A modified-MVA approach for sustainable electricity planning: the case of Portugal

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ABSTRACT

The use of the mean-variance approach (MVA) is well demonstrated in the financial literature for the optimal design of financial assets portfolios. The electricity sector portfolios are also guided by similar objectives, namely maximizing return and minimizing risk. Based on this assumption, this paper proposes a possible MVA for the definition of optimal electricity portfolios relying on renewable energy sources (RES). The model was applied for the Portuguese case and the results demonstrated that the less risky solutions are characterised by a mix of RES technologies. Though recognising the usefulness of the proposed MVA, this case also evidence the need to further proceed with a modified approach recognizing the technical constraints and specificities of the electricity sector.

KEYWORDS

Renewable energy sources, Electricity generation, portfolio selection, mean-variance approach, investment risk

INTRODUCTION

The need for investing in renewable energy sources (RES) is clear given the possibility of depletion of finite resources of earth. This is particularly important for the case of electricity generation, since a project of electricity generation is characterized, in the long run, by high uncertainty and its impact on society and the population's well-being.

With the growth in the deployment of RES in Portugal along with the liberalization of energy markets and the integration in the Iberian electricity market (MIBEL), it becomes pertinent to study possible scenarios of exploiting RES (e.g. hydro, wind, photovoltaic, biomass) in electricity generation projects to ensure the necessary power to customers and quality in supply, while conveying a sense of trust to consumers. Therefore, becomes crucial to introduce methodologies that allow including in electricity planning the correlation between various electricity generation technologies projects, as well as the respective risk.

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For that purpose, recent works (e.g. [1], [2], [3], [4], and [5]) have demonstrated how the mean-variance approach (MVA), formerly applied for investment in portfolios of financial securities, can be adjusted for using in the selection of electricity generation portfolios, as an alternative to the traditional least cost approach. However, it should be recognized that the characteristics of electricity generation technologies are not always comparable to the characteristics of financial assets. Therefore, there is the need to enrich this approach with additional technical, legal and economic constraints when passing from financial markets to the analysis of portfolios of generation technologies projects.

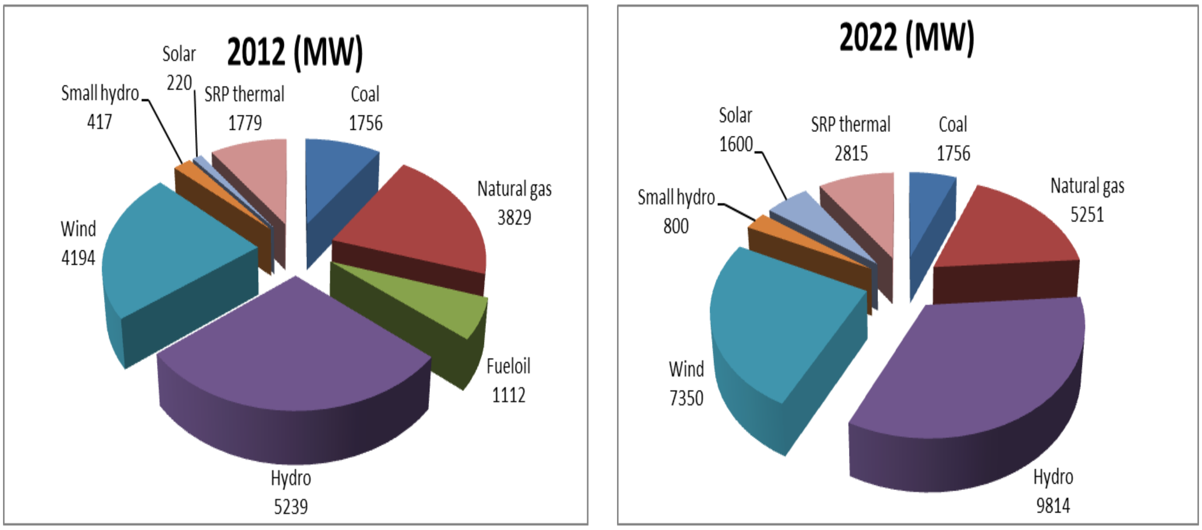
In this paper, a modified-MVA approach including the above mentioned features is proposed for electricity generation planning for the Portuguese case, emphasising the particular role of RES technologies. The preliminary results of the study showed the usefulness of this approach for electricity power planning in a system with strong RES influence contributing to a sustainable future. Simultaneously, it was possible to compare the set of portfolios resulting from the application of the modified-MVA with the combination of technologies currently comprising the Portuguese electricity system. An advantage of the proposed approach is that it enables policy makers to consider the mix of electricity generation technologies from a broader perspective.

