Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 3545 – 3550

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Balancing Energy Efficiency And Fossil Fuel : The Role Of Carbon Pricing

Alice Didelot[a,b], Nadia Maïzi[a], Vincent Mazauric[b,a], Edi Assoumou[a], Sandrine Selosse[a]

[a]*MINES ParisTech, PSL Research University, CMA - Centre de mathématiques appliquées, CS 10207 rue Claude Daunesse 06904 Sophia Antipolis, France*

[b]*Schneider Electric, Strategy & Technology, 38TEC, 38050 – Grenoble cedex 9, France*

Abstract

Energy efficiency is likely to remain a valuable support for meeting climate challenges because it involves using less primary energy to produce the same final service. We explore energy efficiency potential in relation to different fossil fuel extraction cost schemes crossed with a carbon pricing scenario built using various global carbon taxes. This sensitivity analysis relies on prospective studies conducted with the technical-and-economic, bottom-up optimization model TIAM-FR (TIMES Integrated Assessment Model), where energy efficiency is endogenized.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords : energy efficiency, TIAM-FR planning model, optimization, fossil fuel extraction costs, carbon pricing.

1. Introduction

According to the International Energy Agency (IEA), energy efficiency is the gain established when a device "delivers more services for the same energy input, or the same services for less energy input" (IEA, 2015). This notion is closely linked to energy demand management and energy consumption savings. Developing energy efficiency is viewed as a necessity to ensure energy security and decrease greenhouse gas emissions (GHG) by reducing the share of fossil fuels. It could be interpreted as a way of combating energy losses while maintaining a given way of life.

There are two main ways to increase energy efficiency. The first is to invest in new equipment, which is intrinsically more efficient. The second is to add extrinsic technologies to pre-existing devices so that they operate more effectively. This involves either insulation with passive efficiency or monitoring systems for active efficiency. In the following, we only focus on active energy efficiency with extrinsic devices, referred to henceforth as simply "energy efficiency" (EE).

In this study, we deal with energy efficiency in a prospective way in order to explore its potential developments in different scenarios concerning carbon pricing and resource extraction costs. To do so,

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.814

energy efficiency is endogenized in our prospective tool (section 2). This representation has been implemented and calibrated for the industrial, residential and tertiary sectors to improve understanding of the balance between energy efficiency potential when considering fossil fuel extraction costs and carbon pricing patterns (section 3).

2. Methodology

TIAM-FR is the French version - developed at the Center for Applied Mathematics, MINES ParisTech - of the TIMES Integrated Assessment Model, the global multiregional model from the TIMES family of models developed by the Energy Technology Systems Analysis Program (ETSAP), under the aegis of the International Energy Agency (IEA) [1]. TIAM-FR aims to supply energy services at minimum global cost by simultaneously making decisions on equipment investment, equipment operation, primary energy supply, and energy trade. End-use demands (i.e. energy services) are based on socio-economic assumptions and external projections of the growth of regional GDP, as well as population and the volume of various economic sectors (transport, residential, industry, etc.) over the planning horizon. TIAM-FR is a technology-rich, bottom-up model that depicts the energy system with a detailed description of different energy forms, resources, processing technologies and end-uses, in a Reference Energy System (RES), shown figure 1, covering the whole energy chain. Each economic sector is described by means of technologies, individually characterized by their economic and technological parameters.

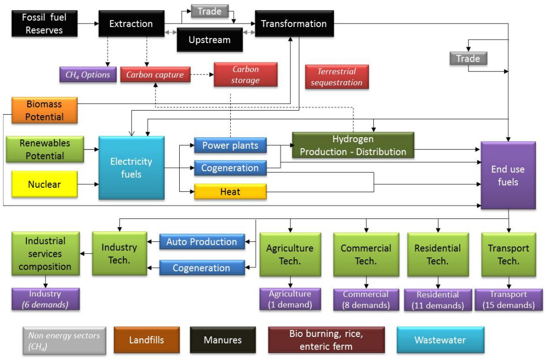

Fig. 1. Overview of the reference energy system

Each conversion process is represented by a brick, with commodities in and commodities out linearly linked by yield, investment, operation and maintenance costs and a lifetime. The TIAM-FR model includes more than 3000 processes and 500 commodities, which gives an indication of its complexity. The final demand is ultimately divided into 42 final demands corresponding to Agriculture, Commercial, Residential, Transport and Industrial services.

