Optimal trade-offs between energy efficiency improvements and additional renewable energy supply: A review of international experiences

Baldini, Mattia and Klinge Jacobsen, Henrik

Technical University of Denmark, Energy Economics and regulation

February 2016

Optimal trade-offs between Energy Efficiency improvements and additional Renewable Energy supply: A review of international experiences

Working Paper February 2016

Mattia Baldini and Henrik Klinge Jacobsen
Technical University of Denmark (DTU), Denmark, Email: mbal@dtu.dk; jhja@dtu.dk

Abstract

Energy efficiency is a key priority also from a climate perspective, but efforts to increase efficiency should be balanced with the effort to increase the share of renewable sources in order to reduce fossil emissions. The climate impact of various energy efficiency measures are quite different depending on the type of fuel used and the impact from the efficiency increase on energy costs and thereby the demand for that particular energy use. Therefore it is important to address the energy efficiency options together with the alternative to switch the energy supply towards renewable sources. This calls for models and analysis that incorporate both types of options and thereby address the trade-off in a consistent way.

The literature dealing with the trade-off in a direct or less explicit way is categorized and reviewed here. The aim of this paper is to review and evaluate international experiences that include the trade-off between efficiency improvements and additional renewable energy supply whether in a partial analysis of a sector or in an energy system optimization model. A critical review of the approach, focusing on purpose, methodology and outcome, is provided along with a review of modelling tools adopted for the analyses. Models are categorized and presented according to their main characteristics (e.g. bottom- up/top-down model, regional/national analysis, partial/general equilibrium, static/dynamic model). This paper intends, to provide future modelers and policy evaluators with an overview of approaches and methodologies suitable for analyzing energy efficiency policies and options with a focus on the optimal trade-off between renewables and energy efficiency measures in energy-systems under different objectives.

I. INTRODUCTION

The enlargement of the energy sector in the past years brought a new problem since the green-house gases (GHG) emission related with energy production began to affect the environment, leading to global complications [1]. Various measurements and policies have been developed since then and, in vision of an international recognized effort, the Annex Icountries signed the Kyoto Protocol in 1997 [2]. The recurrent issues concerning climate change and fossil fuels depletion has thus moved attention towards cleaner ways to produce energy. Among all, two valid solutions for reducing CO_2 emissions have been identified as the most relevant: energy efficiency improvements (EE) and generation by renewable energy sources (RES) [3]. The European Commission already acknowledge the positive contribution of EE and RES policies in the fight against GHG emissions identifying the measures as "no regret options for transforming the energy system [4]" when analyzing future scenarios for the year 2030 [5]. In vision of a greener future, different studies have analyzed (with diverse goals and perspectives) the potential of implementing RES and EE in the energy systems [6]–[8]. Results often show that the implemented support policies have promoted large deployment of renewables, without considering enough improvements made in the energy saving field. Indeed, less attention has been paid to implement energy efficiencymeasures in energy systems modeling, which has resulted in scenarios where expedients for a wise use of energy (e.g. energy savings and RES' share) are unbalanced and cost-savings opportunities are missed [8]–[10]. The causes of this non-perfect scenarios are to be found in the interactions and integrations among these measures. Even though synergies among RES and energy efficiency are commonly acknowledged [11]–[14], the trade- off among them is still an un-explored field. Many studies have been investigating on future energy systems based 100% on renewable sources [15]–[17], as well as scenarios where energy efficiency measures contributes to GHG reduction and reduce energy demand [18]–[20]. However, just few studies have been focusing on the simultaneous implementation of policies regarding EE and RES in energy systems models and analyze their trade off. The aim of this paper is to review and evaluate the international experiences on the integration of energy efficiency measures and additional RES supply in the energy system. The screened studies have been analyzed focusing on the different techniques, purposes, methodology and outcomes. Moreover, the tools used for the analyses have been categorized and presented according to their main characteristics. The article aims at being useful as: starting point for those not familiar with the topic, benchmark for authors who already deals with it, and as a guidance for decision makers in the process of identifying a suitable analysis to investigate on the optimal trade-offs under different objectives. The article is structured as follows: Section II refers to the classification of the models and the studies selected. In Section III the categories previously introduced are used as a starting point to discuss the classification provided. Section IV summarize on the findings, concludes on the topic and suggests future development on the matter.

