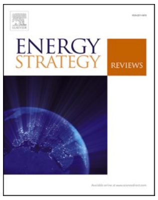
Energy Strategy Reviews 29 (2020) 100495

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: http://www.elsevier.com/locate/esr



Estimating the economy-wide impacts of energy policies in Cyprus

Constantinos Taliotis [a,*], Elias Giannakis [a], Marios Karmellos [a], Nestor Fylaktos [a], Theodoros Zachariadis [b]

[a] *The Cyprus Institute, 20 Konstantinou Kavafi Street, 2121, Aglantzia, Nicosia, Cyprus*
[b] *Cyprus University of Technology, P.O. Box 50329, 3603, Limassol, Cyprus*

ARTICLE INFO

Keywords:
Energy planning
Energy efficiency
Sustainable mobility
Input-output model
Cost-optimisation model
Macroeconomic impacts

ABSTRACT

Decarbonisation of the global economy is necessary to achieve the climate targets set by the Paris Agreement at COP21. Significant investments are required in low-carbon technologies on the supply and demand side of energy systems; the scale of these may pose challenges to national economies. In this paper, an energy forecast model, a cost-optimisation model and an input-output model are combined to conduct an economy-wide assessment of policy pathways for energy transition in Cyprus. The results of the study indicate that a scenario with additional energy efficiency measures and a modal shift in the transport sector can reduce final energy consumption by 10% as compared to a reference case in 2030. The macroeconomic assessment shows that the measures have a moderate but positive effect on economic growth. The construction, metal products and transportation sectors are those mainly benefiting in terms of economic output generation, while the largest negative effects are observed in the energy sector. Our findings highlight the importance of targeted investments to ensure a positive impact of energy policies on the broader economy.

1. Introduction

The Paris Agreement achieved at COP21 in 2015 highlighted the widespread consensus on the ramifications of a changing climate and signalled the intention of 195 nations to contribute towards the mitigation of anthropogenic greenhouse gas (GHG) emissions [1]. Specifically, Parties to the UNFCCC agreed to work towards keeping the global temperature rise well below 2 °C above pre-industrial levels and, if possible, limit the temperature increase to 1.5 °C. At the same time, the United Nations Sustainable Development Goals (SDGs) call for immediate action to combat climate change and its impacts (SDG13) and for universal access to affordable, reliable, sustainable and modern energy services (SDG7), stressing the need for an increased share of renewable energy [2].

Achievement of the objectives set by the Paris Agreement and the UN SDGs requires a transition towards decarbonisation of the global economy. In turn, this entails investments in low-carbon technologies on the supply and demand sides of the energy system. The New Policies scenario of the International Energy Agency's World Energy Outlook projects that by 2040 renewable energy technologies will be the dominant source of electricity generation on a global scale [3]. Further, a continued increase in final energy consumption is projected, adding to the requirement for investments in energy infrastructure. Nonetheless, careful planning is necessary, as investments in energy technologies have long lifetimes and can potentially lead to a lock-in effect with a substantial cost associated to it. Similarly, the adoption of energy efficiency measures and the expansion of clean technologies to mitigate GHG emission of the energy sector requires new investments that affect the entire economy.

The Republic of Cyprus is a European Union (EU) member state bound by several short- and long-term energy and climate targets. The Cypriot energy system is currently heavily dependent on imported oil products, while the renewable energy share is under 10%; according to targets set by the European Union, this share should increase to 13% in 2020 and 23% in 2030 [4]. The electrical grid system of the island state has no interconnection to neighbouring systems and is based on fossil-fired generation. Specifically, 91% of the total electricity generation was powered by heavy fuel oil and diesel in 2018, while 9% was generated by renewable energy sources [5]. Similarly, the renewable energy share in the transport sector is currently limited to 3%, while the relevant targets are 10% by 2020 [6] and 14% by 2030 [7]. Thus, it is evident that significant investments are required to achieve the energy transition foreseen at a regional and, subsequently, at an international level. However, the Cypriot economy is quite small and its industrial

---

* Corresponding author.
E-mail address: c.taliotis@cyi.ac.cy (C. Taliotis).

https://doi.org/10.1016/j.esr.2020.100495
Received 16 December 2019; Received in revised form 11 May 2020; Accepted 14 May 2020
Available online 20 May 2020
2211-467X/© 2020 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

output is minimal, while it is almost entirely dependent on fuel and technology imports. As such there are concerns as to whether the energy transition is financially viable or whether it will impose a heavy economic burden on the consumers.

Energy system models have been used for several decades to guide decision makers in regards to energy planning [8]. These models are typically classified as either bottom-up technoeconomic models or top-down macroeconomic models [9]. The former category utilises a high degree of technological detail but provides limited insights on economy-wide implications of technology options. Optimisation models form a subcategory of bottom-up technoeconomic models, satisfying a specific objective function, which often is the minimisation of a particular system's cost. Typically, focus is on a single sector, thus optimisation considers a section of the economy, ensuring that demand and supply are in equilibrium. Hence, optimisation models are often referred to as partial-equilibrium models [10]. Several examples of optimisation models used for energy planning purposes can be found in the literature [11–17].

Top-down macroeconomic models employ aggregated sector-specific energy demand and supply projections, assessing effects on the entire economy but are not suitable to prove technology investment outlooks, due to insufficient technical detail [9,10]. Various methodologies have been used in the literature to estimate the macroeconomic impacts of the transition of the energy sector, including Input-Output (IO) models [18–23], Computable General Equilibrium (CGE) models [24,25], econometric models [26,27] and analytical methods [28]. IO models have often been used for the quantification of the direct, indirect and induced effects of energy policies, having the advantage of transparency, and for using recent national accounts data [29]. Lambert and Silva [28] found that IO techniques were better suited to national and international studies, while analytical studies using extensive surveys were found to be more appropriate for regional studies.

The importance of assessing the technoeconomic and socioeconomic impacts of policy pathways using both bottom-up and top-down energy system models has been recognised in the literature. Howells and Laitner employed a bottom-up optimisation model and a top-down input-output model to illustrate benefits to the economy achieved by energy efficiency measures in South Africa's industrial sector [30], while the same model types were used by Howells et al. to estimate emission rebound effects by the proposed substitution of gas-fired generation with nuclear power in Korea [31]. Merven et al. [32] linked an optimisation model with a top-down CGE model to assess the socioeconomic effects of improved energy efficiency and the introduction of an ambitious CO_2 reduction target in South Africa. Krook-Riekkola et al. [33] conducted a similar effort, soft-linking an optimisation model with a CGE model for the case of Sweden and highlighting the challenges faced when exchanging information between them in such analyses due to inherent differences in the structure of these models. Input-output models are also used for such soft-linking. For example, Siala et al. [34] combined a linear programming optimisation energy systems model and a multi-regional input-output model to analyse the environmental and socioeconomic effects of new energy systems in Germany. Similarly, Rocco et al. [35] soft-linked a cost-optimisation model with an input-output model to assess the economic and environmental implication on the Egyptian economy due to changes in electricity production mix towards 2040.

Combining elements of both bottom-up and top-down modelling approaches, Integrated Assessment Models (IAMs) have been used for several decades to support climate policy. These quantitative models attempt to represent the interactions between biogeochemical and socioeconomic components, allowing an assessment of the impact of policy choices on greenhouse emission trajectories and the associated climate change scenarios [36]. A selection of IAMs exists in the literature (see for instance Ref. [37–41]); these have primarily a global focus. IAMs have been criticised for an overestimation of mitigation costs, an underestimation of potential benefits connected to mitigation efforts, as well as a lack of appropriate emphasis on the uncertainty behind core assumptions [42]. Furthermore, IAMs often fail to agree on the specific baseline characteristics, while they are criticised for an unfair temporal treatment of cost and benefit estimation, connected with the assumed discount rates, and for their inability to assess the distributional impacts of climate policy [36]. Another limitation of IAMs is the representation of consumer behaviour through simplified economic relationships; an attempt to tackle this has been conducted by McCollum et al. [43]. Similarly, Pietzcker et al. [44] highlight the weakness of IAMs to capture challenges related to the integration of variable renewable energy, due to the spatial and temporal aggregation of these models, and evaluate recent approaches used to address this aspect.

In this study, instead of using a single model to address all relevant aspects, three distinct quantitative tools are employed to assess the future development of the energy sector in Cyprus. A long-term energy forecast model provides final energy consumption for all sectors of the economy except transport. Then, in the main part of the analysis, the outputs of a long-term dynamic optimisation model (Open Source Energy Modelling System - OSeMOSYS) [45] are soft-linked with an IO model to assess the economy-wide effects of potential energy pathways in Cyprus in terms of economic output generation (see par. 2.4.1). Apart from being the first paper to provide a macroeconomic analysis of energy policies in Cyprus, the main novelty of this study lies in the combination of an energy forecast model with an optimisation model and an IO model for providing an integrated assessment of the energy system decarbonisation process in the medium-term (2030).

The first section of the paper sets the context and highlights the importance of the assessed topic. The second section of the paper provides an overview of the methodology and describes the tools used to carry out the analysis; the steps followed to link the various tools are described here. The main outputs of the analysis are presented in section 3, while a discussion on the implications of the results is provided in section 4. The paper concludes with a brief overview of the key messages of the analysis in section 5.