The remainder of the paper is organised as follows. Section 2 presents a brief description of the Portuguese electricity sector emphasising the role of RES. Section 3 presents the theoretical foundations of the MVA approach in the context of electricity generation planning. Section 4 describes the empirical study undertaken focusing on the Portuguese case of a generation system comprised only of RES. Section 5 draws the main conclusions and presents avenues for future work.

PORTUGUESE ELECTRICITY SECTOR

In this section, a brief description of the Portuguese electricity generating system is presented, which is characterised by a diversified structure including several technologies as can be seen in Figure 1. The total installed power reached in 2012 about 18,546 MW, distributed between thermal power plants (coal, fuel oil, natural gas and gas oil), hydro power plants and Special Regime Producers (SRP), as detailed on Panel a) of Figure 1. One feature that should be highlight is the significant share of RES in the current technological production mix. In fact, the role of RES has been increasing over the years due to the government objectives of reducing energy imports and CO_2 emissions. Included also on the generation system is the SRP which comprises the small hydro generation, the production from other renewable sources and the cogeneration. Although these producers have priority access to the grid system under the established feed-in tariffs for the licence period, their integration in the grid is dependent on the energy policy decision makers calls and on tender procedure with specific criteria.

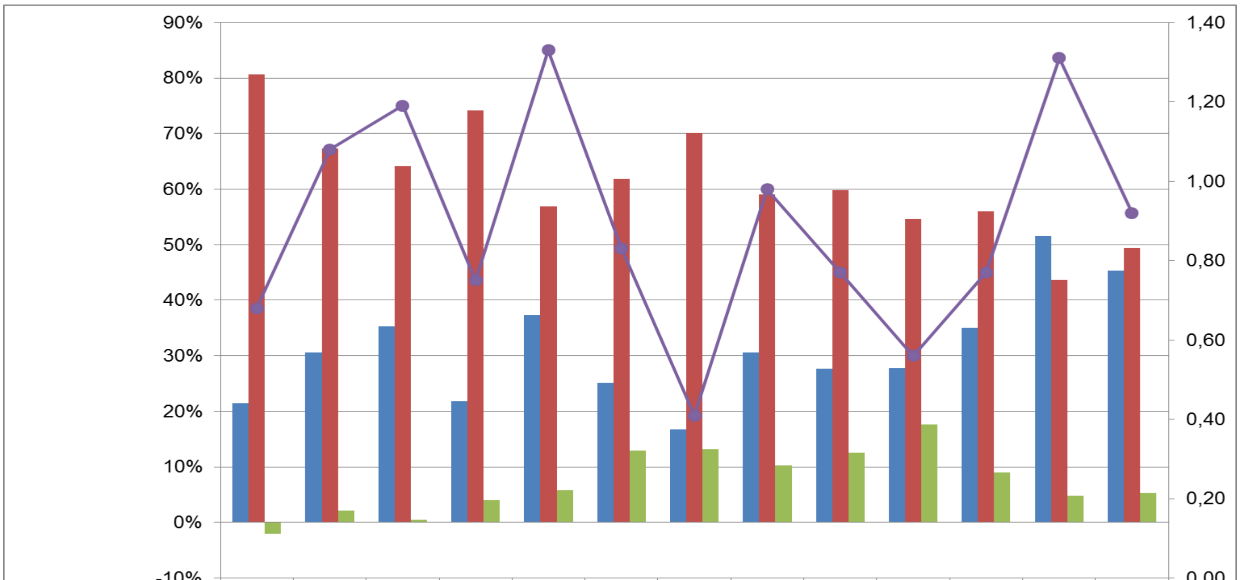
In Panel b) of Figure 1, the forecasted electricity generation mix of 2022 is displayed which confirms the goal of increasing the share of RES in electricity production as well as that of natural gas. At the same time, it is foreseen that the installed capacity of coal power stations will remain unchanged and those power stations based on fuel oil will be shutdown. This forecasted scenario reflects the Portuguese strategy for the electricity system, based on RES and natural gas growth, and is constrained by international environmental agreements, namely the Kyoto protocol and RES Directive, and represents a clear effort for the promotion of endogenous resources, reduction of external energy dependency and diversification of supply.