II. CLASSIFICATION OF THE STUDIES ACCORDING TO THE CATEGORIES

Before starting the analysis, a clarification is reported on the difference between synergy and trade off, energy efficiency and energy savings since the terms are often misconceived. There can be *synergy* between two factors when their combined effect is greater (or smaller) than the sum of their separate effects [21]; on the other hand the *trade-off* refers to a method of reducing or forgoing one or more desirable out- comes in exchange for increasing or obtaining other desirable outcomes in order to maximize the total return or effectiveness under given circumstances [22]. Furthermore *energy efficiency* refers to the technical ratio between the quantity of primary or final energy consumed and the maximum quantity of energy service obtainable (heating, lighting, cooling,...), while *energy savings* implies the reduction of final energy consumption, through energy efficiency improvements or behavioral change [23]. For the trade-off investigation, both energy savings and energy efficiency concepts were considered.

A. Models

The tools adopted in the different analyses cover a wide range of characteristics. Those considered most relevant were used to categorize the models. The focus of the analysis will thus be on the analytical and mathematical approach selected when formulating the problem and writing the equations, on the type of resulting equilibrium and on the interfacing with the model's runtime (i.e. dynamicity). The results are reported in Table I where the models are listed in order of appearance in the studies presented in Table II (i.e. ENPEP-BALANCE is used in [24], MASTER.SO in [8], and so on...). Plenty of other models' features could be investigated and discussed. However, the aim of this section is not to report a full and complete description of the models along with their features, but rather to highlight the most relevant for the paper. For a thorough description of the models investigated, readers can refer to reviews about energy system models [25]–[28].

B. Breaking down the studies

Despite the fact that some authors used the same model to perform the studies (e.g. MARKAL for studies [9], [10]), the reasons for the investigations were different. Therefore, the studies were analyzed according to selected criteria: purpose of the study, methodology, results evaluation and conclusions of the studies. The results are reported in Table II. The intention of the categorization is to:

- investigate on the reasons of the studies
- understand the methodology towards the final goal
- highlight the different ways to evaluate the results
- discuss and reflects on the final findings.

The findings are used for the discussion that follows, where results are then examined identifying common characteristics.

Table I ANALYSIS OF THE TOOLS

Tool	Analytical approach	Mathematical approach	Equilibrium	Model
ENPEP - BALANCE [29]	Top-down	Non linear	Yes	-
MASTER.SO [30]	Bottom-up	Linear	Partial	Static
IOCM [31]	Bottom-up	Linear	Yes	Static
EnergyPLAN - GenOpt [32]	Bottom-up	Linear	Partial	Static
Remap 2030 [33]	Spreadsheet based	-	Yes	-
PRIME 2007 [34]	Top-down	Non linear	Partial	Static
MESSAGE [35]	Hybrid	Linear	Partial	Dynamic
MARKAL - TIME [36]	Bottom-up	Linear	Yes	Dynamic
MARKAL [36]	Bottom-up	Linear	Yes	Dynamic
MDDH [37]	Bottom-up	Linear	Yes	Dynamic
TIMES [38]	Bottom-up	Linear	Partial	Static
IRP [39]	Bottom-up	Linear	Partial	Static
IRSP [40]	Bottom-up	Non linear	Partial	Static
IRSP [41]	Bottom-up	Non linear	Partial	Static

III. OUTCOMES: COMPARISON AND ASSESSMENT

A. Models

Following the categorization reported in Table I the results are here commented. A common factor that joins together all models is the optimization methodology, certainly related to the nature of the final goals of each analysis. Only one model (MDDH) deals with stochasticity. The reasons being that the model deals with an electrical power system with strong hydro generation, thus requiring stochastic techniques to deal with the uncertainties in the water-streamflows [37], [46]. Most of the models are bottom-up, one is hybrid (i.e. combines both top-down and bottom-up approach) and two are top-down. Usually, models referred as top-down emphasize economy- wide features, while bottom-up focus more on sectorial and technological details. The choice of bottom-up models for the analyses is thus in line with the goal of most of the research questions: investigating possible configurations of future energy systems. Depending on the degree of complexity of the analysis on the objective to optimize, the models were classified as linear and non linear. While the theoretical difference among the two methods is commonly acknowledged, it was found that those models which presented non linearity were either considering a multi-objective optimization approach [40], [41], considering non-linear cost supply curves of resources used in power generation [12] or including non linear modules while solving the optimization [24](e.g. BALANCE module for ENPEP [29]). The models are also classified according to the feature of static or dynamic modelling, where the main difference lies in the fact that a dynamic model is, in general, a model describing the state evolution of a system over time while a static model has a time independent view

