Journal of Cleaner Production 112 (2016) 3759–3773

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Assessing emissions–mitigation energy policy under integrated supply and demand analysis: the Colombian case

Laura Milena Cardenas [a], Carlos Jaime Franco [a], Isaac Dyner [b, *]

[a] Universidad Nacional de Colombia, CeiBA, Colombia
[b] Universidad Nacional de Colombia, Universidad Jorge Tadeo Lozano, CIIEN, Colombia

A R T I C L E I N F O

Article history:
Received 6 December 2014
Received in revised form
23 July 2015
Accepted 20 August 2015
Available online 2 September 2015

Keywords:
Low-carbon policy
Climate change
Emission reduction
Renewable energy
Energy modelling
Simulation

A B S T R A C T

The effects of greenhouse gases on climate variation set policy challenges for the energy industry – the largest greenhouse gas contributor globally. In this context, the energy industry is being subjected to reforms focussing on the environment, internalisation of emission costs and the promotion of cleaner technologies. To overcome the challenges posed by the emission of greenhouse gases, governments have implemented mitigation policies in the power supply industries. Most policy instruments include either financial incentives or goals and standards; and these generate impacts on electricity prices and consumer behaviour. This paper models policies' effects on prices and demand, through an integrated demand and supply analysis for the Colombian case. While simulation of carbon taxes shows important reductions of fossil-fuelled power capacity, a feed-in tariff policy promotes clean technologies, though not significantly reducing use of fossil technologies. When applied simultaneously, policy has a greater impact on both emission reductions and the diffusion of clean technologies, while only increasing electricity prices slightly. Even when price-elasticity of demand is low, such policies may have a significant effect on the penetration of renewables and emissions. Furthermore, this structured modelling of policy helps explain how the ultimate intended goal – sustainable emissions reduction – might be achieved.

1. Introduction

The effects of greenhouse gases (GHGs) on climate variation set policy challenges for the energy industry – the sector that contributes most to GHGs worldwide. In this context, in a number of countries, the electricity industry has been subjected to important reforms focussing on the environment, the internalisation of emission costs and the promotion of *clean* technologies. One example of this is the current electricity reform in Great Britain (GB) that aims at reducing emissions while preserving security of supply and maintaining a competitive power sector (DECC, 2012). Other countries, such as Germany, Spain, Denmark, China and Brazil are undergoing major changes in the composition of their power industry in order to change their trend of emissions growth or to take advantage of the opportunities provided by the new electricity-generation technologies (Chalvatzis and Hooper, 2009; Lu et al., 2013).

To overcome the challenges posed by the emission of GHGs, governments have implemented mitigation strategies in power supply industries. These strategies incorporate financial incentives or subsidies by means such as taxes, support funds, premiums, etc., and also non-financial incentives such as regulations, standards and prohibitions (Vachon and Menz, 2006; Van Dijk et al., 2003).

One of the most commonly used policy instruments in electricity markets is the incorporation of economic and financial incentives. Economists and international organisations usually argue that carbon taxes and market policies are efficient policies for the promotion of low-carbon technologies (Ekins et al., 1996; Lin and Li, 2011). However, the specification of these policies and the assessment of their effects once implemented are matters for research and policy study (Haas et al., 2011).

Policies for mitigating emissions (some market-based) seek to make fossil-fuelled technologies more expensive relative to technologies utilising renewable resources. In this direction, several countries have implemented carbon-tax policies, including Finland,

* Corresponding author.
E-mail addresses: lmcardenasa@unal.edu.co (L.M. Cardenas), cjfranco@unal.edu.co (C.J. Franco), idyner@unal.edu.co (I. Dyner).

http://dx.doi.org/10.1016/j.jclepro.2015.08.089
0959-6526/

Denmark, Sweden, Norway, Netherlands, Italy, New Zealand, Canada, Great Britain and Switzerland (Del Río and Mir-Artigues, 2014).

However, the implementation of these policies may bring undesirable collateral effects on the power system. This is the case in Spain, which has achieved significant increases in renewables, by "over allocating" subsidies, thereby becoming a global player and heading to meet its emission goals. However, it is also creating financial difficulties in the system and a financial gap between generation and distribution (European Commission, 2015; Jänicke, 2012; Moreno and Martínez-Val, 2011). Furthermore it is not promoting sufficiently reliable sources, such as fossil thermal generation, which may jeopardise the security of their power supply in the no-distant future (Moreno and Martínez-Val, 2011).

These policies have been implemented in both developing and developed countries. Gan et al. (2007) examine their advantages and disadvantages in Germany, the Netherlands, Sweden and the United States. Berkeley (1998) concludes that the implementation of emission policies requires customised implementation strategies because of the particular set of conditions created by the specific combination of barriers and actors in each country.