Panel a. Panel b.

Figure 1. Distribution of the total installed power in Portugal in 2012 (Panel a.) and the forecasted scenario for 2022 (Panel b.). (Source: [6])

Figure 2 gives another perspective of the Portuguese electricity system based on the evolution of the share of electricity consumption from RES, thermal sources and imports for the period 1999-2011. Again, one can see the increasing share of RES on electricity consumption along those years, starting with a share of 21% in 1999 and reaching a value of 45% in 2011.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Renewables	21%	31%	35%	22%	37%	25%	17%	31%	28%	28%	35%	52%	45%
Themal	81%	67%	64%	74%	57%	62%	70%	59%	60%	55%	56%	44%	49%
Imports-Exports	-2%	2%	1%	4%	6%	13%	13%	10%	12%	18%	9%	5%	5%
HPI	0,68	1,08	1,19	0,75	1,33	0,83	0,41	0,98	0,77	0,56	0,77	1,31	0,92

Figure 2. Evolution of the share of electricity consumption from RES, thermal sources and imports in Portugal, 1999-2011, and the hydroelectricity productivity index (HPI). Source: Own elaboration of [7].

The share of RES is mainly due to large hydro-power and wind-power plants. It should also be noted that, regarding hydroelectricity production, total RES contribution is extremely vulnerable to the rainfall conditions, which explains why in rainy years, such as 2003 and 2010, the share of RES in total production was higher than in remaining years (37% and 52%, respectively) and in dry years, such as 2005, its share is lower. This pattern is also shown by the evolution of the Hydroelectricity productivity index (HPI) which is much higher in rainy years than in dry years. The results also demonstrate that in most recent years the impact of the HPI on the overall RES share is not as high as in the first years of the 2000 decade, which is largely explained by the increasing role of wind power able to smooth to a certain extent the impacts of a dry year.

ELECTRICITY GENERATION PLANNING AND THE MVA APPROACH

Electricity generation planning is related to energy and demand forecasting, supply-side and demand-side management adjustments, analysis of alternative expansion plans, determination of the optimal strategy and the evaluation of financial implications and its feasibility [8].
The traditional approach to electricity generation planning has been the least-cost methodology, which is based on calculating the levelised costs of electricity generation, expressed in €/MWh, for different alternative production technologies and, after comparing those costs, choose the one with the lowest cost.

However, since different technologies are considered in electricity planning which differ not only in terms of costs but have also in terms of the associated level of risk, some authors (e.g. [1], [2], [3], [4], and [5]) argue that a better alternative methodology would be the use of the mean-variance approach.

For example, in the context of combining conventional and renewable technologies for electricity production, [1] emphasises that although renewables may present a higher levelised cost, it does not necessarily mean that the overall cost of the portfolio of generation technologies become more expensive due to the statistical independence of renewables costs, which tend not to correlate with fossil-fuel prices. In fact, the inclusion of renewable technologies in an electricity generation portfolio is a way to reduce the cost and risk of the portfolio, although in a stand-alone basis the cost of those renewable technologies might be higher [2]. Therefore, electricity generation planning should be focused more on developing efficient generation portfolios and less on finding the alternative technology with the lowest production cost ([1] and [2]).