The main outputs of the model are future technology investments and activities for each time period. Furthermore, the structure of the energy system is given as an output, i.e. type and capacity of the energy technologies, energy consumption by fuel, emissions, energy trade flows between regions, transport capacities, detailed energy system costs, and marginal costs of environmental measures, such as GHG reduction targets. TIAM-FR is geographically integrated and offers a representation of the world energy system broken down into 15 regions.

In current prospective tools, energy efficiency is established as an input, that is to say the modeler already knows the amount he wants to study and decreases final demand beforehand. We consider that energy efficiency has an intrinsic value [2]. We endogenously calculate the optimal efficiency level, having already determined its investment cost from the efficiency levels previously attained. Finally, energy efficiency becomes an output. Energy efficiency is thus modeled as a negative power plant that produces unconsumed energy, inserted right at the end of the Reference Energy System (RES), in order to artificially decrease the need for produced energy to cope with the same final demand.

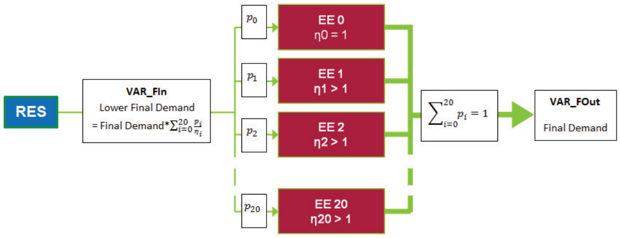

Fig. 2. Modeling of the 20 bricks with different yields, introduced just before sectorial final demands

Because the model is driven by demand, energy efficiency is the proportional input gain required to remain transparent from the user's point of view. In other words, to obtain %EE of energy efficiency means that the process requires %EE fewer inputs to cope with the same final demand. Allocating a price to this plant allows the optimizer to arbitrate between investing in extrinsic energy-efficient devices using these bricks, installing brand-new technologies that are intrinsically more efficient, or continuing as before. The more efficient a technology is, the more it costs. To linearly represent this characteristic, we model energy efficiency with 21 bricks with different yields : the first one is transparent and inserted at every output level studied; it only converts potential efficiency into final demand at no cost and yield $\eta_0 = 1$. It acts as a ground zero reference and has no upper bound to allow the initial use of the model. If investing in energy efficiency were found to be uneconomical, then this would be the only one used. The 20 other bricks are connected in parallel, as represented figure 2, and the mathematical solver arbitrates to invest in the appropriate ones. The final efficiency is a linear combination of the elementary yields purchased. The repartition p_i between the different states of efficiency respects the lowest cost pathway based on the bricks' characterization in order to cope with the final demand.

Energy efficiency penetration rates are not the same the 15 different regions. A classification is thus proposed to rank these regions according to their "efficiency potential" [2] : it is represented in figure 3 for the industrial sector, where each step of the curves represent the effective gain provided by a single efficiency brick in each region. The ordinate axis is divided into unitary levels whereas abscissa axis presents energy efficiency gains for one cost unit from 2007, which is the base comparison year imposed as a relative zero level.

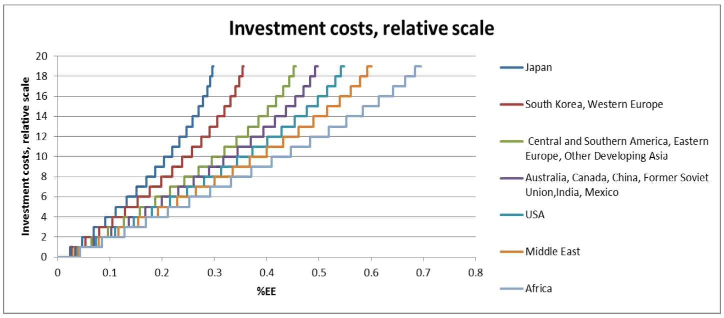

Figure 3: Investment costs for Energy Efficiency, categorization by region linked to efficiency potential

For this study, the focus is on the residential and tertiary sectors. We take for granted former results on the industrial sectors [2].