2. Methods

2.1. Modelling approach

The analysis uses outputs from three separate models which are soft-linked according to the flowchart provided in Fig. 1. Firstly, a long-term energy forecast model (model 1 in Fig. 1) is used to project final energy

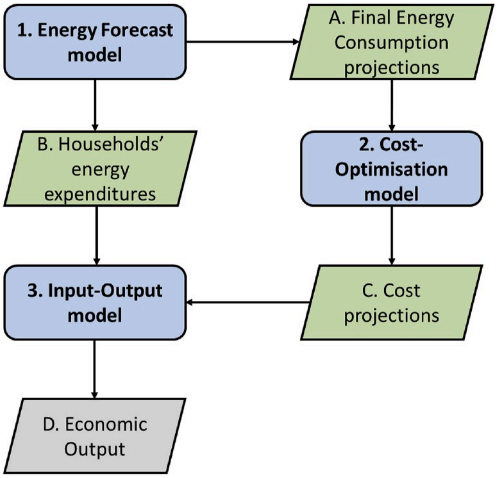


Fig. 1. Simplified flowchart with the soft-linking process for the three models. The models are indicated in light blue colour, while the steps where information is generated from one model and passed on to the next are indicated in light green. The economic output projections, indicated in grey, is the final output of the linking process and is generated by the input-output model.

consumption in the electricity and heating and cooling sectors (step A), which is inserted in a cost-optimisation model (model 2). The energy forecast model uses projections of national GDP and international oil prices, along with assumptions on the short-term and long-term income and price elasticities of energy consumption [46]. The energy forecast model also provides projections of the annual energy consumption expenditure of households (step B), which are introduced in the IO model (model 3) to estimate the multiplier effect of changes in private consumption in the economy of Cyprus. In the second phase of the analysis, a technoeconomic cost-optimisation model (model 2) is used to project the technology and energy mix in the electricity supply and transport sectors, while it also facilitates the estimation of necessary investments in the heating and cooling sector to satisfy the demand projected in the first step. Finally, the associated investments outlook, along with the costs for operation and maintenance of all technology options, are quantified by the cost-optimisation model (step C) and passed on to the IO model (model 3) to estimate the economy-wide impacts on economic growth across the different sectors of the local economy (step D). It should be clarified that, for reasons of consistency, all assumptions are aligned between the three models. The employed models are discussed further in the following subsections.

Two scenarios are evaluated based on specific sets of policies and measures to move towards decarbonisation of the energy system. Table A.1 in the Appendix provides a brief summary of the main measures upon which each scenario is developed:

- Reference (REF) Scenario: An existing package of policies and measures already implemented or officially announced by the authorities is adopted in this scenario. These correspond to the policies and measures mentioned under the 'With Existing Measures' (WEM) scenario of the government in its National Energy and Climate Plan (NECP) [4]. Among the major measures adopted is the substitution of oil-fired electricity generation with gas-fired electricity generation, foreseen to occur by the end of 2021. Other than the existing measures, no additional action is forced by the model, but further investments in low-carbon technologies are allowed, if considered cost-effective. In the transport sector, no promotion of a modal shift is envisioned, as the number of public buses remain at relatively constant levels.
- Energy Efficiency (EE) Scenario: This scenario is inspired by the Cypriot government's proposed additional measures [4] and potential energy efficiency measures examined by Vougiouklakis et al. [47] and Sotiriou et al. [48]. It assumes that emphasis is given on substantial, yet at realistic levels, investments in energy efficiency measures on the end-user side. Examples of such measures include improvements in the thermal insulation of household and commercial buildings, as well as investments in energy-efficient industrial equipment. These aim towards a reduction in the final energy consumption across the major economic sectors. Furthermore, heavy investments in sustainable mobility modes are employed in an effort to reduce fuel consumption in the road transport sector, which has the highest share in the final energy consumption of Cyprus. These entail an enhancement of the public transport fleet to consist of a tram line in the capital city and a considerably higher number of buses. Specifically, the targeted modal shift requires an increase in the total number of buses from approximately 3450 in the REF scenario to 6000 in the EE scenario in 2030, according to estimates provided by the Public Works Department.

Even though the modelling horizon of the energy forecast and cost-optimisation models runs until 2050 on an annual resolution, results are reported until 2030 to be in line with the 2030 reporting horizon of EU member states' National Energy and Climate Plans and consistent with the input-output model's temporal outlook. The latter's outlook is constrained due to the considerable uncertainty in regards to the economy's structure and growth trajectory in the longer term. In view of the medium term (2020–2030) horizon of the study, the industrial structure may be assumed to remain unchanged over this period.

2.2. *Energy forecast model*

As an initial step in the analysis, an energy forecast model developed for Cyprus is applied to project final energy consumption across the economy [46]. The energy forecast model has been used to support official energy planning efforts of national authorities in the recent past [4] and is described in detail in a relevant publication by IRENA [49]. Utilising energy balance statistics for the period 2010–2018 supplied by the Statistics Service of the Republic of Cyprus, an outlook to 2050 is provided. The main energy-consuming sectors of the economy are separately modelled, namely: agriculture, households, cement industry, other industry, services, road passenger transport, road freight transport and aviation. 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. In this study, the forecast model provides final energy consumption projections for all sectors except road transport. These are used as input in the cost-optimisation model. It also provides estimates of the energy consumption expenditure of households, which are used as input in the IO model.

2.3. *Cost-optimisation model*

2.3.1. *OSeMOSYS modelling framework*

The model employed in the second stage of the analysis is developed within the Open-Source Energy Modelling System (OSeMOSYS), which is a long-term cost-optimisation energy system model [45]. OSeMOSYS has been used in numerous studies with focus ranging from a global, regional and national scale [50–52]. 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. An existing model of the Cyprus electricity supply system [53], using code enhancements that allow consideration of short-term grid constraints [54], is expanded to include the transport and heating and cooling sectors.

2.3.2. *Key assumptions*

This subsection provides a brief summary of the main assumptions affecting the developed scenarios. Additional information on technology assumptions are provided in Tables A.2–A.4 of the Appendix. All cost figures are provided in terms of constant Euros 2016, while a currency conversion rate of 1.128 is assumed for Euros to US dollars.

Since the energy system of Cyprus is heavily dependent on imported fossil fuels, the projected price of relevant commodities directly affects the energy mix outlook. As such, oil and natural gas price projections from the country's NECP [4] are adopted in the present analysis (Table 1). Furthermore, an Emission Trading System (ETS) CO_2 price is

Table 1
Fossil fuel and ETS price assumptions [4].

		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Oil	€2016/GJ	5.1	5.4	5.7	6.0	6.3	6.6	6.7	6.8	6.9	6.9	7.0
Natural Gas	€2016/GJ	5.2	5.4	5.7	6.0	6.3	6.7	6.8	6.8	6.9	7.0	7.1
ETS price	€2016/ton CO_2	15.5	17.6	18.6	20.7	21.7	23.3	25.9	27.9	30.0	32.1	34.7

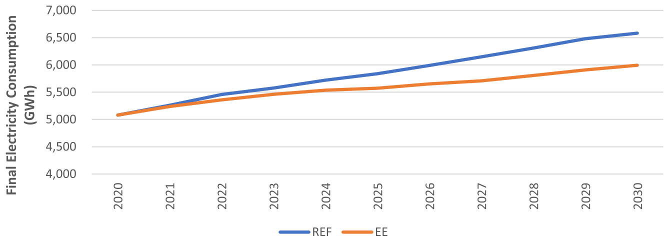


Fig. 2. Final electricity consumption in each scenario, excluding consumption in the transport sector.

used for power generation and heavy industry, based on the official projections of the European Commission [55].

As aforementioned, final electricity consumption projections are retrieved from the outputs of the energy forecast model. As a result of the assumed energy efficiency measures implemented in the EE scenario, a difference of 9% is estimated between the two scenarios by 2030 (Fig. 2). It should be noted that in the case of the transport sector, any electricity consumption in plug-in hybrid or battery electric vehicles is considered as additional to the final electricity consumption projection provided by the energy forecast model. This choice is due to the fact that the entire final energy consumption of the land transport sector, including fossil fuels and biofuels, is derived solely from the cost-optimisation model, which has a greater technological detail than the energy forecast model.

Major infrastructure projects are, naturally, crucial to investment requirements. By the end of 2021, a Floating Storage and Regasification Unit (FSRU) will be developed to enable natural gas imports. This project is estimated to cost approximately €300 million [4]. A second major planned project is the EuroAsia interconnector with the aim to connect the Cypriot grid with the Greek and Israeli grids. Despite recent obstacles arising in the development of the interconnector [56], the project is still part of the official plans of the local government. However, since the systems of Israel and Greece are not explicitly modelled in the present analysis, the level of electricity trade between the three systems is highly uncertain and cannot accurately be represented. Even though projected electricity prices from Israel and Greece exist on an annual basis [57], OSeMOSYS considers endogenously a cost of electricity generation that varies between seasons and between day parts. Due to this inconsistency in terms of available information and the project's speculative development prospect, the EuroAsia Interconnector is excluded from the analysis.

Additional to the foreseen increase in public bus lines in the EE scenario, the tram line in Nicosia will require €225 million in capital expenditure and a yearly operation and maintenance budget of €12 million [58]. Furthermore, infrastructure investments that promote sustainable modes of transport are estimated by the Public Works Department at €500 million for the period 2020–2030; these funds will be diverted towards the development of cycle lanes, bus lanes, bus stops and improvements in pedestrian walkways. According to the figures provided by the same authority, the additional investments in the EE scenario are projected to reduce the trips conducted with private motor vehicles by 21% as compared to the REF scenario for 2030.

Investments in the heating and cooling sector include the replacement of energy-intensive equipment and deployment of alternative technologies, such as heat pumps and solar thermal panels. In addition, energy efficiency measures such as roof and wall insulation, windows replacement and use of efficient lighting are considered exogenously; the technoeconomic assumptions for these measures are provided by Sotiriou et al. [48].

2.4. *Input-output analysis*

2.4.1. *Input-output model*

The second tool presented in this paper is based on the Input-Output (IO) analysis, which is a quantitative technique for studying the interdependence of production sectors in an economy over a stated time period [59]. IO analysis has been extensively applied for policy impact evaluation [60], energy use analysis [61] and environmental analysis [62].

Continuous time models have been applied in macroeconomic studies to analyse the impacts of alternative policy pathways [63]. In this study, a continuous demand-driven IO model with disequilibrium adjustment processes, hereafter IO model, is developed and applied to assess the macroeconomic impacts of the EE scenario in comparison to the REF scenario in the mid-term (i.e. until 2030). Recently, IO models have been applied to forecast energy demand [64–66], assess the energy, economic and environmental performance of bioenergy technologies [67], analyse the dynamics of bioenergy supply chains [68] and renewable resources [69].

