TIMES_PT: Integrated Energy System Modeling

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Abstract. The complexity of energy systems operation and the necessity to design secure and reliable systems, compatible with greenhouse gas (GHG) mitigation goals, have justified the development of energy models. They are capable of representing detailed energy systems (technical and economic characteristics) and the interconnections between supply and consumer sectors, assessing energy consumption and production pathways. Energy modeling tools have been widely used to help energy planners to assess energy systems; from different approaches as the impacts of alternative energy and environmental policies, or the competitiveness of different energy technologies. This paper provides an overview of the energy-environmental-economic modeling tool TIMES_PT, the last generation of the IEA/ETSAP integrated technological energy models, with a focus on its structure, functioning, and calibration for the case of the Portuguese energy system. Applications cases of TIMES_PT, namely for the design of low carbon scenarios for the long-term, are presented. Innovative developments on linking TIMES_PT with a macro-economic model (GEM-E3_PT) and the assessment of non-technological variables are also described.

Keywords: TIMES_PT, Energy modeling, Low carbon scenarios, Energy system, Portugal.

1 Introduction

Since the 70's energy models have been widely used to support energy planning. In that time, models were used to understand the implications of an oil embargo in energy supply security. More recently, climate change and the need to reduce GHG emissions has become one of the main issues in energy planning [1]. Energy models outline how the transition to a more secure and decarbonized energy system can be achieved, identifying the competiveness of energy technologies and giving insights about the most cost-effective energy and environmental policies.

One of the major energy optimization tools used are the bottom-up technology MARKAL (MARKet ALlocation) and TIMES (The Integrated MARKAL-EFOM System) models. These models are used by more than 100 institutions and countries and supported under the ETSAP/IEA.

TIMES_PT [2] is a dynamic linear optimization peer-reviewed model corresponding to the implementation for Portugal (PT) of the technological based model generator TIMES [3]. TIMES_PT represents, in detail, the entire chain of the Portuguese energy system from energy supply, including energy imports and production, to transformation, distribution, as well as end-uses consumption and energy trade, considering different energy carriers.

The objective of the TIMES model is the satisfaction of an exogenous energy service demand at the minimum total system cost over the entire planning horizon (*i.e.* the optimal energy-technology pathways). Thus, supported by a database of more than 2000 technologies, the model determines the optimal mix of technologies and fuels at each period, the associated emissions and trading activities.

The TIMES_PT model has been extensively used in several national and international studies and its technological database has been continuously updated and validated by national stakeholders and international literature. TIMES_PT, as other TIMES models, is written in General Algebraic Modeling System (GAMS) language [4].

This paper aims to provide an overview of the energy-environmental-economic modeling tool TIMES_PT, focused on its general features and main components (Section 2), and applications cases (Section 3). Section 4 of the paper concludes and presents innovative features under development.

2 General characteristics of TIMES_PT

As abovementioned, TIMES_PT is a peer-reviewed linear programming optimization bottom-up technology model. This section describes the main features of the model as well as its specific characteristics that have been improved or updated in the last years. The TIMES_PT model formulates a single, overall mathematical programming (optimization) problem that covers the energy supply system, according to equation 1 [3]:

$$NPV = \sum_{r=1}^{R} \sum_{y=TEARS} \left(1 + d_{r,y}\right)^{REFYR-y} * ANNCOST(r,y) \tag{1}$$

Where the *NPV* is the net present value of the total costs, *ANNCOST* is the total annual cost, *d* is the general discount rate, *r* is the region, *y* is the years, *REFYR* is the reference year for discounting and *YEARS* is the set of years for which there are costs.

TIMES_PT model uses the partial equilibrium version of TIMES, where the demand for energy services depends endogenously on own price elasticity. The model is usually run to deliver information on 5-year periods.

TIMES_PT represents the energy system of PT and its possible long-term developments. The actual system encompasses all the steps from primary resources in place to the supply of the energy services demanded by energy consumers, through the chain of processes which transform, transport, distribute and convert energy into services [5]. Figure 1 presents an overall view of the structure of the energy system modeled in TIMES_PT.

