Renewable and Sustainable Energy Reviews 53 (2016) 1202–1211

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Low emissions development pathways of the Macedonian energy sector

Aleksandar Dedinec [a,*], Verica Taseska-Gjorgievska [a], Natasa Markovska [a], Jordan Pop-Jordanov [a], Gligor Kanevce [a], Gary Goldstein [b], Steve Pye [b], Rubin Taleski [c]

[a] Research Center for Energy and Sustainable Development, Macedonian Academy of Sciences and Arts, Krste Misirkov 2, Skopje, Macedonia
[b] International Resources Group, 1211 Connecticut Avenue, NW, Suite 700, Washington, DC 20036, USA
[c] Faculty of Electrical Engineering and Information Technologies, Skopje, Macedonia

ARTICLE INFO

Article history:
Received 16 October 2014
Received in revised form
7 June 2015
Accepted 18 September 2015
Available online 10 November 2015

Keywords:
Energy modeling
Optimization
CO_2 emissions
Mitigation
Energy system

ABSTRACT

In this paper MARKAL integrated energy system model is applied to explore the impacts and opportunities for low emissions energy system development in Macedonia, identifying CO_2 emission reduction policies and the cost of taking action. Two scenarios with different reduction target have been examined: higher ambition scenario where emissions are restricted to 10% above 1990 levels in 2021 and 2.5% in 2030, and moderate ambition scenario where emissions are restricted to 25% above 1990 levels in 2021 and 15% in 2030. In order to provide insights into the optimal timing of emission reductions, both of these cases have also been run under cumulative constraints, that is, rather than having the specified annual targets, there is a carbon "budget" set for 2015–2030 (44 Mt and 26 Mt for higher and moderate ambition cases, respectively), reflecting the same ambition as the above cases but providing flexibility to reduce emissions in the most cost-optimal way. The results show that most of the CO_2 reductions are in the power generation sector, which is not surprising as this tends to be the most carbon intensive sector. The higher ambition case is considerably more expensive than the reference case, with costs 1.9% higher, while the increase under the moderate ambition case is 1%. Under a cumulative constraint, the additional costs are reduced to 1.5% and 0.6% respectively, highlighting the importance of the timing of action.

Contents

1. Introduction

Standing in front of the challenge called climate change, around the world many actions are taken to reduce emissions in order to avoid rising of the global temperature. Almost all countries in the world create different scenarios economy wide or in different sectors in order to retain economic growth and to reduce the level of greenhouse gases emissions, simultaneously. For example, China is fighting the rapid growth of the fright transport (more

* Corresponding author.
E-mail addresses: dedinc@manu.edu.mk (A. Dedinec), verica@manu.edu.mk (V. Taseska-Gjorgievska), natasa@manu.edu.mk (N. Markovska), jpj@manu.edu.mk (J. Pop-Jordanov), kanevce@manu.edu.mk (G. Kanevce), gary.a.goldstein@gmail.com (G. Goldstein), steve.t.pye@gmail.com (S. Pye), rubin.taleski@feit.ukim.edu.mk (R. Taleski).

http://dx.doi.org/10.1016/j.rser.2015.09.044
1364-0321/

than four times in the period 2000–2013 and annual growth rate of energy consumption of 12%) with intensive demand management measures and modal shift [1]. In [2], it has been shown that a penetration of 10% photovoltaic electricity in ten American States would result in a considerable cost effective reduction of CO_2 emission. In the United Arab Emirates, CO_2 emission reduction and renewable energy production targets as well as subsidy for domestic gas prices are considered [3]. The induction of these policies will reduce GHG emission by 15%, 20% and 45% in 2050 compared to the baseline scenario.

European Union is not an exception. The European energy policy has identified the security of supply, climate mitigation and economic competitiveness as key policy drivers towards sustainable development. Climate change as one of the hot topics in energy and environment policy making has triggered the European Council to set up the EU objective of reducing greenhouse gas (GHG) emissions by 80–95% by 2050, as compared to levels in 1990 [4]. To address this objective a wide range of low-carbon scenarios, roadmaps and pathways has been developed for several European countries and for different sectors of the economy. Hence, [5] covers power generation, petroleum refining, iron and steel, and cement production sectors for the whole EU and the aim is to develop scenarios for GHG emissions reduction in these sectors using the available technologies. In [6], a revision of the European Commission's Energy Roadmap 2050 is proposed taking into account the district heating systems, showing that in such a way the Roadmap goal can be achieved lower cost. In [7] six different scenarios are developed for Portugal, taking into account the energy policies that are in place. The CO_2 reduction of the UK residential sector, as well as the implementation of the EU renewable and climate policy is considered in [8–10]. Analyses regarding the transition of residential sector and its sustainable development for Lithuania in the context of EU energy policy are conducted in [11]. In [12], on the case of the Dutch energy system, the emission trading system is considered as a policy measure for introduction of CO_2 CCS. In the Basque Country (Spain), several scenarios are created in order to reduce energy consumption in the transport sector [13]. It is shown that decarbonization of this sector can be done with efficient mobility, electrification and high occupancies of vehicles. The effect of long term energy demand on Croatian GHG emissions are investigated in [14] and it is shown that 40% reduction can be achieved by 2050 compared to the referent scenario. All sectors must contribute substantially to emission reductions, but if the power sector is more than 95% based on lignite, as in the case of Kosovo, then the focus should be on the power sector [15].

The Republic of Macedonia (RM) is Non-Annex 1 country and European Union (EU) candidate country who signed the Energy Community Agreement, according to which it has to harmonize its national legislation with the existing legislation of the European Union (acquis communautaire) on energy, environment, competition, renewable energy sources, energy efficiency and oil reserves.

In case that RM enters EU by 2020, it will start implementing EU mitigation policies and measures, such as increase of share of renewables, participation in emissions trading system, obligatory buildings and equipment standards, labeling and certification of equipment and buildings, phasing out of inefficient technologies as incandescent light bulbs and retiring or obligatory retrofitting of inefficient plants. The sum of the measures, together with EU effort sharing scheme, will allow for achieving necessary emission reduction. In case that RM does not enter EU by 2020, it will still continue to participate in Energy Community, with similar targets in renewables, energy efficiency and phasing out of inefficient plants. The country will probably choose to continue transposition of other directives, but with slower pace.

The objective of this paper is to present, from a perspective of an EU candidate country, the options for CO_2 emission reductions from the energy sector and to quantify the impact of the policy instruments on marginal and total cost. For this, a set of alternative policy scenarios including different combinations CO_2 emission reduction targets are modeled in MARKAL_Macedonia optimization model for the period 2006–2030. Furthermore, analyzing two types of targets (specified annual targets and cumulative targets), it is proved that the timing of action influences the costs of emissions reduction.

2. Methodology

MARKAL is a widely used, bottom-up, linear programming energy systems modeling framework that is well suited to examine interlocking uncertainties through a systematic approach. The MARKAL/TIMES models produce 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 [16]. 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) and programs (e.g., National Energy Efficiency Action Plan, National Renewable Energy Action Plan) to advise informed decision-making and policy formulation.

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:

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

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.

While minimizing total discounted cost, the MARKAL model must obey a large number of constraints which express the physical and logical relationships that must be satisfied in order to properly depict the associated energy system.

MARKAL analyses not only show what is to be constructed (and also what is not), but also when and for how much [8]. 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