Table II

ANALYSIS OF THE STUDIES REVIEWED

Model	Study	Purpose of the study	Methodology	Assessment of the results	Conclusions of the study
ENPEP-BALANCE	[24]	Analysis of GHG mitigation options	Simulation-based optimization: cost-efficient energy scenario to mitigate GHG emissions	USD/tCO_2, Tg CO_2 emitted	• CO_2 mitigation measures investigated leads to reduction in energy demand and CO_2 emission
MASTER.SO	[8]	Comparison on the costs of achieving CO_2 reduction level through RES or EE support (EX-POST analysis)	Maximize energy system sustainability (i.e. least cost-environmental energy supply options) while satisfying model's constraints	System costs (for each sector), economic savings for each scenario, CO_2 emissions, capacity installed	• DSM dominates RES support if the emission reduction at minimum cost is the only concern • DSM measures facilitate the investments in RES • RES are anyway required in vision of a fully decarbonised energy sector
IOCM	[31]	Describe, investigate and prove CO_2 mitigation measures within Chinese energy power system on the demand and supply side	Multiobjective optimization: cost-effective optimal plan of energy supply/demand side investments	Capacity installed, CO_2 mitigation of virtual energy	• DSM and smart grid operation leads to environmental enhancements • EE and RES planned measures won't be enough to reach the final target
EnergyPLAN-GenOpt	[7]	Planning of sustainable national energy system under EU2030 policy framework (27 % primary energy reduction, 27% RES in final energy consumption, 40% CO_2 emission reduction)	Simulation-based optimization: minimize the cost of the system for optimal energy policy mix implementation under constraints	% decrease in primary energy, % increase in RES share, % decrease in CO_2 emissions	• Optimal combination of economically justified RES and EE measures • Low market price imply no participation of the RES w/o subsidies • EE economic potential exist even without the EU2030 targets
Remap2030	[13]	Doubling the rate of improvements in EE and the share of RES in the selected countries' energy mix	Identification of measures to fulfill SE4all and RES objectives, study of SYNERGIES and TRADE OFF from deploying EE and RES simultaneously	CO_2 emissions avoided, RES share in power generation and TFEC, energy savings in TFEC and TPES	• RES strategies reduce primary energy • EE polices lower energy demand and increase share of RES • Synergies reduce demand growth up to 25% • Trade-off needed to avoid hinder of RES deployment by EE policies
PRIME2007	[12]	Compute and demonstrate RES contribution to the Europe's 2020 EE targets	Assessment of the contribution of RES through the Primary Energy Method. Scenarios comparison analysis.	Primary energy savings, cost of DSM measures	• RES clearly contributes to the EE targets • DSM measures can hinder the development of RES (binding targets problem)
MESSAGE	[42]	Synergies between climate change mitigation and energy related objectives for sustainable development.	Formulation and evaluation of alternative energy supply strategies according with constraints implemented	Energy related investments, Policy costs, CO_2 price, GHG concentration	• RES energy supply and end-use EE useful to achieve low stabilization target • stronger focus on EE leads to lower system costs, exclusion of supply side plants from mitigation portfolio
MARKAL-TIME	[9]	Analysis of the influence of EE and RES programs and policies in the development of the energy system (energy security, diversification, economic competitiveness, CO_2 mitigation)	Simulation-based optimization: minimization of the system costs, adequately discounted over planning horizon, while satisfying constraints.	Energy system costs, primary energy supply, new power capacity, final energy consumption, CO_2 emissions	• EE case shows the greatest CO_2 reduction with the lowest system costs • EE and RES case shows better results for CO_2 emission reduction, however with higher system cost
MARKAL	[10]	Determination of policies guidelines and interventions in the Indian power sector in order to follow a sustainable development path.	Determination of the least-cost pattern of technology investments and utilization (comparative analysis) in order to calculate the resulting pollutants	CO_2 emissions, RES and efficiency power plants (EEP) installed capacity	• Least cost-effective actions on CO_2 emissions and demand reduction lies on EE measures • RES will cover up to 25% of the system and will contribute to the CO_2 emission reduction • EE and RES combined leads to the best achievements in terms of CO_2 emission reduction
MDDH	[43]	Calculate the cost of investments and CO_2 emissions in electricity generation facilities that can be avoided implementing EE policies/measurements	Comparative analyses scenarios: Cost/emissions savings evaluation in an energy systems highly based on uncertainties	Energy and CO_2 emissions savings	• EE investments are preferable to RES investments • Increase of EE policies reduce energy system's operating costs • Additional EE measures implementation still cheaper than new RES project (already selected)
TIMES	[44]	Analysis of the impact of DSM options (e.g EE measures, dynamic demand response) in a closed system characterised by high RES penetration	Minimization of investments and operation costs of RES sources with different DSM options acting on energy demand	RES capacity installed, energy production by source, automation of domestic machines	• DSM stategies delay the investments in RES in the system and improve the operation of already existing plants
IRP	[45]	Analysis on the DSM options' (EE improvements) implications for capacity expansion planning in power sector (considering rebound effect)	System-cost minimization, both for demand and supply side, while adhering to constraints.	Avoided capacity, avoided emissions (CO_2, NOx, SO2)	• Cost-effective selected DSM measures reduce the CO_2 emissions • Rebound effects considered will reduce the savings
IRSP	[40]	Assessment of IRSP performances against IRP models on the integration of EE measures in the Chinese power sector (maximum economic/social benefit return, minimum resource input	Cost-effectiveness choice maximization optimizing the equilibrium between conventional/RES plants and efficiency power plants	Capacity installed and avoided, emissions' savings, total system costs	• IRSP model performs better then IRP due to the better integration of efficiency and conventional power plant
IRSP	[41]	Comparison among power planning pathways under different policies for the promotion of EEP and RES	Power supply and demand costs minimization through optimization of resources, demand and supply side (external, internal and popularization costs included)	Capacity installed, pathway of resource allocation	• The share of efficiency power plants selected decrease, when considering the popularization costs • Non linear IRSP pathways provide a better representation of the real supply curve