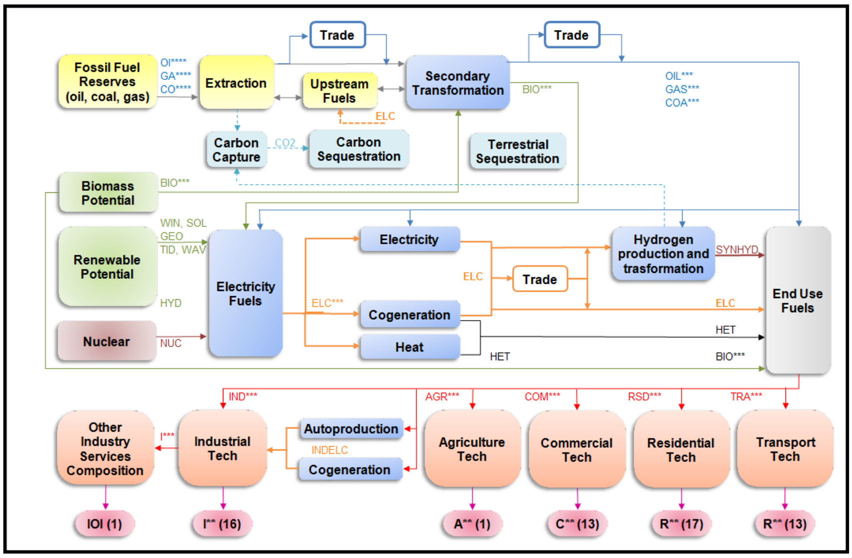

Fig. 1. High-level Reference Energy System of a single region model [5].

Each element in the network is characterized by several input parameters. The TIMES_PT technological database has more than two thousands of existing and future energy related technologies. Technologies are described by means of technical data (*e.g*. capacity, efficiency), environmental emission coefficients (e.g. CO_2, SO_x, NO_x), and economic values (*e.g*. capital cost, date of commercialization). Possible future developments of the system are driven by reference demands for energy services (*e.g*. commercial lighting, residential space heating, air conditioning, mobility and many others), and the supply curves of the resources (*e.g*. amount available at each price level) [6].

Several assets distinguish TIMES_PT from European aggregated models like PET (Pan European TIMES [5]): 1) the information on the majority of technological database is validated by national energy and industry related stakeholders reflecting specific national characteristics; 2) the Portuguese energy system and current policies and expectations are fully detailed; making TIMES_PT a well-established tool for Portugal. There are also a few general differences for other European national models (*e.g*. [7]) like 1) the inclusion of air pollutants like nitrogen oxides, sulfur dioxides and particulate matter and 2) the disaggregation of the national emissions as included/not included in the EU-ETS.

2.1 Time horizon and Time slices

TIMES_PT is a long-term model designed to explore the development of the PT energy system till 2050 through the computation of projections for the period 2005-2050. While in its original version, developed within NEEDS project [8], the model was calibrated to 2000 data, the current version is fully recalibrated to 2005 data. For the year 2010 the model results are partly validated to national statistics [9-10] and taking into account national short-term expectations (*e.g.* installed capacity).

Annual flows of energy consumption and production are split by season - spring, summer, fall, winter; and daily load profiles - night, day and peak, considering the Portuguese electricity demand profile.

2.2 Representation of the primary supply sectors

The supply side of the TIMES_PT model represents the primary energy sector: resource extraction or imports, processing and transport to transformation – plants and refineries, coke ovens and bio-conversion, etc. – followed by transport and distribution of the final energy products.

Each primary resource is modeled independently, and represented by a linearized stepwise supply function. The number of steps approximating each curve depends on the resource and on the country reserves. The energy commodities are disaggregated to the level of detail of the extended national energy balances reported by [9].

2.3 Representation of the demand sectors

TIMES_PT model includes five main end-use sectors: Agriculture (AGR), Industry (IND), Services (SERV), Residential (RSD) and Transport (TRA).
The AGR sector is represented in a simplified way, and future energy demand is driven by the projection of the sectorial economic activity.

Regarding IND, TIMES_PT model breaks-out the national industrial sector in eleven sub-sectors: hollow and flat glass, high and lower quality paper, chemistry, cement, iron & steel, lime, other non-ferrous metals, other non-metallic minerals and other chemical. Each of them includes diverse manufacturing processes and is modeled according to its mass and energy balance.

The SERV sector represents several different economic sub sectors like offices, banks, hospitals, etc. However, due to the lack of data for PT on specific sub sectors energy consumption and equipment, this sector is modeled in an aggregated way, considering two types of SERV - large (>1000m^2) and small (<1000m^2). The SERV sector energy demand includes: space heating and cooling, water heating, cooking, lighting, refrigeration and other electric equipment.
RSD sector includes the same categories as the SERV, but improved disaggregation on electric equipment including cloth washing and drying machines and cloth washing, among others. The devices that supply warm water, space heating and cooling are broken out by building type as its need vary significantly – namely multi apartment building, single house in urban areas and single house in rural areas.