Developing countries differ significantly from developed countries. Pandey (2002) mentions that these differences are characterised by the: "existence of large scale inequity and poverty, dominance of traditional life-styles and markets in rural areas, existence of multiple social and economic barriers to capital flow and technological diffusion" (Huenteler et al., 2014). Furthermore, developing countries face major challenges in improving access to, and the affordability of, electricity services for poor households, and have responded to the challenges differently according to their income levels (Besant-Jones, 2006).

However, developing countries are often also characterised by their great potential in renewable technologies. Colombia's prospects in hydro, wind and solar power are among the most important in Latin America (Caspary, 2009; Valencia, 2009). Despite its great potential, Colombia has not developed solar and wind technologies sufficiently, and the implementation of a low-carbon strategy is still in the initial stages. This paper explores emissions–mitigation policy in electricity in the non-industrialised world from an integrated supply and demand perspective. The scope of this paper is the integrated modelling through price elasticity of demand, and it explores the likely consequences of implementing an emissions–mitigation energy policy in terms of security of supply, affordability and emissions reduction, using the Colombian case of a resource-rich country.

The next section provides a methodological background. Section 3 presents the fundamentals behind the developed model, and discusses how some policy instruments are incorporated in the model. This is followed, in Section 4, by the description of the scenarios created for policy analysis. Section 5 shows simulations of policy effects in the Colombian case and, finally, conclusions and policy implications are discussed in Section 6.

2. Methods

Models involving climate variables in the power industry are abundant (IPCC, 1996; Huntington and Weyant, 2002; Zhang and Folmer, 1998). Usually, these models have been classified as "bottom-up", "top-down", hybrid (a mix of bottom-up and top-down) and those that integrate the evaluation of climate change (IAMs: integrated assessment models of climate change).

Bottom-up models show how changes in energy efficiency, fuels, emissions control equipment and infrastructure, can influence the usage of energy and its environmental impacts (Morris et al., 2002). Usually, these models are computable general-equilibrium models that focus on the optimisation of the energy sector costs, or a specific sector, but omit the relationships among these sectors and the economy. Furthermore, the computable general equilibrium approach can underrate important feedbacks in the economy, which can be better captured with a total equilibrium approach. So, the bottom-up models end up ignoring these feedbacks, which leads to an inappropriate assessment of policies and technologies (Murphy et al., 2007).

Top-down models estimate additional relationships among the relative costs, the participation in the energy market and other economic variables, and relate them to other sectors and with the economy as a whole, within a framework of equilibrium. However, they lack technology detail, and therefore the top down models focus on the simulation of financial policies, leaving aside the policies that involve technology development, or those handled exogenously. Under this approach it is only possible to analyse instruments such as taxes, subsidies and regulations (Murphy et al., 2007).

The integrated assessment models combine scientific aspects of climate change with socioeconomic aspects (Kolstad and Kelly, 1998). IAMs give special emphasis to climate modelling and have no interest in modelling markets. The CIMS model (Murphy et al., 2007) is a hybrid model that combines the strengths of the top down and bottom up approaches, focussing on three specific characteristics: technology detail, reality in the behaviour of the variables and the ability to capture the systems' feedbacks. The approximations involved in this model provide satisfactory results for the first two characteristics but has difficulties in capturing feedbacks because of the iterative nature of this type of model (equilibrium model) (Jaccard et al., 2003).

However, the study of emissions-reduction policies in particular country or regional contexts is characterised by: a) uncertainties regarding climate variations, b) nonlinearities among the variables that describe the system, c) asymmetric distribution of geographic and temporal (delay) impacts, and d) long-term time horizons, as well as by the multiplicity of social and physical interactions in the system – that many times have no common goals – which together make difficult the search for optimal solutions in this problem area (IPCC, 1996).

Under these conditions, system dynamics may offer an alternative approach to policy assessment, focussing on some social, techno-economic and environmental aspects of the country/region, without leaving aside feedback effects within the system components. The system dynamics literature that studies electricity markets is extensive. Ford (1997) offers an overview of the main studies in the area. Fiddaman (1997) investigates policy mitigation of greenhouse gases from electricity generation by way of levies: carbon taxes, energy taxes and depletion taxes; Ford (1990, 2008, 2010) makes a more extensive study of the U.S. electricity market for evaluating efficiency standards and cap and trade mechanisms. Dyner et al. (1995) and Dyner and Franco (2004) assess efficiency issues in the developing world and Blumberga et al. (2014) present a study for the assessment of energy efficiency polices in the residential building sector. Franco et al. (2015), Sterman et al. (2012) and Zuluaga and Dyner (2007) present energy models that appraise carbon pricing incentives for renewables and subsidies.

While recent research with system dynamics on energy-emission issues focuses on the supply side, there is much less emphasis on the demand side, and only limited research that integrates both. This paper studies the effects that mitigation policies can have on electricity price and demand, through an integrated supply-demand analysis, specifically in the Colombian power industry. This integrated analysis explores the likely consequences of implementing an emissions–mitigation energy policy in terms of security of supply, affordability and emissions reduction, as recently executed in Great Britain (Franco et al., 2015).