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

$$X = AX + Y \tag{1}$$

where, the supply X is an $n \times 1$ vector of production in each sector of economic activity. Total demand (consumption) for each sector's product is the sum of intermediate demand (AX) and final demand (Y). 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:

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

The IO model applied in this study is based on the dynamic macroeconomic model developed by Leontief [70] and adapted by Johnson [71] and Bryden et al. [72]. In these models, the static equilibrium conditions of the variables are replaced by equations of motion and the system is described as a disequilibrium adjustment process [73,74]. Similar to ecologic or mass-balance systems, production and consumption move toward equilibrium at a rate that depends on the difference between demand and supply, which is a function of the unplanned change in inventories [72]. Inventories are used as buffer mechanisms to absorb the short-run differences between demand and supply. When production and consumption are equal, inventories are in equilibrium, while when inventories are larger or smaller than ideal, then production decreases or increases respectively. The economy, in general, is not in equilibrium. Because of unexpected changes in demand, there are unplanned changes in inventories of the commodities [75,76]. Defining changes in inventories as the equilibrium changes plus any changes due to disequilibrium adjustments, the basic equation of IO analysis in disequilibrium conditions is as follows [71,75,76]:

$$X(t) = A \times X(t) + Y_{EXP}(t) + Y_{CONS}(t) + Y_{INV}(t) + INVENT(t)^{E} - INVENT(t) + U(t) \tag{3}$$

The functional notation indicates that each element of these vectors is a continuous function of time with the exception of technical coefficients (A) and the superscript E indicates variables at their equilibrium levels. Total economic output $(X(t))$is the sum of intermediate demand $(A \times X(t))$ and final demand that consists of exports $(Y_{EXP}(t))$, private and government consumption $(Y_{CONS}(t))$ and investment demand $(Y_{INV}(t))$; $INVENT(t)^{E}$ is the equilibrium level of inventories; $INVENT(t)^{E} - INVENT(t)$ 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 $(U(t))$ as follows [75,76]:

$$\dot{X}(t) = \Delta\left[X(t) - \left(A \times X(t) + Y_{EXP}(t) + Y_{CONS}(t) + Y_{INV}(t) + INVENT(t)^{E} - INVENT(t)\right)\right] \tag{4}$$

where, Δ is the inter-sectoral adjustment rate and the dot over the variables indicate a first derivative with respect to time. 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.

One of the assumptions underlying the demand-driven nature of the applied IO model is the unrestricted supply of factor inputs. Here, this assumption is justifiable as the purpose of the model is to quantify the supply of factor inputs required under each scenario and compare the available factors over the scenarios' required factor inputs. Instead, production is constrained when labour supply is lower than the labour demand [72,75]. Other sources of uncertainty typically associated with IO models relate to the assumptions of: (a) constant returns to scale; (b) fixed prices and (c) fixed technical coefficients [59].

2.4.2. Data and application

The initial static equilibrium conditions of the IO model are based on the latest available national symmetric IO table of Cyprus for the year 2015 [77], which includes 65 sectors of economic activity. The national table is aggregated into 20 sectors of economic activity (Table A.5 in the Appendix). Similar to the energy forecast model, the demand growth rates for the economic sectors are defined based on the GDP projections for the period up to 2030, which were obtained from the Ministry of Finance and comprise the official macroeconomic forecasts of the government of Cyprus that were submitted to EU authorities by the end of 2018.

2.5. Linking OSeMOSYS with IO model

The rationale of linking an energy optimisation model with an IO model is that the EE scenario will involve additional and/or diverse types of investments during the period 2020–2030 in comparison to the REF scenario, thus generating different macroeconomic impact. The projected annual expenditures, including capital investments and operation and maintenance costs, from the OSeMOSYS model (section OSeMOSYS modelling framework) are introduced in the IO model to reflect changes in the investment demand of the specific sectors. These expenditures are classified in seven categories, namely: (a) industry, (b) power generation technologies, (c) electricity storage technologies, (d) gas infrastructure, (e) public transport, (f) private transport, and (g) 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 relevant literature [78,79], as well as on experience from the development and operation of actual projects in Cyprus; the relevant assumptions are presented in the Appendix (Tables A. 6–A. 8).

Table 2
Total installed capacity in the electricity supply sector in each scenario.

	2020	2025		2030	
		REF	EE	REF	EE
Existing thermal units	1478	1120	1120	1120	1120
New CCGT units	0	432	432	432	432
Solar PV	360	565	460	1141	879
Solar Thermal	0	50	50	50	50
Wind	175	175	175	175	175
Biogas	17	50	50	50	58
Pumped Hydro	0	0	0	130	0

3. Results

The first and second parts of this section of the paper present results on technology and energy mix, and the associated investments extracted from the cost-optimisation model. The third part of this section presents the impacts of the two scenarios on economic growth, as estimated by the input-output analysis.

3.1. Technology and energy mix outlook

The projected increase in electricity consumption along with the assumed fuel and technology cost trends result in capacity investments in the power system (Table 2). Specifically, two new combined cycle gas turbine (CCGT) units of 220 MW are installed in both scenarios by 2030. During this time, renewable energy technology investments also take place. A planned concentrated solar thermal installation of 50 MW is developed, while the capacity of biogas-fired generation units also increases substantially. A considerable volume of the investments is directed to solar PV deployment; total installed capacity of this technology increases to 1141 MW and 879 MW in the REF and EE scenarios respectively by 2030. The difference between the two cases is attributed to the lower electricity consumption projection adopted in the latter case (Fig. 3), which results in lower capacity investment requirements. Similarly, whereas a pumped hydro facility of 130 MW is developed in the REF scenario driven by the increased integration of variable renewable energy technologies, the lower level of solar PV in the EE scenario removes this necessity.

The foreseen power expansion outlook leads to a corresponding generation mix evolution (Fig. 3). A planned shift from oil-fired generation to gas-fired generation by the end of 2021 has a direct impact on the fuel mix of the electricity supply sector in both scenarios. Even though the absolute contribution of fossil-fired generation remains

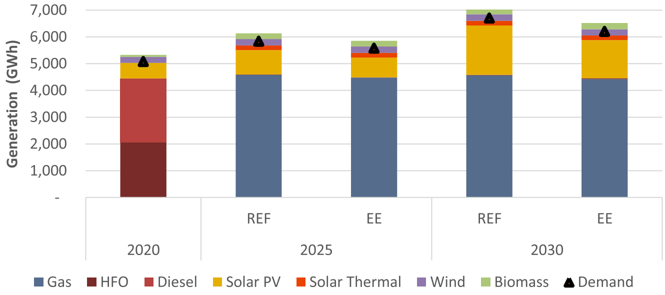


Fig. 3. Generation mix in 2025 and 2030 in the REF and EE scenarios.

relatively stable throughout the period 2020–2030, the aforementioned renewable energy investments increase the renewable energy share of the electricity supply sector. This increases from 16% in 2020 to 35% in the REF scenario and 32% in the EE scenario in 2030.

In the transport sector, a shift towards alternative technologies is observed, albeit at varying levels in each of the two scenarios. As one of the main vehicle technologies deployed, the total number of battery electric vehicles (BEVs) increases substantially to approximately 38,000 in the REF and 57,000 in the EE scenario by 2030 (Table 3). The number of hybrid vehicles also increases to 7% of the total vehicle fleet by 2030 in both scenarios. The main aspect to highlight is the fact that the total number of vehicles in 2030 is lower by 145,000 in the EE scenario as compared to the REF scenario. The difference is attributed to a lower number of passenger cars, whose passengers are primarily served by an increased bus fleet and a tram line to be developed in the city of Nicosia; the total number of buses in 2030 is nearly double in the EE scenario. Even though such a difference between the two scenarios may appear highly optimistic, the EE scenario assumes that the passenger car fleet will be reduced by merely 10% as compared to the present situation.

The final energy consumption projections in both scenarios indicate a gradual decrease in the consumption of fossil fuels, accompanied with an increased level of electricity consumption and a slight increase in the contribution of renewable energy sources (Table 4). Even though the REF scenario foresees a growth of the total final energy consumption, this decreases to a small extent in the EE scenario. The EE scenario achieves a reduction in total final energy consumption of 158 ktoe by 2030 as compared to the REF scenario, corresponding to a difference of approximately 10%. This is primarily attributed to a reduced gasoline consumption by 115 ktoe in the transport sector, as a result of the assumed modal shift, and to a secondary degree to a decrease of 43 ktoe in electricity consumption, enabled by the additional energy efficiency measures. When the primary energy supply figures are compared with the total final energy consumption, we can see an overall energy system efficiency improvement. Specifically, the efficiency of the system rises from 69% in 2020 to over 75% in both scenarios by 2030. This improvement is largely achieved through a higher share of renewable energy in the electricity supply sector, as well as a shift towards more energy efficient gas-fired generation. In terms of greenhouse gas emissions, the total emissions decrease from 6380 ktons in 2020 to 4940 and 4540 ktons by 2030 in the REF and EE scenarios respectively.

3.2. *Investment requirements*

The two scenarios illustrate mild but important differences in terms of technology and infrastructure investments. In the REF scenario, these are focused primarily on supply side technologies in the electricity supply sector and private-owned passenger cars in the transport sector. However, in the case of the EE scenario, the level of investments in energy efficiency measures and in the development of sustainable modes of transport is increased compared to the REF scenario (Table 5). Despite these larger investments in certain aspects of the energy system, overall cost savings are foreseen in this latter case; annual capital cost savings reach up to €82 million in 2030 (Fig. 4). The main reason for this difference is the lower number of passenger cars, enabled by the larger number of buses and the tram development in Nicosia.

As shown in Table 5, a higher volume of investments occurs in the EE scenario in energy efficiency measures, such as improvements in thermal insulation of buildings and substitution of energy-intensive equipment, in the industrial, residential and commercial sectors. The required level of renovations and their associated investments correspond to those foreseen in the “Realistic” scenario of a separate study conducted by Vougiouklakis et al. [47]. These measures ultimately result in a decrease of the final energy consumption in the EE scenario. In turn, a lower electricity consumption reduces the need for power generation and electricity storage infrastructure, leading to corresponding cost savings. Both scenarios assume that the Floating Storage and Regasification Unit for gas import purposes is developed as scheduled; hence, no

Table 4
Evolution of Final Energy Consumption (ktoe) in each scenario.

	2020	2025		2030	
		REF	EE	REF	EE
Diesel	284	260	277	270	273
Gasoline	398	423	361	387	273
LPG	63	63	62	68	65
Pet Coke	77	59	59	51	51
Other petroleum products	163	160	158	158	154
Electricity	437	502	479	576	533
Biomass (includes biofuels)	40	55	53	60	61
Geothermal	1	1	1	1	1
Solar thermal	72	76	73	90	84
District Heating and Cooling	–	–	–	–	6
Total	**1534**	**1600**	**1523**	**1661**	**1503**

Table 3
Evolution of the motor vehicle fleet in the two scenarios until 2030.