3. Sensitivity analyses of fossil fuel extraction costs and carbon pricing

3.1. Fossil fuel extraction costs and Carbon pricing

Various and increasing tax scenarios were built to study the impact on energy efficiency fields. The adopted scheme is quite simple: from 2020, producers have to pay an imposed and fixed amount to release 1 ton of carbon equivalent. The tax begins in 2020; its level is given for 2020 (0, 20, 50, 100, 150, 200 or 500 euros) and annually updated with a 5% discount rate as shown figure 4(a) for 100 euros in 2020. A significant CO2 tax could be a sufficient incentive to reach GHG emissions goals.

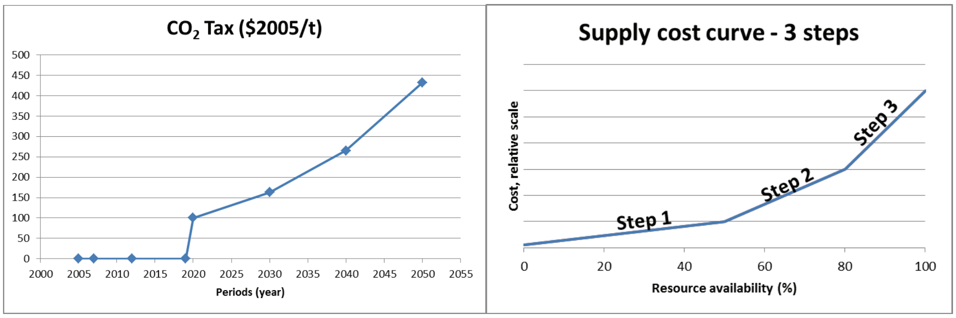

Fig. 4. (a) Example of an imposed tax of 100$2005/t in 2020 with a 5% discount rate (b) Generic model of the three-step curve representing fossil fuel extraction costs

Oil, gas and coal cost is divided into four parts: an extraction cost, an upgrading cost if needed (mainly for unconventional resources), a trade cost to model international exchanges, and a final cost established by the markets. We focus on this first cost, regrouping fixed and variable costs where stocks are divided into three types: Conventional supply, divided into recoverable reserves or producing pools, enhanced recovery or reserve growth, and new discoveries; Non-conventional supply; Additional occurrences/not connected (for gas). A single step characterizes the cost of the resource and its annual recoverable amount at this cost. In figure 4(b), the first step represents 50% of the resource, the second 30%, and the third and final one 20% [3].

3.2. Scenario results

From a specific Business As Usual scenario (BAU) we added the energy efficiency brick characteristics in all regions as described above: this new reference for energy efficiency studies is called BAU-EE.

New technologies are intrinsically more efficient than old ones. Comparing investments between new technologies and energy efficiency bricks is an easy way to study how competitiveness affects intrinsic and extrinsic energy efficiency: does one destroy the other's field? For each set of commodities, we assess the annual investments in new technologies on the one hand, and in efficient bricks on the other hand. In the industrial sector, shown figure 5, investment in energy efficiency bricks remains very sensitive to carbon pricing, and seems to appear as a viable alternative to reach climate objectives.

Industries have more to gain from developing ambitious solutions to better use installed devices than from investing in new ones. All world regions can gain from investing in the energy efficiency field but, the higher the industrial growth, the more valuable the efficient bricks will be. In China, the switch in investments between new technologies and energy efficiency as carbon pricing increases is clearly observable. However, investments in new technologies lag behind to a lesser extent in the residential (see figure 6), and tertiary sectors [4].

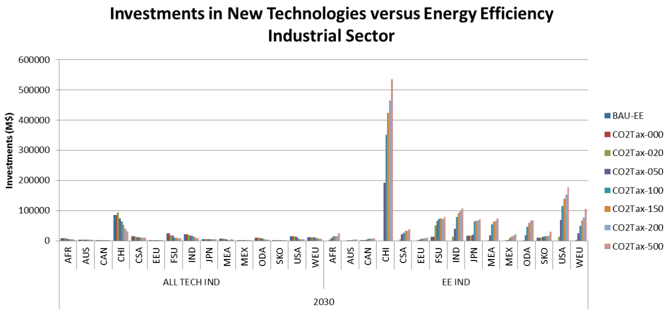

Fig. 5. Investments for the industrial sector in 2030 with the increasing carbon tax scheme

