# *OPTIMAL SELECTION OF GREENHOUSE GAS EMISSIONS ABATEMENT MEASURES UNDER UNCERTAINTY: THE CASE OF CYPRUS*

Marios Karmellos, The Cyprus Institute, +357 22 397 502, m.karmellos@cyi.ac.cy
Chryso Sotiriou, Cyprus University of Technology, cx.sotiriou@edu.cut.ac.cy
Theodoros Zachariadis, The Cyprus Institute, +357 22 208 720, t.zachariadis@cyi.ac.cy

## Overview

Tackling climate change is perhaps the major challenge our planet faces. In this context, the reduction of Greenhouse Gas Emissions (GHG) is of paramount importance. Therefore, policymakers need to design and implement appropriate and cost-effective strategies. In the EU, several policy packages have been designed up to now, culminating in the European Green Deal and subsequenstly the recent 'Fit for 55' package, with concrete and ambitious targets to boost green transition and make the EU a carbon-neutral economy.

Cyprus, a member-state of EU needs to follow these targets and to that end it needs to select an appropriate set of measures. For this purpose, a Marginal Abatement Cost Curve (MACC) was developed by Sotiriou et al. [1] to serve as a useful tool for the selection of the least-cost GHG emission abatement pathways. Furthermore, a framework for the optimal identification of a set of measures has been developed and applied by Sotiriou and Zachariadis in [2,3], using a single-objective and a multi-objective mathematical programming model. Nevertheless, these models fail to grasp the impact of uncertainties in techno-economic and the dynamic policy context that changes frequently. The present paper aims to present a model for the optimal selection of GHG emissions abatement measures under uncertainty, particularly using stochastic optimisation (Monte Carlo Simulations).

## Methods

Following the model developed by Sotiriou and Zachariadis [2] the optimal selection of abatement measures is calculated by minimising the total discounted abatement cost as shown in eq. (1):

$$min\ [Z_1] = \sum_j \sum_t AC_{j,t} * a_{j,t} \qquad (1)$$

where, $a_{j,t}$ is the GHG abatement, including emissions of $CO_2$, $CH_4$, and $N_2O$, achieved by the $j^{th}$ mitigation option for the year t, and $AC_{j,t}$ is the discounted abatement cost associated with each measure for a specific year. The abatement cost is expressed in Euros per tonne of $CO_{2e}$ emissions avoided and $a_{j,t}$ is expressed in avoided annual emissions in tonnes of $CO_{2e}$.

Monte Carlo is based on the construction of probabilistic scenarios for the uncertain parameters, which are assumed to follow a specific probabilistic distribution, out of which a value is drawn for each iteration. The result of this approach is the generation of a set of probable solutions. The models for both the deterministic and stochastic problems have been developed with Pyomo, a Python-based open-source software package [4].

To examine the impacts of uncertainty extensively two scenarios have been constructed:

(1) Scenario 1: Uncertainty only in the speed of implementation for each measure;
(2) Scenario 2: Uncertainty in the speed of implementation for each measure, and additionally in the abatement cost.

Furthermore, these scenarios are also examined for two cases (similarly to [3]):

(1) Case 1: The basic approach, in which the only the economic abatement costs are associated with each measure;
(2) Case 2: An approach where the abatement costs include also the external costs of GHG, $NO_x$, $SO_2$, and PM emissions.

A set of basic and advanced mitigation measures have been considered, which aim to tackle emissions from several sectors – industry, road transport, and agriculture. These measures have been deemed to be suitable in regards to the Cypriot efforts towards reducing GHG emissions and are analytically described in [2,3]. The parameters that were assumed to be uncertain are the speed of implementation and the abatement cost, following a specific probability distribution for each measure. Typically, uncertainty exists in parameters such as fuel costs, electricity cost, or demand for a specific measure. However, abatement cost and speed of implementation are calculated externally and are used as input parameters in the model. Therefore, to avoid constructing a large and complex model an auxiliary parameter was introduced, which would reflect a variation of its deterministic value, as shown in eq. (2):

$$y = u \times (1 + r) \qquad (2)$$

where, $y$ the value of the uncertain parameter, $u$ the original value of the parameter for each measure, and $r$, a random generated number based on the respective probability distribution. Parameters were assumed to follow typical probability distributions, such as normal, triangular, and uniform. More details regarding the combination of mathematical programming and Monte Carlo simulations can be found in literature [5].

## Results

The optimisation problem has been solved for each respective scenario and case, for a total of 1000 iterations, using different random numbers for the period until 2030, with an abatement target of 928.12 t $CO_{2e}$, following the official GHG emissions commitment of Cyprus. The results are depicted on violin plots in **Error! Reference source not found.**. It is noted that the total cost for the deterministic model is -133.93 M€ and -1099.24 M€, for Case 1 and Case 2, respectively. Evidently there are major differences between Case 1 and Case 2, given that considering the external costs of GHG, $NO_x$, $SO_2$, and PM decreases the abatement cost dramatically.