		2020	2025		2030	
			REF	EE	REF	EE
Passenger cars	Diesel	69,175	40,372	53,722	53,560	57,163
	Diesel Plug-in Hybrid	0	0	252	0	799
	Gasoline	471,730	539,790	459,927	473,209	333,432
	Gasoline Hybrid	5170	5170	5170	59,927	46,300
	BEV	100	100	100	38,006	54,858
	LPG	214	739	739	1174	1174
Buses	Diesel	3014	3230	4372	3450	5574
	BEV	0	0	138	0	436
Motorcycles	Gasoline	50,925	54,667	48,476	58,383	46,000
Trucks	Diesel	12,978	13,923	14,146	14,542	13,738
	BEV	0	0	0	326	1573
Light Trucks	Diesel	119,614	128,323	126,670	137,032	133,726
Total		**732,920**	**786,314**	**713,710**	**839,609**	**694,771**

Table 5
Difference in Energy and Climate Related Investments (million Euros) between the REF and EE scenarios. Negative values denote higher investments in the REF scenario, while positive values denote higher investments in the EE scenario.

Investments by Economic Sector		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Industry	Capital Investments (m€)	7	7	7	7	7	7	7	7	7	7	7
	O&M Investments (m€)	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7
Power generation (new CCGT plants, PVs etc.)	Capital Investments (m€)	0	0	0	0	0	−11	−31	−52	−52	−17	−20
	O&M Investments (m€)	0	0	0	0	0	−1	−2	−4	−4	0	−1
Electricity storage technologies (pumped hydro & batteries)	Capital Investments (m€)	0	0	0	0	0	0	0	0	−14	−14	−14
	O&M Investments (m€)	0	0	0	0	0	0	0	0	−2	−2	−2
Gas Infrastructure (FSRU)	Capital Investments (m€)	0	0	0	0	0	0	0	0	0	0	0
	O&M Investments (m€)	0	0	0	0	0	0	0	0	0	0	0
Sustainable mobility (bus lanes, cycle lanes, buses & tram)	Capital Investments (m€)	8	29	50	71	92	113	135	156	215	226	250
	O&M Investments (m€)	0	1	1	2	3	3	4	5	17	18	18
Private transport (more efficient cars, hybrid vehicles, electric cars etc.)	Capital Investments (m€)	−1	−42	−83	−126	−165	−207	−241	−255	−293	−329	−374
	O&M Investments (m€)	0	−7	−13	−20	−27	−34	−41	−47	−54	−62	−69
Residential & commercial buildings (energy efficiency renovations, heat pumps, solar panels etc.)	Capital Investments (m€)	66	70	68	70	60	62	66	65	65	65	69
	O&M Investments (m€)	2	2	2	3	3	3	3	3	4	4	4
Total	**All investments (m€)**	**82**	**61**	**33**	**7**	**−27**	**−64**	**−101**	**−120**	**−110**	**−103**	**−130**

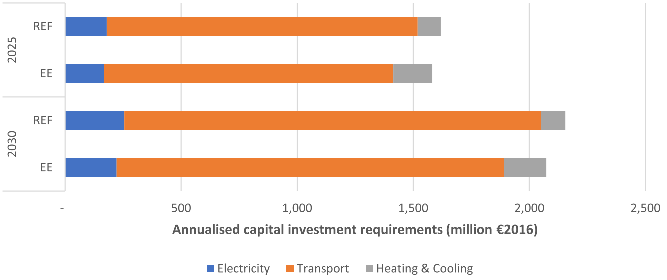


Fig. 4. Annual level of annualised capital investments (M€) in each scenario for the three sectors of the energy system.

cost difference is observed in this regard.

The most significant differences between the two scenarios are observed in the transport sector. The modal shift from passenger cars towards sustainable modes of transport diverts investments away from privately-owned motor vehicles towards public transport infrastructure. It should be highlighted that the cost savings resulting from a lower purchase and ownership rate of private motor vehicles significantly exceeds the financing requirements for sustainable mobility. A total cost difference of €175 million is observed in 2030. Table 5 provides a summary of the capital, operation and maintenance investments of the relevant investment categories, which are introduced in the IO model.

Here, we have to note that the pronounced modal shift does not assess the fiscal impact of the proposed measures on the economy of Cyprus. The shift examined in the EE scenario has to be backed by considerable public investments, which would pose very different questions to economic planners compared to the private ownership-centric approach of the REF scenario. It is the view of the authors, however, that significant changes pointing towards decarbonisation in an energy system with high reliance on private transportation cannot happen without the necessary investments.

The distribution of the annual spending, associated with investments and private consumption by sector of economic activity under the REF and EE scenarios for the period 2020–2030, is presented in the Appendix (Tables A. 9 and A. 10 respectively). As the geographical scope of this study is limited to Cyprus, a critical factor of the analysis is to what extent the production of the necessary equipment for implementing the investments of the two scenarios, and thus the relative expenditures, occurs inside the local economy. The estimation of the associated macroeconomic impacts is based on this part of the expenditure that is spent in the economy of Cyprus. Impacts on foreign economies are not evaluated. Economic sectors with a high share of domestically-produced inputs lead to larger output gains within the domestic economy, compared to sectors with relatively high share of imports [29].

3.3. *Economy-wide effect of proposed policies*

The results of the IO model simulations, in essence the economy-wide effects in terms of generated economic output by the investments and private consumption under the two scenarios, are presented in Table 6. The investments in the EE scenario result in an annual increase

Table 6
Annual total economic output (in million €) associated with the investments under REF and EE scenarios for the period 2020–2030.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
REF	57,522	59,219	60,778	62,274	63,722	65,097	66,569	68,123	69,681	71,264	72,747
EE	57,657	59,381	60,930	62,420	63,845	65,210	66,679	68,233	69,817	71,427	72,926
Difference (EE-REF)	0.23%	0.27%	0.25%	0.23%	0.19%	0.17%	0.17%	0.16%	0.20%	0.23%	0.25%

Table 7
Change in economic output by main sector of the national economy of Cyprus in 2030 due to investments in the EE scenario, in comparison to the REF scenario.

Sectors of economic activity	2030
Agriculture	−0.11%
Forestry	0.00%
Mining	0.19%
Food Manufacturing	−0.09%
Textile	0.02%
Wood and Paper	0.45%
Chemical and Plastic Products	0.27%
Metal Products	1.10%
Machinery and Equipment	0.11%
Energy	−1.42%
Construction	1.80%
Trade	−0.31%
Accommodation and Food Services	0.06%
Transportation	0.63%
Banking-Financing	0.19%
Real Estate	0.20%
Public Administration	0.00%
Education	0.01%
Health	0.00%
Other Services	0.11%

of the economic output of the country ranging from 0.16% to 0.27% higher compared to the annual increase due to the investments under the REF scenario for the period 2020–2030. Specifically, in 2030 the economic output of the country under the EE scenario will be higher by 0.25% compared to the respective figure of year 2030 under the REF scenario.

The estimated macroeconomic effects of the EE scenario are relatively higher during the first (i.e. from 2020 to 2022) and the last (i.e. from 2028 to 2030) years of the study period. The largest effects on the generation of economic output from 2020 to 2022 are attributed to the increased capital and operational investments for the Metal Products, Chemical and Plastic Products and Construction sectors. These are driven by investments in energy efficiency measures in residential and commercial buildings, which are higher in this period than in the middle of the decade (Table 5). The increased generation of economic output from 2028 onwards is mainly attributed to the large investments for the transportation sector in the EE scenario, namely substantial investments in new buses, the Nicosia tramline and other interventions to promote sustainable urban mobility. Thus, the increase in the demand for products and services of sectors with high backward linkages (e.g. Construction and Transportation) through demand for investments, generate indirect growth effects to the other sectors of the economy (e.g. Machinery and Equipment, Banking-Financing, Real Estate, Accommodation and Food Services and others).

The sectoral distribution of the generated economic output in the Cypriot economy in 2030 associated with the investments and personal consumption under the REF and EE scenarios is presented in Table 7. The differences are overall quite small without a single sector showing disproportionately large changes compared to the others. It can be observed that the economic sectors which mainly benefit in the EE scenario are Construction (1.80%), Metal Products (1.10%), Transportation (0.63%) and Wood and Paper (0.45%). The Construction sector has a strong local character and creates the highest backward linkages in the economy and it is skewed by large-scale investments under the EE scenario, notably in new transport and energy infrastructure. In the rest of the economy, there is a notable increase in the output of the Metal Products sector due to their use in the energy efficiency measures adopted under the EE scenario. The highest negative multiplier effects are observed in the economic output of the energy sector, reaching −1.42%, due to the reduced energy consumption that is attributed to the implementation of energy efficiency measures in the EE scenario. A minor negative effect in the economic output of traditional activities of the economy such as agriculture is created, principally due to lower numbers of biofuels diverted towards additives for diesel, which is forecasted to be used in larger quantities in the EE scenario.

4. Discussion

Two sets of measures have the biggest impact on the energy mix of Cyprus. Namely, measures on energy efficiency and promotion of sustainable modes of transport are of importance. Promotion of energy efficiency lowers the need for additional supply and storage infrastructure investments, while it decreases the rate at which existing infrastructure is operated, thus reducing operation and maintenance costs. The "energy efficiency first" principle is already an integral part of EU energy and climate policy [80].

Moreover, the analysis highlights the central role that transport sector measures have in the official planning towards decarbonisation of the Cypriot energy system, as the package of relevant measures in the EE scenario leads to a further reduction in greenhouse gas emissions in 2030 by 340 ktons CO_2 eq as compared to the REF scenario. Giannakis et al. [81] estimated that the CO_2 emissions of the road transport sector in Cyprus will grow by 24% between 2016 and 2030 if no action is taken and highlighted the urgency of implementing in-sector cost-effective decarbonisation strategies. Besides the prospective climate change mitigation potential, these measures can lead to substantial financial benefits. Nonetheless, the success of the modal shift depends on the political will to push the proposed plans forward and mobilise funds for the development of the necessary infrastructure. Even though the cost savings from the lower deployment of private vehicles outweigh the projected cost of the sustainable mobility plans in the EE scenario, it has to be highlighted that the latter will be financed primarily through public funds. In addition, the social acceptance of the measures is a critical factor, as individuals will have to be convinced that use of sustainable modes of mobility is a viable alternative to the use of private motor vehicles.