of a system [47]. Among all the models considered, only MARKAL, MESSAGE and MDDH considered a dynamic mathematical approach; all the other, for a matter or simplicity, considered a static approach. Concerning the final equilibrium in the markets, the tools can be categorized according to the level of inspection. When the aim is to investigate the changes in a particular sector without considering the interaction of this last with the whole system then the model will be classified as partial equilibrium. On the other hand, a model will be labeled as general equilibrium if the assumption is that every market has an effect on every other market and therefore a change in one market may result in changes in another market. A close observation of the results reported in Table I shows that there is a fair split between the two categories, thus implying that half of the studies has been focusing entirely on a sector (i.e. energy sector), while the others investigated the goals considering the changes in different sectors and the interactions among them.

B. Studies

The studies selected were investigated according to the selected criteria previously introduced. The resulting considerations from the results in Table II are here remarked. The purposes can be divided in three categories: (1) GHG/CO_2 mitigation options investigation, (2) targets fulfillment study and (3) analysis of policies and programs development. Ac- cording to this division, the studies [8], [24], [31] belongs to the first category, [7], [12], [13] to the second, while the remaining to the third (see Table II). Concerning the technique adopted, due to the nature of the models and the way the problems were mathematically formulated, almost all the studies follow the "system operation/investments-cost minimization while adhering to constraints" approach. Besides, the policies objectives are implemented as constraints on the different variables under investigation. The results of the analysis are assessed with different indicators, usually related with the focus of the analysis. Among the most employed there are: decrease in primary energy (due to energy savings), increase in RES share, CO_2 emission levels, new capacity investments as well as policy cost, cost of emission reduction, energy system costs, economic savings and CO_2 avoided. Regarding the conclusions of the studies, the findings point to similar outcomes. Among the most supported, there are the following:

- EE measures are the most cost-effective options for CO_2 reduction in energy systems
- EE measures should be implemented first, RES after
- RES energy supply and end-use EE is the best combination to achieve low system energy costs and high CO_2 reduction (however, with higher system prices)
- Synergies between RES and EE are commonly acknowledged, while trade-offs are still well not defined
- Attention must be paid to the rebound effect since it can decrease the savings (economic, energy and emissions)
- EE measures imply popularization costs (necessary to spread the knowledge) that can hinder their development.