The MVA approach was initially proposed by [9] for the efficient selection of financial investment portfolios and is based on an investor's goal of maximising future expected return for a given level of risk he is willing to take. The main underlying assumption is that investors are risk averse which means that when faced with the choice between two investments with the same standard deviation they always choose the one with higher expected return. Therefore, the MVA approach allowed to explain the advantage that an investor has to diversify their investments among several financial securities.

Since the expected return, $E(r_P)$, and the variance, σ^2_P, for a given investment portfolio, P, comprising N assets is, respectively:

$$E(r_P) = \sum_{i=1}^{i=N} \omega_i E(r_i) \quad (1)$$

and

$$\sigma_P^2 = \sum_{i=1}^{i=N} \sum_{j=1}^{j=N} \omega_i \omega_j \rho_{ij} \sigma_i \sigma_j \quad (2)$$

One concludes that the variance of a portfolio is partially determined by the variance of individual assets and partly by the way they move together – the covariance of the assets belonging to the portfolio (which can also be measured statistically by the coefficient of correlation). And is this term that explains why and in what amount portfolio diversification reduces the risk of investment. Therefore, portfolios of financial assets should be chosen not only based on their individual characteristics but taking also into account how the correlation between assets affects the overall risk of a portfolio [10]. This suggests that the proportion (or share) of each asset in the portfolio can be determined solving the following optimisation problem:

$$
\begin{aligned}
&Max \mathrm{E}(r_P) = \sum_{i=1}^{i=N} \omega_i E(r_i) \\
&s.t. \\
&\sigma_P^2 = \sum_{i=1}^{i=N} \sum_{j=1}^{j=N} \omega_i \omega_j \sigma_{ij} \leq \hat{\sigma}^2 \\
&\sum_{i=1}^{N} \varpi_i = 1 \\
&\varpi_i \geq 0
\end{aligned}
$$

where two additional restrictions have been included: the fact that the sum of individual share of each asset is equal to one; and that the share of each asset is a non-negative number.

In the following section an application of the MVA approach to the case of Portuguese electricity generation planning is shown, with a particular focus on the role of RES technologies.

EMPIRICAL STUDY

One advantage of the MVA approach is the fact that it explicitly recognize portfolio risk as a decision variable influenced by the risk of each technology output and, most importantly, by the correlations between those risks. In the empirical study undertaken, the main goal was to present possible RES generation mixes that would ensure minimum cost for each given portfolio risk level, obtaining the correspondent efficient frontier. The use of the Portuguese case, as an electricity system strongly influenced by RES seasonality behaviour, is expected to contribute to demonstrate how MVA approach can provide a way to complement cost optimization models with a quantitative risk evaluation of the electricity generation portfolio.

To solve the optimisation model, 2010 data drawn from public information available on REN site (www.ren.pt) was used. The data consisted, for each technology included in the study (i.e. wind, small-hydro, and photovoltaic), of the load output measured for each quarter of an hour for a one year period, which comprises 35,040 measures for each technology, which allowed to capture the daily and yearly seasonality of RES technologies output. To get some insights about this variability, Figure 3 shows the monthly average of the load output of wind, small-hydro, and photovoltaic.