The potential for improvements in energy efficiency and reduction in greenhouse gas emissions through promotion of public transport has been recognised in the literature. Peng et al. projected that the transport sector's energy consumption and CO_2 emissions in the city of Tianjin can decrease by 22% in 2040 by shifting passenger journeys from private vehicles to public transport modes [82]. In another study, Zawieska and Pieriegud [83] estimated that smart public transport solutions may offer up to 10–15% CO_2 emissions reduction in Warsaw, even though 46% of passenger trips are already conducted with public transport. Similarly, Bueno [84] calculated a final energy consumption reduction potential of 57% in the transport sector of the Basque Autonomous Community, via aggressive deployment of public transport, carpooling and carsharing schemes.

The large-scale utilization of energy efficiency measures in Cyprus during the upcoming decade in the context of the European Union's 2030 climate and energy framework is expected to have positive, although marginal, implications on the macroeconomic environment of the country. The results of this study are in line with the findings from reviewed articles [18,85], which also claim positive macroeconomic impacts of energy efficiency and renewable energy policies and measures, although it is difficult to compare results of studies employing different methodologies and applied in heterogeneous locations.

Specifically, Yushchenko and Patel [18] estimated the impact of energy efficiency programmes on the gross domestic product (GDP) in Switzerland. The results of the study indicated net positive effects, that is, for each Swiss Franc within the energy efficiency program 0.2 Swiss Franc of additional GDP are created in comparison with the reference case scenario. Markaki et al. [79] measured the macroeconomic impact of clean energy investments on the Greek economy. The authors showed that €47.9 billion investments over the period 2010–2020 result in an annual average increase of GDP by €9.4 billion. The largest positive effects are observed in the output of the manufacturing and construction sectors, while negative effects appear on the output of the electricity sector. Kamidelivand et al. [19] applied an extended IO model to compare the net macroeconomic impacts on Ireland's economy when substituting imported fossil fuels for electricity with renewable resources. They found that the substitution of gas and coal imported for electricity generation with renewables resulted in small positive net value-added impact of €0.9–5 million for gas and €0.4–3 million for coal. Andini et al. [27] applied a structural vector autoregression model to estimate the macroeconomic impact of renewable electricity power generation projects for Portugal. Their findings suggest that these projects have positive effects on real economic growth in the medium term, through both the investment and the operations phases. There are, however, examples of negative macroeconomic impacts of renewable energy policies available in the literature [86,87].

The likely reason underlying the relatively low impact of the selected energy measures on the economic output of the country in this study is that Cyprus heavily relies on imports for the manufacturing and installation of the necessary equipment. Similar findings are reported for other Mediterranean countries, such as in Greece [79].

5. Conclusions

In this study, an energy forecast model and a dynamic optimisation model are successfully linked with an IO model to estimate the macroeconomic consequences of the imminent energy transition in Cyprus in the next decade. The results of the present analysis indicate that the energy transition does not compromise economic growth. Despite the overall lower level of investments in the EE scenario, targeted investments and measures can strengthen the local economy. In the case of Cyprus, lower investments in specific technologies lead to a reduction in associated imports. As shown in the present analysis, adoption of proposed measures leads to positive economic output, even though the impact is not homogeneous across the economy. For instance, energy efficiency measures in the building sector boost the output of the construction sector, but lead to negative effects in the energy sector's output due to reduced fuel consumption. Then again, the benefits to the economy from reduced fuel consumption are not fully captured and should be evaluated further in a separate study; Cyprus has domestic gas reserves which could be dedicated for export rather than domestic consumption.

The findings presented in this paper can support policy makers in evaluating the consequences of energy policies from a national and sectoral perspective. The positive macroeconomic impacts of energy efficiency policies could be enhanced by preferring expenditures on local goods and services by executing a significant part of the manufacturing activities domestically. Identification of components that are essential for the projected technological integration can bring forth opportunities for the development of an associated local industry. However, the present analysis assumes that the level of reliance on imported goods for each sector of the economy remains constant throughout the model horizon. Another important limitation relates to the estimation of the economic impact of the package of measures as a whole; an evaluation of the impact of each measure separately, quantifying economic output in each economic sector, could assist decision-makers in the prioritisation of these measures and potentially facilitate a more robust policy design minimising negative impact. These are aspects that merit further investigation and can be pursued in future enhancements of this work. Future research could analyse the welfare impacts of energy policies in Cyprus through the application of a recursive dynamic CGE model. The scenarios examined in this study could be expanded both in terms of technological pathways towards GHG reductions, and also for time-frames beyond 2030 with an eye on the currently debated 2050 carbon neutrality for Europe. Furthermore, a weakness of the analysis relates to the soft-linking process, which requires information to be exchanged between models, while making sure underlying key assumptions, such as cost of electricity, remain consistent in all tools. This can be time-consuming and necessitates a certain degree of iterative process.

Even though the focus of the study is on Cyprus, the insights offered can be representative of other national and sub-national economies with comparable economic size and structure. Many European states are reliant on fossil fuel imports, while several are also dependent on technology imports; especially so when considering technologies at the forefront of the energy transition. This applies for a range of developed and developing countries beyond Europe as well. As such, quantification of the economy-wide effects of energy pathways should form an indispensable part of national energy planning.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Constantinos Taliotis: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Elias Giannakis:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft. **Marios Karmellos:** Data curation, Writing - review & editing. **Nestor Fylaktos:** Conceptualization, Methodology, Writing - review & editing. **Theodoros Zachariadis:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - review & editing, Supervision, Project administration.

Acknowledgements

This work was supported by the European Union's Horizon 2020 Research and Innovation Programme within the context of the CySTEM ERA Chair project, under grant agreement no. 667942. Although the scenarios included in this paper have similarities with the scenarios adopted by the government of Cyprus in its National Energy and Climate Plan, the assumptions and results of this study do not reflect any official views of the government of Cyprus.

Appendix

Table A. 1
Key measures adopted in the analysis.

Sector	REF scenario	EE scenario (additional to REF)
Electricity supply	Net-metering scheme for PV systems in households	Improved forecasting for PV and wind electricity generation
	Net-billing scheme for generation from renewable energy sources (RES)	Development of Renewable Energy Communities
	Self-consumption scheme of electricity from RES	
	Installation of RES for operation within the competitive electricity market	
Transport	Biofuel blending with conventional fuels	Nicosia Tramway System
	“Park and drive” stations for use of public transport	Environmental Fees for use of Road Network
	Reduction in average age of bus fleet to 10 years	Sustainable Urban Mobility Plans in each city
	Installation of public charging points for electric vehicles	Promotion of public vehicles with low or zero GHG emissions
	Development of natural gas pumping stations in each district	Incentives for the purchase of battery electric vehicles
Buildings & Industry	Minimum energy performance requirements for new buildings	Incentives for RES-based process heat systems
	Schemes for deep renovation of residential and commercial buildings	Energy efficiency measures in the public sector
	Minimum 25% RES in new buildings	Removal of administrative barriers on energy efficiency investments
	Scheme for the promotion of roof thermal insulation and use of RES in households	Promotion of renewable cooling measures (e.g. reversible heat pumps, photovoltaic cooling, vapour compression cooling systems)
	Energy efficiency measures in existing public buildings	Financing mechanism for energy efficiency investments
		Scheme for energy efficiency investments in agriculture
Other	Promotion of anaerobic digestion for the treatment of animal waste	Use of Refuse-Derived Fuel for district heating and cooling
	Rollout of smart meters	Reduction of organics to landfills
	Import of natural gas by last quarter of 2021	Biogas recovery from landfills
	Energy Efficient street lighting	

Source: National Energy and Climate Plan of the Republic of Cyprus [4].

Table A. 2
Renewable energy generation technology technoeconomic assumptions.

	Investment Cost (EUR2016/kW)		Fixed Cost O&M cost (EUR2016/kW)	Capacity Factor	Lifetime (years)
	2020	2030			
Utility-scale PV	1161	886	9	18.5%	20
Wind	1394	1330	53	16%	25
Biomass-biogas	2461	2438	62	48.5%	30
Rooftop PV	1467	1241	12	18.5%	20
EOS 50 MW CSP with storage	3355		106	39.3%	30

Table A. 3
Motor vehicle purchase cost projections for each vehicle category and technology.

		Vehicle purchase cost (EUR2016/unit)		
		2020	2025	2030
Passenger Cars	Diesel	17,063	17,063	17,063
	Gasoline	16,230	16,230	16,230
	Hybrid Gasoline	19,764	19,636	19,509
	Hybrid Diesel	19,654	19,459	19,265
	PHEV Gasoline	27,167	26,856	26,548
	PHEV Diesel	27,987	27,666	27,349
	BEV	29,040	28,456	27,883
	CNG	18,366	18,366	18,366
	LPG Conversion	1463	1463	1463
Motorcycles	Gasoline	5762	5762	5762
Buses	Diesel	292,553	292,553	292,553
	CNG	382,824	379,011	375,235
	BEV	409,500	401,126	392,924
Trucks	Diesel	31,693	31,693	31,693
	BEV	124,394	121,857	119,372
	CNG	56,073	56,073	56,073
Light Commercial Vehicles	Diesel	19,791	19,791	19,791
	BEV	46,428	45,488	44,566
	PHEV	32,187	31,817	31,452
	Hybrid Diesel	23,056	22,826	22,599

Table A. 4

Technology costs for solar panels and heat pumps in the Heating and Cooling sector.

Building type	Resource	Technology	Investment cost (EUR2016/kW)	Fix O&M (EUR2016/kW)
Households	Electricity	Heat pumps	1263	9.3
	Solar	Solar panels	1191	23.8
Other buildings	Electricity	Heat pumps	838	16.8
	Solar	Solar panels	893	17.9

Table A. 5

NACE (Statistical classification of economic activities in the European Union) codes of the sectors of economic activity that make up the 20 sectors for the input-output analysis for Cyprus (2015).

