_{ij} = x_{ij}/x_j \qquad (2)$$

In the dynamic IO model, supply and demand move towards equilibrium at a rate which is a function of the unplanned change in inventories because of changes in demand. The basic equation of IO analysis in equilibrium conditions is the following (Alva-Lizarraga et al., 2011; Bryden et al., 2011; Johnson, 1993):

$$X(t)^E = A \times X(t)^E + Y_{EXP}(t) + Y_{CONS}(t) + Y_{INV}(t) + INV\dot{E}NT^E \qquad (3)$$

where, the superscript E indicates variables at their equilibrium levels and the dot over the variables indicates a first derivative with respect to time. Total demand is the sum of intermediate demand $(A \times X(t)^E)$ and final demand that consists of exports $\left(Y_{EXP}(t)\right)$, private and government consumption $\left(Y_{CONS}(t)\right)$, investment demand $(Y_{INV}(t))$ and the planned change in inventory in each sector $\left(INV\dot{E}NT^E\right)$.

The economy, in general, is not in equilibrium. Divergence between the equilibrium levels change inventories. Defining changes in inventories as the equilibrium changes plus any changes due to disequilibrium adjustments, equation (3) becomes:

$$X(t) = A \times X(t)^E + Y_{EXP}(t) + Y_{CONS}(t) + Y_{INV}(t) + INVENT(t)^E - INVENT(t) + U(t) \qquad (4)$$

where, $INVENT^E(t)$ is the equilibrium level of inventories; $INVENT^E(t) - INVENT(t)$ is the equilibrium change in inventories, and $U(t)$ is the difference between actual rate of production and the equilibrium levels.

In such system dynamic models, the production changes in response to the short-term imbalance in supply and demand, i.e., $U(t)$. By differentiating equation (4) we create the primary dynamism in the model:

$$\dot{X}(t) = \mathit{\Delta}[X(t) - (A \times X(t)^E + Y_{EXP}(t) + Y_{CONS}(t) + Y_{INV}(t) + INVENT(t)^E - INVENT(t))] \quad (5)$$

where, $\mathit{\Delta}$ is the inter-sectoral adjustment rate. Consequently, changes in exogenous expenditures, i.e., expenditures for investments, exports and private and government consumption, represent changes in the final demand of the economic sectors.

Typically, dynamic IO models impose a capacity constraint on production. Here, this feature is ignored due to a lack of information on sectoral capacity, capital purchase coefficients and fixed investment coefficients (Alva-Lizarraga et al., 2011; Giannakis et al., 2014). Instead, production is constrained when labour supply is lower than the labour demand.

The initial static equilibrium conditions of the dynamic IO model were based on the latest available IO table of Cyprus for the year 2019, which includes 65 sectors of economic activity. The national table was aggregated into 20 sectors of economic activity.

A5. Consumer Demand Model

Household demand for energy and the subsequent distributional effect of energy efficiency or renewable energy policies has been analysed in several countries. These studies rely, inter alia, on data from household expenditure surveys conducted annually by national statistical agencies; this enables the empirical estimation of detailed income and substitution patterns. However, in some countries (Cyprus being one of them) household expenditure surveys are conducted less frequently. This poses problems to performing empirical demand analysis, as price variation over time is limited. To overcome this problem, an alternative approach was developed and applied with data from Cypriot households by Pashardes et al. (2014). This approach is based on the fact that price changes differ across goods, hence their effect can vary between households due to preference heterogeneity. For example, vegetarians are not affected by changes in the price of meat; therefore, when the only item in the food basket that increases in price is meat, only meat eaters face an increase in the unit cost of food.

In the case of energy, the unit cost is made from the prices of items such as electricity, gasoline, gas, heating oil, solid fuels and renewable sources. To the extent that these items do not increase proportionately in price and their shares in consumption vary across households due to preference heterogeneity, then the unit cost of energy also varies across households. Similar to the vegetarian example mentioned above, households without a car are not affected by a change in automotive fuel prices, whereas multi-car households may see a considerable increase in their cost of living if fuel prices rise.

Thus, Pashardes et al. (2014) constructed a consumer-theory-based measure of the unit cost of composite goods commonly used for empirical demand analysis, and used the variation in this cost across households to estimate a demand system from a limited household expenditure surveys. They applied the method to estimate the price elasticity of household demand for energy in the context of an integrable complete demand system using data drawn from three household expenditure surveys conducted in Cyprus in 1996, 2003 and 2009 by the Statistical Service of Cyprus. Then they simulated the welfare effects of price increases assumed to result from the adoption of EU's 2020 energy and climate package on households grouped by income, location and demographic characteristics.

The model was re-estimated in 2019, using in addition the data from the household expenditure survey of year 2015, and was used in the first NECP of Cyprus. We use the same model in this NECP revision, simulating the effect of the price changes in electricity and automotive fuel that are calculated by the OSeMOSYS model, in order to explore the welfare impact of the WAM scenario as compared to the 'business as usual' evolution foreseen in the WEM scenario.