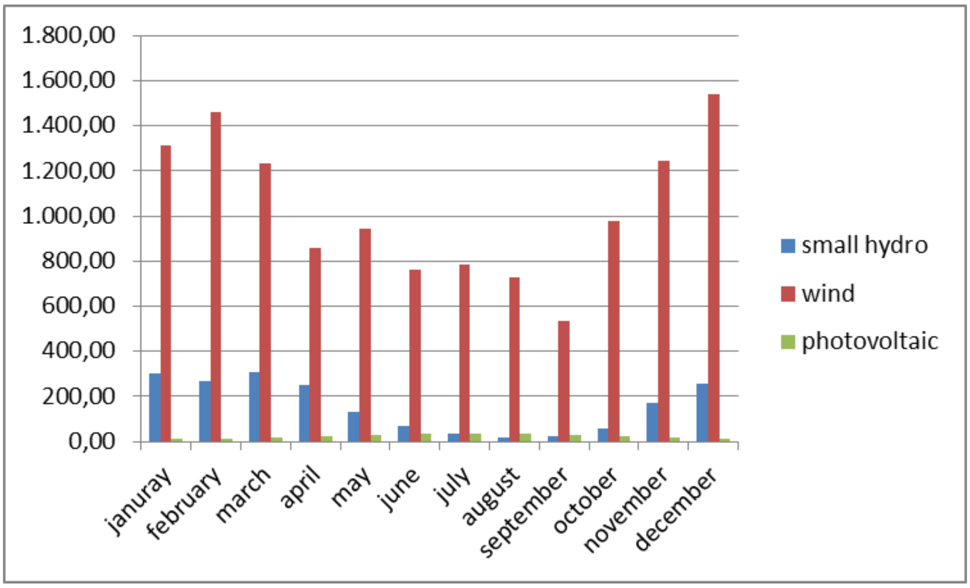


Figure 3. Monthly average of load output for wind, small-hydro, and photovoltaic, in 2010. (Source: Own elaboration of [6] data)

From the figure one can observe the high variability of the RES output, which is mainly due to the non-storage capacity of RES production. The wind and small-hydro output production is much higher on autumn and winter seasons than in summer whereas for photovoltaic the contrary happens. As for the small hydro power plants most of them do not present storage capacity and as so it was assumed that their production could represent a proxy variable for the hydro availability. Both the wind power and photovoltaic loads were assumed as proxy variables for the underlying resource availability.

To allow for comparability among variables, the output of each technology (wind, small-hydro, and photovoltaic) was normalized by the installed power in 2010. The proxy variables included on the proposed MVA model are characterised in Table 1 and include the normalized wind power output, representing the wind availability of the system; the normalized small hydro output, representing the hydro inflows (hydro availability) to the system; and the normalized photovoltaic output, representing the sun availability of the system.

Table 1. Characteristics of the proxy variables for MVA models.

	Wind	Hydro	Photovoltaic
Mean (MW/Installed MW)	0,278	0,383	0,194
Standard deviation (MW/Installed MW)	0,210	0,281	0,264
Correlation coefficient			
Wind	1	0,335	-0,255
Hydro		1	-0,152
Photovoltaic			1

The optimisation problem aims to achieve an efficient frontier with the objective of minimising the total expected cost of the RES system per unit of installed capacity for each risk level. The optimization model is described by (3) to (6).

Objective function:

$$\text{Min } E(\mathrm{LC_P}) = \sum_{i=1}^{3} \mathrm{W_i LC_i E(L_i)} \tag{3}$$

Constraints:

$$\sigma(\mathrm{LC_P}) = \sqrt{\sum_{i=1}^{3} W_i^2 \mathrm{LC}_i^2 \sigma_i^2 + \sum_{i=1}^{3} \quad \sum_{k=1(k\neq i)}^{3} W_i\, W_k \rho_{ik} \sigma_i \mathrm{LC_i} \sigma_k \mathrm{LC_k}} \tag{4}$$

$$\sum_{i=1}^{3} \mathrm{W_i} = 1 \tag{5}$$

$$\mathrm{W_i} \geq 0 \quad \forall_i \tag{6}$$

where $E(LC_p)$ represents the expected levelised cost of the portfolio per unit of installed capacity, $\sigma(LC_p)$ represents the standard deviation of levelised cost of the portfolio and LC_i represents the levelised cost of each i technology.

Figure 4 and Table 2 describe the results obtained, including the efficient frontier and the characterization of a set of optimal portfolios.