Sector	Description NACE
Agriculture	A01, A03
Forestry	A02
Mining	B
Food Manufacturing	C10, C11, C12
Textile	C13, C15
Wood and Paper	C16, C17, C18
Chemical and Plastic Products	C19–C23
Metal Products	C24, C25
Machinery and Equipment	C26–C33
Energy	D
Construction	F
Trade	G45-G47
Accommodation and Food Services	I
Transportation	H49–H53
Banking-Financing	K64–K66
Real Estate	L68
Public Administration	O
Education	P
Health	Q
Other Services	E, J58-63, M69-75, N, R, S, T, U

Table A. 6

Assumptions on distribution of spending (%) for the development (C) and operation (O&M) of the power generation technologies, divided into imported (I) and local (L) investments.

Power Generation	New thermal technologies				Solar PV				Solar Thermal				Wind				Biogas			
Sector of economic activity	C	O & M	I	L	C	O&M	I	L	C	O & M	I	L	C	O& M	I	L	C	O & M	I	L
Agriculture																				
Forestry																				
Mining																				
Food Manufacturing																				
Textile																				
Wood and Paper																				
Chemical and Plastic Products		6	100										12	5	100					
Metal Products					14		100		14		100		12		100		5		100	
Machinery and Equipment	60	35	100		63	40	100		58	40	100		43	42	100		50	15	100	
Energy		15		100		35		100		35		100		15		100		10		100
Construction	27.4	37.5	10	90	20			100	25			100	26			100	40	5		100
Trade	1.5	1	90	10														25	90	10
Accommodation and Food Services	0.5	0.5		100									0.5	2		100		5		
Transportation	3.5	2		100	1			100	0.5			100	1	1		100	0.5	25		100
Banking-Financing	1	1		100	1	5		100	0.5	5		100	0.5	5		100	0.5	5		100
Real Estate	4.7	1		100	2	20		100	1.5	20		100	4	30		100	3.5	10		100
Public Administration	1.4	1		100	1			100	1			100	1			100	0.5			100

Table A. 7
Assumptions on distribution of spending (%) for the development (C) and operation (O&M) of the storage technologies, divided into imported (I) and local (L) investments.

Storage	Pumped Hydro				Li-Ion batteries			
Sector of economic activity	C	O&M	I	L	C	O&M	I	L
Agriculture								
Forestry								
Mining								
Food Manufacturing								
Textile								
Wood and Paper								
Chemical and Plastic Products								
Metal Products	2		100		25		100	
Machinery and Equipment	23	35	95	5	10	70	100	
Energy								
Construction	65	15		100	15		100	
Trade					45		90	10
Accommodation and Food Services								
Transportation	1			100				
Banking-Financing	1.5	20		100	1.5	10		100
Real Estate	6.5	30		100	3	20		100
Public Administration	1			100	0.5			100

Table A. 8
Assumptions on distribution of spending (%) for the development (C) and operation (O&M) of the infrastructure upgrades, divided into imported (I) and local (L) investments.

Infrastructure	Gas infrastructure				Public transport				Private transport			
Sector of economic activity	C	O&M	I	L	C	O&M	I	L	C	O&M	I	L
Agriculture									3		90	10
Forestry												
Mining												
Food Manufacturing									1			100
Textile												
Wood and Paper												
Chemical and Plastic Products									5		100	
Metal Products												
Machinery and Equipment	73	70	95	5	6.2	70	95	5		79.5	95	5
Energy									1.3	0.5		100
Construction	10	10		100	25	10		100	6			100
Trade					52.5	10	90	10	81.2	19	90	10
Accommodation and Food Services	1			100	0.5			100				
Transportation	10		50	50	10.3			100				
Banking-Financing	1	10		100	2	8		100	2	1		100
Real Estate	4.5	10		100	3	2		100				
Public Administration	1			100	0.5			100	1			100

Table A. 9
Annual spending associated with investments and households' consumption under the REF Scenario by sector of economic activity for the period 2020–2030 (in million Euros).

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Agriculture	0.7	1.1	1.5	1.9	2.4	2.8	3.2	3.7	3.8	3.8	3.9
Forestry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Food Manufacturing	2.4	3.8	5.1	6.4	7.8	9.3	10.7	12.2	12.5	12.8	13.1
Textile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood and Paper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chemical and Plastic Products	9.0	8.5	8.7	8.5	9.5	9.9	10.0	10.1	10.3	10.4	10.5
Metal Products	4.5	4.2	4.3	4.2	4.7	5.0	5.0	5.1	5.2	5.2	5.3
Machinery and Equipment	14.1	17.4	16.8	16.4	16.1	16.0	15.6	15.3	16.0	16.2	16.2
Energy	448.4	475.2	498.1	516.5	531.7	545.2	566.1	586.9	604.1	625.8	638.3
Construction	119.5	143.5	162.6	175.5	197.7	215.7	233.6	252.5	266.8	273.1	276.3
Trade	51.7	65.1	78.6	92.2	105.8	119.5	133.0	147.3	150.6	153.9	157.2
Accommodation and Food Services	0.7	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.5
Transportation	5.2	10.0	11.1	12.4	14.3	15.4	16.8	18.0	18.3	19.4	18.2
Banking-Financing	16.4	20.6	24.4	27.9	31.5	35.1	38.7	42.5	43.9	44.8	45.7
Real Estate	6.1	9.8	11.6	12.1	13.7	14.5	15.6	16.7	18.2	18.6	18.6
Public Administration	3.3	4.9	5.8	6.7	7.8	8.7	9.7	10.7	11.0	11.3	11.5
Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Health	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Services	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A. 10

Annual spending associated with investments and households' consumption under the EE Scenario by sector of economic activity for the period 2020–2030 (in million Euros).

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Agriculture	0.7	1.1	1.4	1.7	2.0	2.3	2.7	3.1	3.1	3.1	3.1
Forestry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Food Manufacturing	2.4	3.5	4.5	5.5	6.6	7.7	8.8	10.3	10.2	10.2	10.2
Textile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood and Paper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chemical and Plastic Products	16.6	16.6	16.6	16.6	16.6	17.2	17.6	17.8	18.0	18.1	18.6
Metal Products	8.3	8.3	8.3	8.3	8.3	8.6	8.8	8.9	9.0	9.0	9.3
Machinery and Equipment	18.0	21.6	20.9	20.7	19.9	20.2	20.3	20.3	21.0	20.7	21.0
Energy	448.0	473.3	493.7	510.9	523.9	534.1	551.7	568.8	583.4	603.1	614.2
Construction	156.8	185.6	206.6	223.4	243.7	263.3	282.7	302.3	321.0	336.8	345.1
Trade	54.5	65.6	76.7	87.9	99.0	110.5	122.3	136.5	139.7	140.6	141.5
Accommodation and Food Services	0.7	1.2	1.3	1.5	1.7	1.9	2.1	2.2	2.5	2.7	2.7
Transportation	6.1	13.0	16.3	19.8	23.8	27.1	30.6	33.9	40.1	43.0	44.2
Banking-Financing	16.5	20.3	23.7	26.8	30.0	33.0	36.2	40.0	42.2	43.0	43.3
Real Estate	6.4	10.7	13.1	14.3	16.5	17.6	18.7	19.8	22.0	24.1	24.7
Public Administration	3.3	4.8	5.6	6.4	7.5	8.2	9.0	10.0	10.3	10.5	10.6
Education	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Health	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Services	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

References

[1] n.d. UNFCCC, What is the Paris agreement? https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement. (Accessed 23 October 2019).

[2] United Nations, Sustainable Development Goals. http://www.un.org/sustainabledevelopment/sustainable-development-goals/, 2016. (Accessed 23 March 2016).

[3] International Energy Agency, World Energy Outlook 2018, OECD, 2018, https://doi.org/10.1787/weo-2018-en.

[4] Republic of Cyprus, Cyprus' Integrated National Energy and Climate Plan, Nicosia, Cyprus, 2020. http://www.mcit.gov.cy/mcit/EnergySe.nsf/All/0FC95262EE5B4273C22582FE003158A8/$file/INECP_v.1.1-2001201002%20SUBMITTED.pdf.

[5] TSO Cyprus, RES Penetration, 2019. https://www.dsm.org.cy/en//cyprus-electrical-system/electrical-energy-generation/energy-generation-records/yearly/res-penetration. (Accessed 29 January 2019).

[6] European Union, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC, 2009. https://eur-lex.europa.eu/eli/dir/2009/28/oj. (Accessed 16 October 2019).

[7] European Union, DIRECTIVE (EU) 2018/2001 of the EUROPEAN PARLIAMENT and of the COUNCIL of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources, 2018. https://eur-lex.europa.eu/eli/dir/2018/2001/oj. (Accessed 16 October 2019).

[8] H.G. Huntington, J.P. Weyant, J.L. Sweeney, Modeling for insights, not numbers: the experiences of the energy modeling forum, Omega 10 (1982) 449–462, https://doi.org/10.1016/0305-0483(82)90002-0.

[9] A. Herbst, F.A. Toro, F. Reitze, E. Jochem, Introduction to energy systems modelling, Swiss J. Econ. Stat. SJES. 148 (2012) 111–135.

[10] M. Gargiulo, B.Ó. Gallachóir, Long-term energy models: principles, characteristics, focus, and limitations, Wiley Interdiscip. Rev. Energy Environ. 2 (2013) 158–177, https://doi.org/10.1002/wene.62.

[11] A. Chiodi, M. Gargiulo, F. Rogan, J.P. Deane, D. Lavigne, U.K. Rout, B.P. Ó Gallachóir, Modelling the impacts of challenging 2050 European climate mitigation targets on Ireland's energy system, Energy Pol. 53 (2013) 169–189, https://doi.org/10.1016/j.enpol.2012.10.045.

[12] R. Kannan, H. Turton, A long-term electricity dispatch model with the TIMES framework, Environ. Model. Assess. 18 (2012) 325–343, https://doi.org/10.1007/s10666-012-9346-y.

[13] C. Taliotis, A. Shivakumar, E. Ramos, M. Howells, D. Mentis, V. Sridharan, O. Broad, L. Mofor, An indicative analysis of investment opportunities in the African electricity supply sector — using TEMBA (The Electricity Model Base for Africa), Energy Sustain. Dev. 31 (2016) 50–66, https://doi.org/10.1016/j.esd.2015.12.001.

