Energy 94 (2016) 124–137

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Towards post-2020 climate change regime: Analyses of various mitigation scenarios and contributions for Macedonia

Aleksandar Dedinec [a], Verica Taseska-Gjorgievska [a, *], Natasa Markovska [a], Teodora Obradovic Grncarovska [b], Neven Duic [c], Jordan Pop-Jordanov [a], Rubin Taleski [d]

[a] Research Center for Energy and Sustainable Development, Macedonian Academy of Sciences and Arts, Skopje, Republic of Macedonia
[b] Ministry of Environment and Physical Planning, Skopje, Republic of Macedonia
[c] University of Zagreb, FSB, Croatia
[d] Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of Macedonia

ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form
11 October 2015
Accepted 19 October 2015
Available online 21 November 2015

Keywords:
MARKAL model
Climate change mitigation
EU targets
Quantified emission limitation and reduction commitments

ABSTRACT

The goal of this paper is to showcase a modelling exercise, conducted for the Republic of Macedonia, a non-Annex I country under UNFCCC and a candidate for EU membership, by making use of MARKAL energy system model. Baseline Scenario and three groups of mitigation scenarios have been developed until 2050, reflecting different types of targets with different levels of ambition regarding CO_2 emissions reduction: (1) EU scenarios – end-year targets compared to 1990 level; (2) QELRC (Quantified Emission Limitation and Reduction Commitment) scenarios – a range of targets over the period 2021–28 and for each subsequent 8-year period, and (3) Baseline deviation scenarios – deviation compared to baseline emission level. The comparative assessment of mitigation scenarios, based on the cumulative emissions, cumulative total system costs and incremental specific reduction cost, has generated a basis for setting the national mitigation contributions and formulating the most appropriate national mitigation action plan.

1. Introduction

The trend towards low-carbon sustainability pathways that is in place worldwide, has made the climate change mitigation an overriding issue and increased the number of studies that analyse different climate change mitigation policies in national contexts. Most of them [1–3] have recognized the energy sector, particularly the electricity generation system, as the one with the highest potential for decarbonization. To achieve this, a switch to a low emission generation technologies is necessary, such as technologies based on RES (renewable energy sources) [4–6]. Also, some of the existing baseload technologies in a combination with CCS (carbon capture and storage) plant can contribute to CO_2 emissions reduction [7,8], but as shown in Ref. [9] such transformation may not be the most cost-effective option if the CCS has few utilization hours during the year. However, as shown in Refs. [10,11] the introduction of carbon price may encourage the technology switching even more, mostly towards RES. Besides the energy sector, the transport sector has shown to be also challenging for decarbonization [12–14], considering its persistent reliance on fossil fuels. The other sectors, such as waste and LULUCF, could also have a significant role in climate change mitigation actions, especially for the developing countries [15,16].

At political stage, as the on-going international negotiations on climate change are getting closer to their decisive stage (UNFCCC (United Nations Framework Convention on Climate Change) Conference of Parties 21 in 2015), it is becoming increasingly likely that for the first time in over 20 years of UN negotiations, all the nations of the world will be bound by a universal agreement on climate, containing commitments for the post-2020 period that are applicable to all countries, developed and developing alike. Toward this agreement, all UNFCCC Parties have been invited to initiate or intensify the domestic preparation for their intended nationally determined contributions [17].

Hence, in this paper, MARKAL energy system model is used to develop different mitigation scenarios for the Republic of Macedonia, which are accountable for the international context (universal

* Corresponding author.
E-mail addresses: dedinec@manu.edu.mk (A. Dedinec), verica@manu.edu.mk (V. Taseska-Gjorgievska), natasa@manu.edu.mk (N. Markovska), t.grncarovska@moepp.gov.mk (T. Obradovic Grncarovska), neven.duic@fsb.hr (N. Duic), jpj@manu.edu.mk (J. Pop-Jordanov), rubin.taleski@feit.ukim.edu.mk (R. Taleski).

http://dx.doi.org/10.1016/j.energy.2015.10.085
0360-5442/

climate agreement with commitments applicable also to developing countries) and the country's EU candidate status (requiring alignment with EU climate policy). MARKAL/TIMES family of models has proved as an effective planning tool, and has been widely used, not just in several major international and global applications, but also in dozens of developed and developing countries for national strategic planning (see e.g. Refs. [18–20]), including analysis of low-carbon policies such as increased utilization of RES [4], impact of CCS deployment [8], introduction of CO_2 taxes [11] and different decarbonisation pathways from the energy system perspective [21,22] and/or at sectoral level [23,24]. Also, it has been used as a tool for evaluation or the effects from the climate changes impact on energy demand [25], as well as the impact of environmental awareness campaigns on end-use energy consumption behaviour [26].