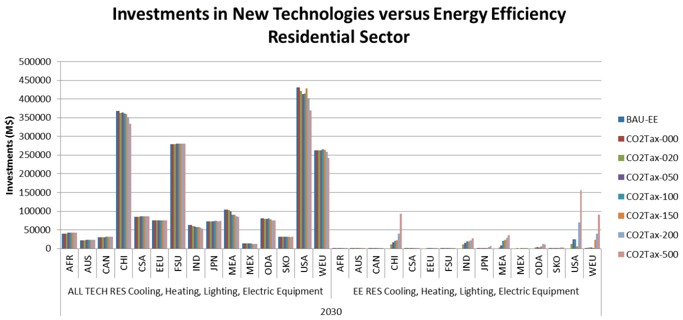

Fig. 6. Investments for the residential sector in 2030 with the increasing carbon tax scheme

As a single variation in fossil fuel extraction costs is not enough of an incentive to develop energy efficiency, we propose to conduct sensitivity analysis combined with carbon pricing measures. We set up a given CO2 tax, 100 $/t in our case, with variant fossil fuel extraction costs. The result is some variations in energy efficiency expansion. While the residential sector seems to remain insensitive to fossil fuel extraction costs [4], the tertiary sector reacts appreciably in Africa (AFR), China (CHI), South America (CSA), India (IND), Middle East (MEA), South East Asia (ODA), USA and Western Europe (WEU) as shown figure 7.

4. Conclusion

Active energy efficiency was modeled as an endogenized brick in TIAM-FR in order to determine the optimal energy efficiency level under various sets of constraints. The first step of building these bricks also provided the opportunity to understand how the prospective model was constructed. In addition, the calibrating work provided a genuine insight into how the model was run, and therefore an occasion to set up automatization tools for sensitivity and post-treatment methods.

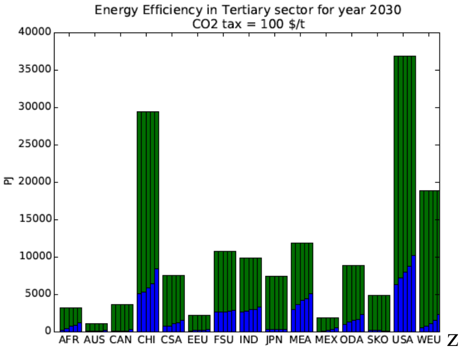

Fig. 7. Energy efficiency for the commercial sector in 2030 with the fossil fuel extraction costs scheme

Finally, by elaborating various scenarios featuring CO_2 tax and fossil fuel extraction costs for sensitivity analyses, we gathered all of the acquired skills and combined them exhaustively.

Acknowledgements

This research was supported by the Chair Modeling for sustainable development, driven by MINES ParisTech, Ecole des Ponts ParisTech, and AgroParisTech, supported by ADEME, EDF, GRTgaz and SCHNEIDER ELECTRIC and the French Ministry of Environment, Energy and Sea.

References

[1] Loulou, R., & Labriet, M. ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. *Computational Management Science,* 2008, Volume 5, Number 1-2, Page 7.

[2] Mazauric V, Thiboust M., Maïzi N., Selosse S., Assoumou E. Arbitrage between energy efficiency and carbon management: an industry sectorial study. Retool for a competitive and sustainable industry, *ECEEE 2014 Industrial Summer Study Proceedings*. Jun 2014, Papendal, Arnhem, Netherlands. hal-01103208.

[3] Anandarajah G., Pye S., Usher W., Kesicki F., & Mcglade C. TIAM-UCL Global Model Documentation. (2011).

[4] Didelot A., Maïzi N., Mazauric V., Assoumou E., Selosse S. Impacts of fossil fuels extraction costs and carbon pricing on energy efficiency policies, *International Energy Workshop*, Cork (2016).

Biography

Nadia Maïzi is Professor in Applied Mathematics at the Ecole des Mines de Paris, and is running the Center for Applied Mathematics www.cma.mines-paristech.fr where she leads a team of 40 researchers and PhD students in the field of energy system optimization. She is director of the Chair Modeling for sustainable development www.modelisation-prospective.org and is closely involved in sustainability and climate-energy initiatives and policies within the United Nations Framework Convention on Climate Change and the French government. She is member of the Expert committee