[14] T.H.Y. Føyn, K. Karlsson, O. Balyk, P.E. Grohnheit, A global renewable energy system: a modelling exercise in ETSAP/TIAM, Appl. Energy 88 (2011) 526–534, https://doi.org/10.1016/j.apenergy.2010.05.003.

[15] J. Hörsch, F. Hofmann, D. Schlachtberger, T. Brown, PyPSA-Eur: an open optimisation model of the European transmission system, Energy Strategy Rev 22 (2018) 207–215, https://doi.org/10.1016/j.esr.2018.08.012.

[16] Y.Y. Rady, M.V. Rocco, M.A. Serag-Eldin, E. Colombo, Modelling for power generation sector in developing countries: case of Egypt, Energy 165 (2018) 198–209, https://doi.org/10.1016/j.energy.2018.09.089.

[17] A. Dhakouani, F. Gardumi, E. Znouda, C. Bouden, M. Howells, Long-term optimisation model of the Tunisian power system, Energy 141 (2017) 550–562, https://doi.org/10.1016/j.energy.2017.09.093.

[18] A. Yushchenko, M.K. Patel, Contributing to a green energy economy? A macroeconomic analysis of an energy efficiency program operated by a Swiss utility, Appl. Energy 179 (2016) 1304–1320.

[19] M. Kamidelivand, C. Cahill, M. Llop, F. Rogan, B. O'Gallachoir, A comparative analysis of substituting imported gas and coal for electricity with renewables – an input-output simulation, Sustain. Energy Technol. Assess. 30 (2018) 1–10, https://doi.org/10.1016/j.seta.2018.08.003.

[20] K. Stadler, R. Wood, T. Bulavskaya, C.-J. Södersten, M. Simas, S. Schmidt, A. Usubiaga, J. Acosta-Fernández, J. Kuenen, M. Bruckner, S. Giljum, S. Lutter, S. Merciai, J.H. Schmidt, M.C. Theurl, C. Plutzar, T. Kastner, N. Eisenmenger, K.-H. Erb, A. de Koning, A. Tukker, EXIOBASE 3: developing a time series of detailed environmentally extended multi-regional input-output tables, J. Ind. Ecol. 22 (2018) 502–515, https://doi.org/10.1111/jiec.12715.

[21] Z. Guevara, T. Domingos, The multi-factor energy input–output model, Energy Econ. 61 (2017) 261–269, https://doi.org/10.1016/j.eneco.2016.11.020.

[22] CERI, Development of a Hybrid Energy Input-Output Model of the Canadian Economy, Canadian Energy Research Institute, Canada, 2016. https://goo.gl/TnhA7W.

[23] A.L. de Carvalho, C.H. Antunes, F. Freire, C.O. Henriques, A hybrid input–output multi-objective model to assess economic–energy–environment trade-offs in Brazil, Energy 82 (2015) 769–785, https://doi.org/10.1016/j.energy.2015.01.089.

[24] P. Fragkos, L. Paroussos, Employment creation in EU related to renewables expansion, Appl. Energy 230 (2018) 935–945, https://doi.org/10.1016/j.apenergy.2018.09.032.

[25] V. Lekavičius, A. Galinis, V. Miškinis, Long-term economic impacts of energy development scenarios: the role of domestic electricity generation, Appl. Energy 253 (2019) 113527, https://doi.org/10.1016/j.apenergy.2019.113527.

[26] U. Lehr, C. Lutz, D. Edler, Green jobs? Economic impacts of renewable energy in Germany, Energy Pol. 47 (2012) 358–364, https://doi.org/10.1016/j.enpol.2012.04.076.

[27] C. Andini, R. Cabral, J.E. Santos, The macroeconomic impact of renewable electricity power generation projects, Renew. Energy 131 (2019) 1047–1059, https://doi.org/10.1016/j.renene.2018.07.097.

[28] R.J. Lambert, P.P. Silva, The challenges of determining the employment effects of renewable energy, Renew. Sustain. Energy Rev. 16 (2012) 4667–4674, https://doi.org/10.1016/j.rser.2012.03.072.

[29] H. Garrett-Peltier, Green versus brown: comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model, Econ. Modell. 61 (2017) 439–447, https://doi.org/10.1016/j.econmod.2016.11.012.

[30] M.I. Howells, J.A. Laitner, Industrial efficiency as an economic development strategy for South Africa, in: American Council for an Energy-Efficient Economy (ACEEE), 2005.

[31] M. Howells, K. Jeong, L. Langlois, M.K. Lee, K.-Y. Nam, H.H. Rogner, Incorporating macroeconomic feedback into an energy systems model using an IO approach: evaluating the rebound effect in the Korean electricity system, Energy Pol. 38 (2010) 2700–2728, https://doi.org/10.1016/j.enpol.2008.10.054.

[32] B. Merven, C. Arndt, H. Winkler, UNU-WIDER, The Development of a Linked Modelling Framework for Analysing the Socioeconomic Impacts of Energy and Climate Policies in South Africa, 40th ed., UNU-WIDER, 2017 https://doi.org/10.35188/UNU-WIDER/2017/264-9.

[33] A. Krook-Riekkola, C. Berg, E.O. Ahlgren, P. Söderholm, Challenges in top-down and bottom-up soft-linking: lessons from linking a Swedish energy system model with a CGE model, Energy 141 (2017) 803–817, https://doi.org/10.1016/j.energy.2017.09.107.

[34] K. Siala, C. de la Rúa, Y. Lechón, T. Hamacher, Towards a sustainable European energy system: linking optimization models with multi-regional input-output analysis, Energy Strategy Rev 26 (2019) 100391, https://doi.org/10.1016/j.esr.2019.100391.

[35] V.M. Rocco, Y. Rady, E. Colombo, Soft-linking bottom-up energy models with top-down input-output models to assess the environmental impact of future energy scenarios, Modell., Meas. Control, C 79 (2018) 103–110, https://doi.org/10.18280/mmc_c.790307.

[36] J. Weyant, Some contributions of integrated assessment models of global climate change, Rev. Environ. Econ. Pol. 11 (2017) 115–137, https://doi.org/10.1093/reep/rew018.

[37] K. Calvin, P. Patel, L. Clarke, G. Asrar, B. Bond-Lamberty, R.Y. Cui, A.D. Vittorio, K. Dorheim, J. Edmonds, C. Hartin, M. Hejazi, R. Horowitz, G. Iyer, P. Kyle, S. Kim, R. Link, H. McJeon, S.J. Smith, A. Snyder, S. Waldhoff, M. Wise, GCAM v5.1: representing the linkages between energy, water, land, climate, and economic systems, Geosci. Model Dev. (GMD) 12 (2019) 677–698, https://doi.org/10.5194/gmd-12-677-2019.

[38] S. Fujimori, T. Masui, Y. Matsuoka, AIM/CGE V2.0 model formula, in: S. Fujimori, M. Kainuma, T. Masui (Eds.), Post-2020 Clim. Action Glob. Asian Perspect., Springer, Singapore, 2017, pp. 201–303, https://doi.org/10.1007/978-981-10-3869-3_12.

[39] R. Loulou, M. Labriet, ETSAP-TIAM: the TIMES integrated assessment model Part I: model structure, Comput. Manag. Sci. 5 (2008) 7–40, https://doi.org/10.1007/s10287-007-0046-z.

[40] D. Huppmann, M. Gidden, O. Fricko, P. Kolp, C. Orthofer, M. Pimmer, N. Kushin, A. Vinca, A. Mastrucci, K. Riahi, V. Krey, The MESSAGEix Integrated Assessment Model and the ix modeling platform (ixmp): an open framework for integrated and cross-cutting analysis of energy, climate, the environment, and sustainable development, Environ. Model. Software 112 (2019) 143–156, https://doi.org/10.1016/j.envsoft.2018.11.012.

[41] V. Bosetti, C. Carraro, M. Galeotti, E. Massetti, M. Tavoni, WITCH A World Induced Technical Change Hybrid Model, 2006. https://www.unive.it/pag/fileadmin/user_upload/dipartimenti/economia/doc/Pubblicazioni_scientifiche/working_papers/2006/WP_DSE_Carraro_46_06.pdf.

[42] F. Ackerman, S.J. DeCanio, R.B. Howarth, K. Sheeran, Limitations of integrated assessment models of climate change, Climatic Change 95 (2009) 297–315, https://doi.org/10.1007/s10584-009-9570-x.

[43] D.L. McCollum, C. Wilson, H. Pettifor, K. Ramea, V. Krey, K. Riahi, C. Bertram, Z. Lin, O.Y. Edelenbosch, S. Fujisawa, Improving the behavioral realism of global integrated assessment models: an application to consumers' vehicle choices, Transport. Res. Part Transp. Environ. 55 (2017) 322–342, https://doi.org/10.1016/j.trd.2016.04.003.

[44] R.C. Pietzcker, F. Ueckerdt, S. Carrara, H.S. de Boer, J. Després, S. Fujimori, N. Johnson, A. Kitous, Y. Scholz, P. Sullivan, G. Luderer, System integration of wind and solar power in integrated assessment models: a cross-model evaluation of new approaches, Energy Econ. 64 (2017) 583–599, https://doi.org/10.1016/j.eneco.2016.11.018.

[45] M. Howells, H. Rogner, N. Strachan, C. Heaps, H. Huntington, S. Kypreos, A. Hughes, S. Silveira, J. DeCarolis, M. Bazillian, A. Roehrl, OSeMOSYS: the open source energy modeling system, Energy Pol. 39 (2011) 5850–5870, https://doi.org/10.1016/j.enpol.2011.06.033.

[46] T. Zachariadis, E. Taibi, Exploring drivers of energy demand in Cyprus – scenarios and policy options, Energy Pol. 86 (2015) 166–175, https://doi.org/10.1016/j.enpol.2015.07.003.