The mitigation scenarios developed in this paper reflect different types of targets, as well as different levels of ambition regarding CO_2 emissions reduction: (1) EU scenarios – end-year type mitigation targets imposing 20%–40% reductions in 2030, 30%–60% reduction in 2040 and 40%–80% reductions in 2050 compared to 1990 level as the base; (2) QELRC (Quantified Emission Limitation and Reduction Commitment) scenarios – a wide range of cumulative targets for 2021–28, ranging from +20% to −20% relative to 1990 level and, for each subsequent 8-year period, the targets are reduced for 10 percentage points; and (3) Baseline deviation scenarios – deviation compared to baseline emission level of −10% to −20% for 2020, −15% to −30% for 2028 and −30% to −60% for 2050. Ever-increasing carbon price is introduced beyond 2020 in all mitigation scenarios. The outputs of the modelling include final energy consumption by fuel, installed capacity of power plants, electricity generation and import, primary energy supply, CO_2 emissions and total cumulative discounted system costs (cumulative over period 2011–2050), calculated for the Baseline Scenario and all mitigation scenarios.

The paper concludes with a comparative assessment of the mitigation scenarios in terms of their cumulative total system costs, cumulative emissions and incremental specific reduction costs and based on that, it provides an indicative range for the national mitigation contribution.

2. Methodology

The modeling methodology employed, MARKAL/TIMES, is a consistent framework for analysis and assessment. The MARKAL/TIMES models produces robust, scenario-based projections of a country's energy balance, fuel mix and energy system expenditures over time. The models relate economic growth to the necessary energy system resources, trades and investments, while satisfying national environmental standards (or goals), to identify the least-cost energy future for the country that satisfies all the requirements [27]. Thus, the models provide a comparative framework for examining the impact of variations in key assumptions (e.g., fuel price, use of nuclear, availability of natural gas), policies (e.g., RE targets, climate change mitigation goals)

The MARKAL objective is to minimize the total cost of the system, adequately discounted over the planning horizon. The objective function (eq. (1)) is the sum over all regions of the discounted present value of the stream of annual costs incurred in each year of the horizon. Therefore:

$$NPV = \sum_{t=1}^{R} \sum_{t=1}^{NPER} (1+d)^{NYRS\cdot(1-t)} \cdot ANNCOST(r,t) \cdot \Big(1 + (1+d)^{-1} + (1+d)^{-2} + \ldots + (1+d)^{1-NYRS}\Big) \quad (1)$$

where:

NPV is the net present value of the total cost for all regions
ANNCOST(r,t) is the annual cost in region *r* for period *t*, discussed below
d is the general discount rate
NPER is the number of periods in the planning horizon
NYRS is the number of years in each period *t*
R is the number or regions

The total annual cost *ANNCOST(r,t)* is the sum over all technologies, all demand segments, all pollutants, and all input fuels, of the various costs incurred, namely: annualized investments, annual operating costs (including fixed and variable technology costs, fuel delivery costs, costs of extracting and importing energy carriers), minus revenue from exported energy carriers, plus taxes on emissions, plus cost of demand losses.

MARKAL analyses not only show what is to be constructed (and also what is not), but also when and for how much [27]. Based on the engineering and economic representations of energy supply, conversion plants and end-use devices in each country (mines, power plants, heat and power facilities, air conditioners, furnaces, light bulbs, etc.) the least cost energy supply and demand balance that can satisfy the physical and policy requirements can be explored.

3. Definition of baseline and mitigation scenarios for Macedonia

3.1. Baseline Scenario

To assess the impact of different climate change mitigation policies and measures on the evolution of the energy system, a Baseline Scenario was developed, taking into account the specific characteristics of the national energy system, such as existing technology stock, all possible new technology options, resource availability and import options, and near-term policy interventions.

The energy demand projections for the Baseline Scenario over the considered planning horizon (2011–2050) are based on the exogenous economic and demographic projections (drivers) and assumptions regarding each service demand's sensitivity to changes in the assumed driver. The model must satisfy these demands in each time period, by using the existing capacity and/or by implementing new capacity for end-use technologies. Table 1 provides key demand drivers, GDP and population growth rates, and how they reflect on the future energy demands in all sectors by end-use services.

In order to develop more plausible scenarios and properly reflect the situation in Macedonia a series of constraints has been introduced (Table 2). According to the Energy Law [30], in order to stimulate the construction of the new power plants using

Table 1
Key demand drivers in the Baseline Scenario.

Category	Assumption
GDP growth rate (annual average)	3.4% (2012–2050) [28]
Population growth rate (annual average)	−0.24% [29]
Sectoral growth rates[a]	
Residential	1.58%
Commercial	2.30%
Industry	1.62%
Agriculture	2.80%
Transport	3.6% (pkm); 3.3% (tkm)

[a] Annual average growth rate for useful energy based on projections for the different energy services in each sector, during the period 2011–2050.