In support, an analysis performed on the Spanish sector [8], reported that if the reduction of emissions at a minimum cost is the only concern, implementing EE measures would lead to almost 5 mill € of savings (both in RES promotion and to meet the reduced demand). Moreover, on the interaction between EE-RES, the EE measures can act both positively and negatively. In the short term, the increase of EE measures leads to a decrease of the energy demand, thus increasing the share of RES in the system and fostering their use [48]. In the long term, the additional measures towards efficiency hinder and delay RES deployment, since the reduced energy demand is already covered by a well balanced energy system [12], [44]. Different studies have already acknowledge the significance of the rebound effect and popularization costs when analyzing EE implementation in energy systems [49]–[51]. The magnitude is usually estimated in a range between 0% and 30% (rebound)
[52] and 20% (popularization) [41] of the savings gained, thus making both of them essential factors to consider in analyses of energy system highly based on EE. Nevertheless, a proper mix of measures on both demand and supply is necessary in order to gain significant emission reduction [53]. Hence both EE and RES are necessary. The challenge then is to coordinate support policies in order to achieve the desired result at the lowest cost.

IV. CONCLUSIONS

When planning future development of the energy system it is important to focus on the trade-off between energy efficiency improvements and additional renewable energy supply. The reasons lies on economical and environmental benefits that can be gained by such investigation. The trade-off can be found to be different from system to system depending on the structure of the already existing energy system, on the availability of RES sources/EE measures and on the potential of implementation of such. Thus contextualization is an im- portant factor when comparing different trade-offs outcomes. The goal of the paper was to analyze studies that investigated on the trade-off between RES and EE. The selected studies along with the models used were split in categories. The features of the tools were found to be different according to the kind of investigation performed. Concerning the studies, the analysis highlighted that the purposes could be gathered in three categories (GHG/CO_2 mitigation options investigation, targets fulfillment study and analysis of policies development). Moreover, all the studies point toward a path of integration between RES and EE measures. A trade-off is nonetheless necessary in order not to hinder the development of the RES. Finally, just few studies were found to be focusing entirely on finding the optimal trade-off, highlighting the lack of examples in the literature about the topic. Questions like “what should be the share of RES and EE in the system, given a pre-defined goal” and “which technologies/measures are more suitable to cover the share for each system” should be answered by these kind of studies. Future works of future modelers should thus strength the focus on finding the trade-off (RES-EE) for each of the investigated systems. The results of these analysis will lead to shape future energy systems towards configurations where expedients for a wise use of energy will be balanced.

REFERENCES

[1] IPCC, “Climate Change 2014 Synthesis Report Summary Chapter for Policymakers,” *Ipcc*, 2014.

[2] Unfccc, “Kyoto Protocol To the United Nations Framework Kyoto Protocol To the United Nations Framework,” *Review of European Community and International Environmental Law*, 1998.

[3] P. Ekins, “Step changes for decarbonising the energy system: research needs for renewables, energy efficiency and nuclear power,” *Energy Policy*, 2004.

[4] European Commission, “Green Paper - A 2030 framework for climate and energy policies,” 2012.

[5] I. M. de Alegr´ıa Mancisidor, P. D´ıaz de Basurto Uraga, I. Mart´ınez de Alegría Mancisidor, and P. Ruiz de Arbulo López, “European Union’s renewable energy sources and energy efficiency policy review: The Spanish perspective,” *Renewable and Sustainable Energy Reviews*, 2009.

[6] P. Del R´ıo, “Analysing the interactions between renewable energy pro- motion and energy efficiency support schemes: The impact of different instruments and design elements,” *Energy Policy*, 2010.

[7] N. Rajakovi, “Simulation-based optimization of sustainable national energy systems,” 2015.