The TRA sector corresponds to the economic sector “transport services” and private mobility. The demand for TRA is first broken out by: road, rail, navigation and aviation. Road and rail transport are split between passenger and freight. The demand for road passengers’ transportation is further divided to short and long distance private car transport, urban busses, intercity busses and motorcycles. Passenger’s rail transport is further divided into urban metro transport and intercity train transport.

Freight transport is disaggregated into road transport by heavy and light trucks and intercity rail transport [11].

2.4 Energy Services Demand

Energy end-use demand is an exogenous model input, commonly generated according to the methodology presented in [12]. This energy services demand generation is supported by a top-down method for industry, services and agriculture and bottom-up calculation for buildings [13] and transport. The top-down method is mainly sustained by the sector value added growth, while the bottom-up method is more complex and depends on several drivers, namely the number and characteristics of the dwellings, occupancy rate and building area, transport typology, population, average travel km, among other parameters.

2.5 Renewable Energy Potential

For Portugal, the endogenous primary energy potential solely relates to renewable energy sources (RES) once there are not known endogenous fossil resources. For most resources the potential is given not only having in mind the technical potential but also possible deployment of technologies in the near future.

These technical economical potentials restrict the use and future deployment of each technology, limiting its capacity. Generally speaking, the 2020 figures are in line with the expectation presented in National Renewable Energy Action Plan [14], after that the potentials are a result of national stakeholders best guess and analysis (see [10]).

2.6 Primary Energy Prices

Primary energy prices definition is crucial for setting the boundaries of an energy system future development. Average primary energy import prices projections are annually updated based on the scenarios from [15]. The import costs until 2050 for the different types of liquid biofuels (*e.g.* bioethanol) and due to no best available information are linked to the oil energy price. Extraction costs for municipal solid wastes; biogas and sludge are originated from [16] The import costs for wood biomass are from [17] and endogenous forestry and wood waste biomass production from [18].

2.7 Technology costs and characteristics

The evolution of the costs of supply and demand technologies between 2010 and 2050, are dependent on the actual expectation in terms of development and implementation, and are crucial to evaluate the competitiveness of the technologies. The model combines the technical economic data with energy prices to dynamically calculate supply cost curves for year and energy demand category. The combination between supply cost curves defines the competitiveness of the technologies. Fig. 2 presents an example of a supply curve for cooling services buildings.

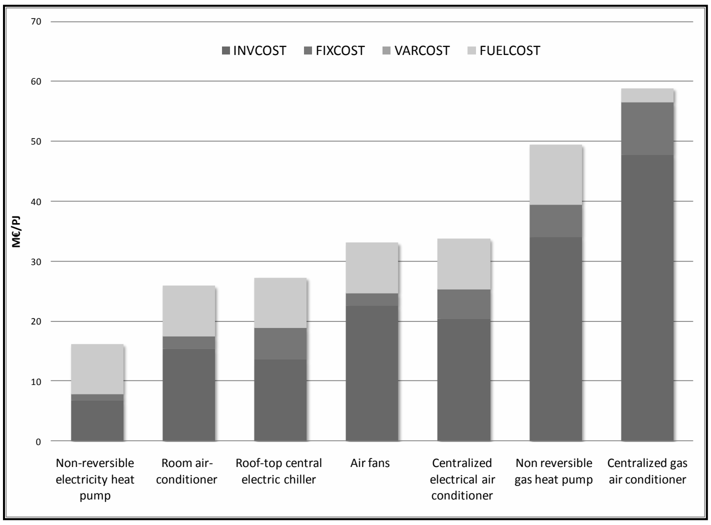

Fig. 2. Example of a supply curve for Services space cooling for 2030 ([11])

TIMES_PT technological database is frequently updated in order to reflect recent technological developments and national specificities. Table 1 presents, an example investment costs expectations for different RES and combined cycle natural gas power plants for Portugal.