[47] Y. Vougiouklakis, B. Struss, T. Zachariadis, A. Michopoulos, An Energy Efficiency Strategy for Cyprus up to 2020 , 2030 and 2050, 2017. Deliverable 1.2. Project funded by the European Commission Structural Reform Support Service under grant agreement SRSS/S2016/002 and by the German Federal Ministry of Economy, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

[48] C. Sotiriou, A. Michopoulos, T. Zachariadis, On the cost-effectiveness of national economy-wide greenhouse gas emissions abatement measures, Energy Pol. 128 (2019) 519–529, https://doi.org/10.1016/j.enpol.2019.01.028.

[49] IRENA, Renewable Energy Roadmap for the Republic of Cyprus, 2015. Abu Dhabi, http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=501.

[50] V. Sridharan, O. Broad, A. Shivakumar, M. Howells, B. Boehlert, D.G. Groves, H.-H. Rogner, C. Taliotis, J.E. Neumann, K.M. Strzepek, R. Lempert, B. Joyce, A. Huber-Lee, R. Cervigni, Resilience of the Eastern African electricity sector to climate driven changes in hydropower generation, Nat. Commun. 10 (2019) 302, https://doi.org/10.1038/s41467-018-08275-7.

[51] F. Gardumi, A. Shivakumar, R. Morrison, C. Taliotis, O. Broad, A. Beltramo, V. Sridharan, M. Howells, J. Hörsch, T. Niet, Y. Almulla, E. Ramos, T. Burandt, G. P. Balderrama, G.N. Pinto de Moura, E. Zepeda, T. Alfstad, From the development of an open-source energy modelling tool to its application and the creation of communities of practice: the example of OSeMOSYS, Energy Strategy Rev 20 (2018) 209–228, https://doi.org/10.1016/j.esr.2018.03.005.

[52] J. Peña Balderrama, T. Alfstad, C. Taliotis, M. Hesamzadeh, M. Howells, J.G. Peña Balderrama, T. Alfstad, C. Taliotis, M.R. Hesamzadeh, M. Howells, A sketch of Bolivia's potential low-carbon power system configurations. The case of applying carbon taxation and lowering financing costs, Energies 11 (2018) 2738, https://doi.org/10.3390/en11102738.

[53] C. Taliotis, H. Rogner, S. Ressl, M. Howells, F. Gardumi, Natural gas in Cyprus: the need for consolidated planning, Energy Pol. 107 (2017) 197–209, https://doi.org/10.1016/j.enpol.2017.04.047.

[54] M. Welsch, P. Deane, M. Howells, B. Ó Gallachóir, F. Rogan, M. Bazilian, H.-H. Rogner, Incorporating flexibility requirements into long-term energy system models – a case study on high levels of renewable electricity penetration in Ireland, Appl. Energy 135 (2014) 600–615, https://doi.org/10.1016/j.apenergy.2014.08.072.

[55] European Union, EU Reference Scenario 2016: Energy, Transport and GHG Emissions - Trends to 2050, Publications Office of the European Union, Luxembourg, 2016.

[56] Financial Mirror, Cyprus: parliament to summon energy minister over EuroAsia debacle. http://www.financialmirror.com/news-details.php?nid=37720, 2019. (Accessed 17 October 2019).

[57] ENTSO-E, TYNDP 2018 - Europe's Network Development Plan to 2025, 2030 and 2040, 2018. https://tyndp.entsoe.eu/tyndp2018/. (Accessed 21 March 2019).

[58] M. Lambrinos, Long Term Strategies to Reduce Car Dependency: the Nicosia Tram – Findings of the Feasibility Study, 2018. https://www.eltis.org/sites/default/files/side_session_lambrinos.pdf.

[59] R.E. Miller, P.D. Blair, Input–Output Analysis: Foundations and Extensions, second ed., Cambridge University Press, 2009.

[60] E. Giannakis, A. Bruggeman, Economic crisis and regional resilience: evidence from Greece: economic crisis and regional resilience, Pap. Reg. Sci. 96 (2017) 451–476, https://doi.org/10.1111/pirs.12206.

[61] L. Zhang, Q. Hu, F. Zhang, Input-output modeling for urban energy consumption in beijing: dynamics and comparison, PloS One 9 (2014), e89850, https://doi.org/10.1371/journal.pone.0089850.

[62] E. Giannakis, J. Kushta, D. Giannadaki, G.K. Georgiou, A. Bruggeman, J. Lelieveld, Exploring the economy-wide effects of agriculture on air quality and health: evidence from Europe, Sci. Total Environ. 663 (2019) 889–900, https://doi.org/10.1016/j.scitotenv.2019.01.410.

[63] C.R. Wymer, Continuous-time models in macroeconomics: specification and estimation, in: G. Gandolfo (Ed.), Contin.-Time Econom. Theory Appl., Springer Netherlands, Dordrecht, 1993, pp. 35–79, https://doi.org/10.1007/978-94-011-1542-1_3.

[64] O. Dejuan, Forecasting energy demand through a dynamic input-output model, Econ. Bus. Lett. 4 (2015) 108–115, https://doi.org/10.17811/ebl.4.3.2015.108-115.

[65] L. Pan, P. Liu, Z. Li, Y. Wang, A dynamic input–output method for energy system modeling and analysis, Chem. Eng. Res. Des. 131 (2018) 183–192, https://doi.org/10.1016/j.cherd.2017.11.032.

[66] X. Zhang, Z. Li, L. Ma, C. Chong, W. Ni, Forecasting the energy embodied in construction services based on a combination of static and dynamic hybrid input-output models, Energies 12 (2019) 300, https://doi.org/10.3390/en12020300.

[67] J. Song, W. Yang, Y. Higano, X. Wang, Dynamic integrated assessment of bioenergy technologies for energy production utilizing agricultural residues: an input–output approach, Appl. Energy 158 (2015) 178–189, https://doi.org/10.1016/j.apenergy.2015.08.030.

[68] J.B. Cruz, R.R. Tan, A.B. Culaba, J.-A. Ballacillo, A dynamic input–output model for nascent bioenergy supply chains, Appl. Energy 86 (2009) S86–S94, https://doi.org/10.1016/j.apenergy.2009.04.007.

[69] I. Dobos, P. Tallos, A dynamic input-output model with renewable resources, Cent. Eur. J. Oper. Res. 21 (2013) 295–305, https://doi.org/10.1007/s10100-011-0235-2.

[70] W. Leontief, Studies in the Structure of the American Economy: Theoretical and Empirical Explorations in Input-Output Analysis, Oxford University Press, 1953.

[71] T.G. Johnson, A dynamic input-output model for small regions, Rev. Reg. Stud. 16 (1986) 14–23.

[72] J.M. Bryden, S. Efstratoglou, T. Ferenczi, K. Knickel, T. Johnson, K. Refsgaard, K. J. Thomson, Towards Sustainable Rural Regions in Europe Exploring Inter-relationships between Rural Policies, Farming, Environment, Demographics, Regional Economies and Quality of Life Using System Dynamics, first ed., Routledge, 2011.

[73] S. Alva-Lizarraga, T.G. Johnson, A dynamic demand driven, supply constrained input output approach to modeling economic impacts of water disruption events, in: Minnesota Bloomington (Ed.), 2012, pp. 159–177.

[74] E. Giannakis, S. Efstratoglou, D. Psaltopoulos, Modelling the impacts of alternative CAP scenarios through a system dynamics approach 15 (2014) 21.

[75] S. Alva-Lizarraga, K. Refsgaard, T.G. Johnson, Comparative analysis of agriculture and rural policies in Västerbotten and Hordaland using the POMMARD-model, Food Econ. - Acta Agric. Scand. Sect. C 8 (2011) 142–160, https://doi.org/10.1080/16507541.2011.607589.

[76] T.G. Johnson, The dynamics of input-output introduction, in: Microcomput. Based Input-Output Model. Appl. Econ. Dev., Westview Press, 1993.

[77] Eurostat, Symmetric Input-Output Table at Basic Prices, 2018. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=naio_10_cp1700&lang=en. (Accessed 25 September 2019).

[78] C. Tourkolias, S. Mirasgedis, D. Damigos, D. Diakoulaki, Employment benefits of electricity generation: a comparative assessment of lignite and natural gas power plants in Greece, Energy Pol. 37 (2009) 4155–4166, https://doi.org/10.1016/j.enpol.2009.05.015.

[79] M. Markaki, A. Belegri-Roboli, P. Michaelides, S. Mirasgedis, D.P. Lalas, The impact of clean energy investments on the Greek economy: an input–output analysis (2010–2020), Energy Pol. 57 (2013) 263–275, https://doi.org/10.1016/j.enpol.2013.01.047.

[80] European Commission, Energy efficiency first: Commission welcomes agreement, Eur. Comm. - Press Corner (2018). https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_18_3997. (Accessed 29 November 2019).

[81] E. Giannakis, D. Serghides, D. Dimitriou, G. Zittis, Land transport CO2 emissions and climate change: evidence from Cyprus, Int. J. Sustain. Energy (2020).

[82] B. Peng, H. Du, S. Ma, Y. Fan, D.C. Broadstock, Urban passenger transport energy saving and emission reduction potential: a case study for Tianjin, China, Energy Convers. Manag. 102 (2015) 4–16, https://doi.org/10.1016/j.enconman.2015.01.017.

[83] J. Zawieska, J. Pieriegud, Smart city as a tool for sustainable mobility and transport decarbonisation, Transport Pol. 63 (2018) 39–50, https://doi.org/10.1016/j.tranpol.2017.11.004.

[84] G. Bueno, Analysis of scenarios for the reduction of energy consumption and GHG emissions in transport in the Basque Country, Renew. Sustain. Energy Rev. 16 (2012) 1988–1998, https://doi.org/10.1016/j.rser.2012.01.004.

[85] M. Ram, A. Aghahosseini, C. Breyer, Job creation during the global energy transition towards 100% renewable power system by 2050, Technol. Forecast. Soc. Change (2019) 119682, https://doi.org/10.1016/j.techfore.2019.06.008.

[86] U. Lehr, J. Nitsch, M. Kratzat, C. Lutz, D. Edler, Renewable energy and employment in Germany, Energy Pol. 36 (2008) 108–117, https://doi.org/10.1016/j.enpol.2007.09.004.

[87] M. Frondel, N. Ritter, C.M. Schmidt, C. Vance, Economic impacts from the promotion of renewable energy technologies: the German experience, Energy Pol. 38 (2010) 4048–4056, https://doi.org/10.1016/j.enpol.2010.03.029.