[8] Á. López-Peña, I. Pérez-Arriaga, and P. Linares, “Renewables vs. energy efficiency: The cost of carbon emissions reduction in Spain,” *Energy Policy*, 2012.

[9] V. Taseska-Gjorgievska, A. Dedinec, N. Markovska, G. Kanevce, G. Goldstein, and S. Pye, “Assessment of the impact of renewable energy and energy efficiency policies on the Macedonian energy sector development,” *Journal of Renewable and Sustainable Energy*, 2013.

[10] S. Mallah and N. Bansal, “Renewable energy for sustainable electrical energy system in India,” *Energy Policy*, 2010.

[11] P. Hennicke, S. Thomas, and W. Irrek, “Towards Sustainable Energy Systems: Integrating Renewable Energy and Energy Efficiency is the Key,” *Discussion paper for Renewables 2004 International Conference, Wuppertal / Eschborn, May 2004*, 2004.

[12] R. Harmsen, B. Wesselink, W. Eichhammer, and E. Worrell, “The unrecognized contribution of renewable energy to Europe’s energy savings target,” *Energy Policy*, 2011.

[13] IRENA, “Synergies between renewable energy and energy efficiency. A working paper based on REMAP 2030,” 2015.

[14] T. M. Lenard, “Renewable Electricity Standards, Energy Efficiency, and Cost-Effective Climate-Change Policy,” *Electricity Journal*, 2009.

[15] H. Lund and B. Mathiesen, “Energy system analysis of 100% renewable energy systems The case of Denmark in years 2030 and 2050,” *Energy*, 2009.

[16] G. Krajačić, N. Duić, Z. Zmijarević, B. V. Mathiesen, A. A. Vučinić, and M. da Graça Carvalho, “Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction,” *Applied Thermal Engineering*, 2011.

[17] D. Connolly, H. Lund, B. Mathiesen, and M. Leahy, “The first step towards a 100% renewable energy-system for Ireland,” *Applied Energy*, 2011.

[18] T. J. Brennan, “Optimal energy efficiency policies and regulatory demand-side management tests: How well do they match?” *Energy Policy*, 2010.

[19] K. Gillingham, R. G. Newell, and K. Palmer, “Energy Efficiency Economics and Policy,” *Discussion paper*, 2003.

[20] J. Tao and S. Yu, “Implementation of energy efficiency standards of household refrigerator/freezer in China:

Potential environmental and economic impacts," *Applied Energy*, 2011.

[21] J. Luukkanen, J. Vehmas, F. Allievi, J. Panula-Ontto, and J. Kaivo-oja, "Synergies and trade-offs between unsustainable trends identified in the European Union- Empirical analysis carried out with the advanced sustainability analysis (ASA) approach," *Research Report. Finland Futures Research Centre. University of Tampere. Tampere*, 2006.

[22] BusinessDictionary.com, "Business Dictionary," 2014. [Online]. Available: http://www.businessdictionary.com/definition/tradeoff.html

[23] V. Oikonomou, F. Becchis, L. Steg, and D. Russolillo, "Energy saving and energy efficiency concepts for policy making," *Energy Policy*, 2009.

[24] C. Christov, K. Simeonova, S. Todorova, and V. Krastev, "Assessment of mitigation options for the energy system in Bulgaria," *Applied Energy*, 1997.

[25] D. Connolly, H. Lund, B. Mathiesen, and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," *Applied Energy*, 2010.

[26] F. Urban, R. Benders, and H. Moll, "Modelling energy systems for developing countries," *Energy Policy*, 2007.

[27] R. Pandey, "Energy policy modelling: agenda for developing countries," *Energy Policy*, 2002.

[28] N. V. Beeck, "Classification of Energy Models," *Tilburg University & Eindhoven University of Technology*, 1999.

[29] G. Conzelmann, "Greenhouse Gas Mitigation Analysis Using ENPEP," *International Atomic Energy Agency*, 2001.

[30] Á. López-Peña, P. Linares, and I. Pérez-Arriaga, "MASTER.SO: a Model for the Analysis of Sustainable Energy Roadmaps. Static Op- timisation version," 2013.