Table 1. Wind, solar and combined cycle gas power plant investment cost perspectives

Years	Wind Onshore	Wind Offshore	PV Solar (Roof panel)	PV Solar (plant technology)	Combined cycle power
	Investment costs (M€$_{2000}$/GW)				
2010	1012	3140	2202	1966	385
2015	910	3140	1849	1793	381
2020	860	2747	1636	1587	377
2025	835	2551	1488	1443	377
2030	810	2355	1339	1299	377
2035	772	2159	1255	1217	370
2050	658	1570	1087	1054	363

Availability factors are also an important characteristic of a technology, especially for RES, influencing its future uses. For wind turbines and solar technologies the availability was defined based on the data from the production of the existing plants and parks in Portugal and Spain and national stakeholder's. The availability factors for hydro power plants are updated to an average Portuguese hydraulicity year.

3 Application cases

TIMES_PT model can be used for a wide set of policy and technological analysis associated with GHG and air pollutants emissions and energy related activities (*e.g.* Fig. 3). This section presents a sample of international and national projects where TIMES_PT has been used for different purposes.

- *COMET - Integrated infrastructure for CO_2 transport and storage in the west Mediterranean* - is a EU research project aiming at identifying and assessing the most cost effective infrastructure of CO_2 transport and geologic storage, that will be able to serve the West Mediterranean area (Spain, Portugal and Morocco), as well as the location, capacity and availability of potential CO_2 storage in geological formations.
- *HybCO_2 - Hybrid approaches to assess economic, environmental and technological impacts of long term low carbon scenarios: the Portuguese case* - is a national research project aiming to develop and implement two hybrid modeling tools to improve the cost-effectiveness assessment of energy/climate policy instruments.
- *Low Carbon RoadMap: Portugal 2050* - outlines how the transition to a low carbon economy in Portugal can be achieved, focusing on changes in the national energy system and evaluating its economic impact. The model was used to outline a -60% and -70% GHG decarbonization pathways (face to 1990) [10].
- *RoadMap for New Energy Technologies: Portugal 2010-2050* - Policy support project for assessing the competitiveness of national energy technologies, namely RES electricity generation and electric mobility technologies and its long-term impact in the PT energy system [12].

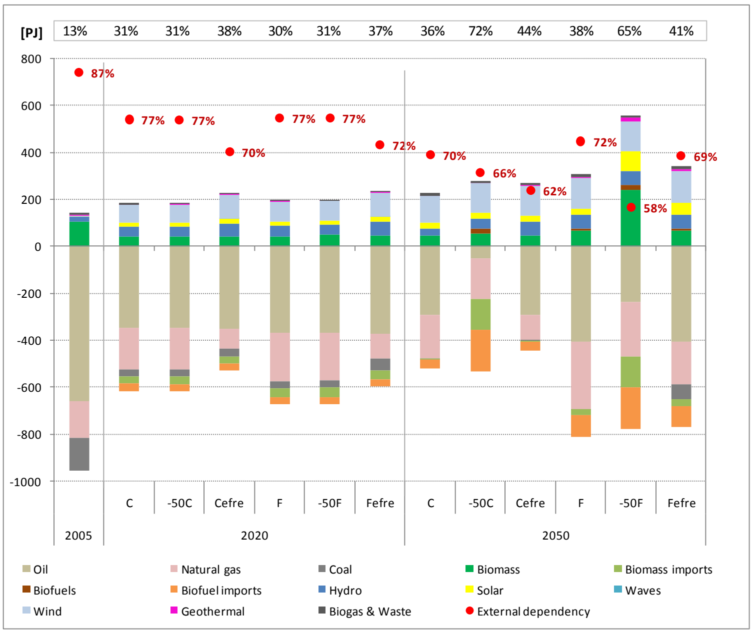

Fig. 3. Policy and technological analysis results from TIMES_PT (Primary energy consumption in Portugal in different emissions scenarios - % of RES (in the top rectangle)) [12]

4 Conclusion

The complexity of energy systems operation and the necessity to design secure and reliable systems, compatible with GHG mitigation goals, have justified the development of energy models. In this paper we describe the linear optimization model TIMES_PT that has been improved and updated to reflect the PT energy system and policies, and selected projects supported by it. Although technological based models have been useful to design future scenarios of energy systems, they present limitations that have been identified and researched.

Future work will advance energy modeling in two areas: a) by integrating non-technological features as the case of consumer behavior in residential sector, based on the knowledge behind energy consumption drivers; b) by linking with an economic computable general equilibrium (GEM-E3_PT) constituting a hybrid technology-economic platform (HybTEP), which overcome the state of the art absence of macro-economic feedbacks of different energy system pathways, namely the impact on gross domestic product or industry production, underestimating the costs of mitigation policies. These advancements will improve greatly the ability to model energy systems and reduce uncertainty for the medium to long term.

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