Moreover, there are significant variations between the deterministic model and the stochastic models. In both cases adding uncertainty to the parameters causes an increase in the total cost of the system. For Case 1, in scenario 1 the expected value of the cost for the stochastic model is approximately -69.44 M€, while in scenario 2 it is -45.8 M€, which is 48% and 66% higher compared to the deterministic scenario, respectively. In Case 2, the impacts of uncertain parameters are much more evident. Particularly, in scenario 1 the expected value of the stochastic model is -542.31 M€, whereas for scenario 2 it is -524.51 M€ (an increase of approximately 50% and 52% respectively from the respective deterministic value). The violin plots are a useful way of illustrating the probability distributions of the results. It can be observed that for Case 1, more values are around the median, whereas for Case 2 there is higher variation.

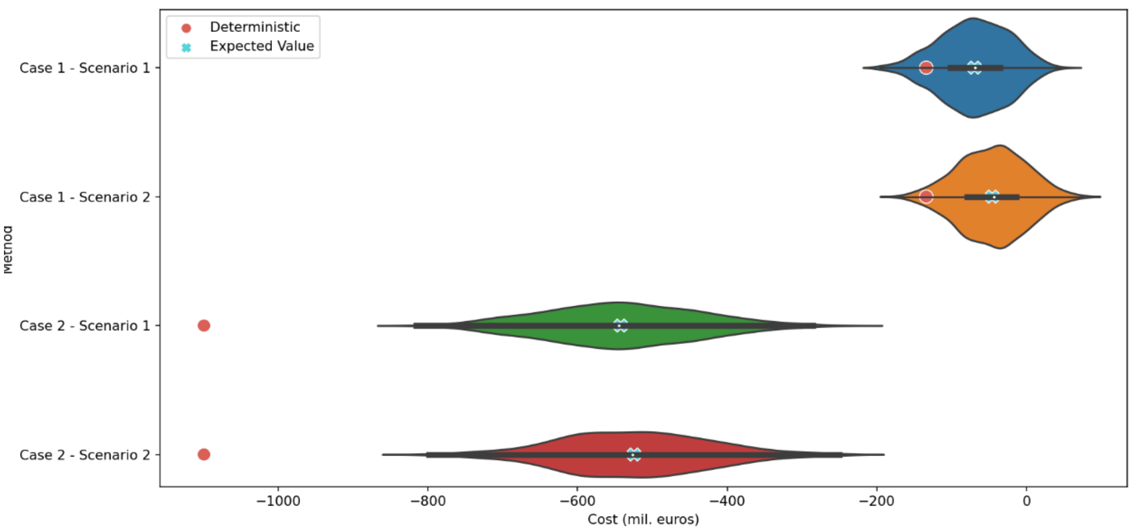


*Figure 1. Violin plots for the variation of the total cost under each scenario and case in 2030*

## Conclusions

This model highlights the impact of uncertainty for the optimal selection of cost abatement measures. For this type of long-term problems policy-makers need to consider variations in the values of specific parameters, as the results might change significantly. Therefore, this tool could help making a more risk-averse selection of measures, while also following the target of GHG emissions reduction set in the relevant EU policies.

## References


[1] Sotiriou C, Michopoulos A, Zachariadis T. On the cost-effectiveness of national economy-wide greenhouse gas emissions abatement measures. Energy Policy 2019;128:519–29. https://doi.org/10.1016/j.enpol.2019.01.028.

[2] Sotiriou C, Zachariadis T. Optimal timing of greenhouse gas emissions abatement in Europe. Energies 2019;12. https://doi.org/10.3390/en12101872.

[3] Sotiriou C, Zachariadis T. A multi-objective optimisation approach to explore decarbonisation pathways in a dynamic policy context. J Clean Prod 2021;319:128623. https://doi.org/10.1016/j.jclepro.2021.128623.

[4] Bynum ML, Hackebeil GA, Hart WE, Laird CD, Nicholson BL, Siirola JD, et al. Pyomo — Optimization Modeling in Python. vol. 67. Cham: Springer International Publishing; 2021. https://doi.org/10.1007/978-3-030-68928-5.

[5] Mavrotas G, Florios K, Vlachou D. Energy planning of a hospital using Mathematical Programming and Monte Carlo simulation for dealing with uncertainty in the economic parameters. Energy Convers Manag 2010;51:722–31. https://doi.org/10.1016/j.enconman.2009.10.029.