[31] P. Dai, G. Chen, H. Zhou, M. Su, and H. Bao, "CO(2) Mitigation Measures of Power Sector and Its Integrated Optimization in China." *TheScientificWorldJournal*, 2012.

[32] Aalborg University, "EnergyPLAN. Advanced energy systems analysis computer model," 2016. [Online]. Available: http://www.energyplan.eu/

[33] Irena, "A Renewable Energy Roadmap," Tech. Rep. June, 2014.

[34] National Technical University of Athens, "The PRIMES Energy System Model. Summary Description," Tech. Rep.

[35] International Institute for Applied Systems Analysis, "MESSAGE - IIASA." [Online]. Available: http://www.iiasa.ac.at/web/home/research/ researchPrograms/Energy/MESSAGE.en.html

[36] R. Loulou, G. Goldstein, and K. Noble, "Documentation for the MARKAL Family of Models," 2004.

[37] B. H. Dias, A. L. M. Marcato, R. C. Souza, M. P. Soares, I. C. Silva Junior, E. J. D. Oliveira, R. B. S. Brandi, and T. P. Ramos, "Stochastic dynamic programming applied to hydrothermal power systems operation planning based on the convex hull algorithm," *Mathematical Problems in Engineering*, 2010.

[38] Energy Technology System Analysis Program (ETSAP), "TIMES." [Online]. Available: http://www.iea-etsap.org/web/Times.asp

[39] N. T. Nguyen and M. Ha-duong, "The potential for mitigation of CO2 emissions in Vietnam s power sector," 2009.

[40] Z. Hu, X. Tan, F. Yang, M. Yang, Q. Wen, B. Shan, and X. Han, "Integrated resource strategic planning: Case study of energy efficiency in the Chinese power sector," *Energy Policy*, 2010.

[41] J. Yuan, Y. Xu, J. Kang, X. Zhang, and Z. Hu, "Nonlinear integrated resource strategic planning model and case study in China's power sector planning," *Energy*, 2014.

[42] O. van Vliet, V. Krey, D. McCollum, S. Pachauri, Y. Nagai, S. Rao, and K. Riahi, "Synergies in the Asian energy system: Climate change, energy security, energy access and air pollution," *Energy Economics*, 2012.

[43] R. F. Calili, R. C. Souza, A. Galli, M. Armstrong, and A. L. M. Marcato, "Estimating the cost savings and avoided CO2 emissions in Brazil by implementing energy efficient policies," *Energy Policy*, 2014.

[44] A. Pina, C. Silva, and P. Ferrão, "The impact of demand side management strategies in the penetration of renewable electricity," *Energy*, 2012.

[45] R. M. Shrestha and C. O. P. Marpaung, "Integrated resource planning in the power sector and economy-wide changes in environmental emissions," *Energy Policy*, 2006.

[46] R. C. Souza, A. L. M. Marcato, B. H. Dias, and F. L. C. Oliveira, "Optimal operation of hydrothermal systems with Hydrological Scenario Generation through Bootstrap and Periodic Autoregressive Models," *European Journal of Operational Research*, 2012.

[47] B. Apolloni, A. Ghosh, F. Alpaslan, L. C. Jain, and S. Patnaik, *Machine Learning and Robot Perception*, Springer, Ed., 2005.

[48] A. C. Marques and J. a. Fuinhas, "Do energy efficiency measures promote the use of renewable sources?" *Environmental Science and Policy*, 2011.

[49] S. Sorrell, J. Dimitropoulos, and M. Sommerville, "Empirical estimates of the direct rebound effect: A review," *Energy Policy*, 2009.

[50] R. Madlener and B. Alcott, "Energy rebound and economic growth: A review of the main issues and research

needs," *Energy*, 2009.

[51] L. A. Greening, D. L. Greene, and C. Difiglio, "Energy efficiency and consumption - the rebound effect - a survey," *Energy Policy*, 2000.

[52] R. Madlener and M. Hauertmann, "Rebound Effects in German Residential Heating: Do Ownership and Income Matter?" *FCN Working Paper*, 2011.

[53] B. Ćosić, N. Markovska, V. Taseska, G. Krajačić, and N. Duić, "The potential of GHG emissions reduction in Macedonia by renewable electricity," *Chemical Engineering Transactions*, 2011.