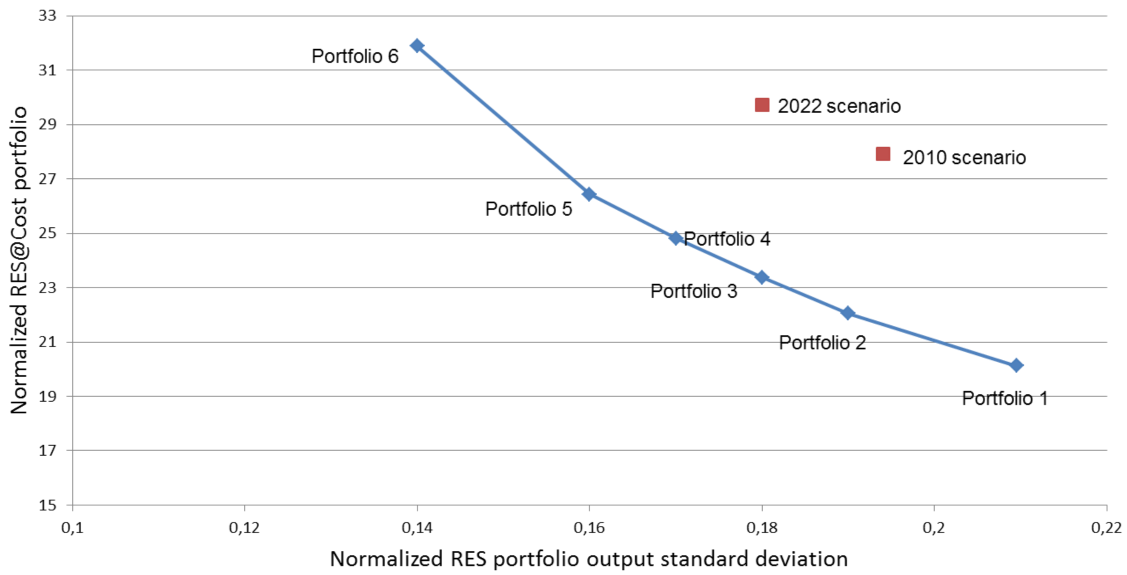


Figure 4. Efficient frontier for minimizing the levelised cost of the portfolio

Table 2. Characterization of the set of optimal portfolios

	$\sigma(LC_p)$	$E(LC_p)$	Wind	Hydro	Photovoltaic
Portfolio 1	0,21	20,13	100%	0%	0%
Portfolio 2	0,19	22,05	85,5%	14,3%	0,2%
Portfolio 3	0,18	23,37	80,8%	15,1%	4,2%
Portfolio 4	0,17	24,81	75,5%	16,0%	8,5%
Portfolio 5	0,16	26,43	69,7%	17,0%	13,3%
Portfolio 6	0,14	31,88	50,0%	20,4%	29,6%
2010 Scenario	0,194	27,92	42,03%	56,59%	1,38%
2022 Scenario	0,18	29,71	38,22%	53,46%	8,32%

From the figure and the table the following findings emerge. Firstly, the results seem to be driven by the levelised cost of the technologies. Secondly, a strong reliance on wind power is evident along the efficient frontier. Thirdly, what seems to be the best solution (Portfolio 1) in terms of minimum cost achieved is, however, compromised by a 100% wind power share. From a technical point of view it would be a nonsense solution, due to the already existing hydro capacity and for motives of security of supply. Fourthly, the solutions with lower risk (e.g. Portfolio 6) are characterized by a mix of wind, hydro and photovoltaic technology. Fifthly, the 2010 mix and the 2022 forecasted scenario are far from the efficient frontier. This means that, for example, it would be possible to decrease the cost of the portfolio of electricity generation technologies for the same level of risk and, therefore, increase the efficiency of the production mix. Finally, it should be noted that the proposed MVA model only included data related to small hydropower plants, which show a much higher variability than large storage hydropower.

CONCLUSION

Sustainable development depends, in some extent, on changing the electricity generation paradigm. In this regard, RES have an important role for the design of strategies for sustainable future. These strategies have been fostered by several international environmental agreements, such as the Kyoto protocol and the RES Directive, which have the advantage, for countries like Portugal, of promoting the use of endogenous resources, reducing external energy dependency and diversifying energy supply.

However, the raising trend of RES brings considerable challenges to decision makers due to uncertainty of the production highly dependent on the availability of the underlying resources. Therefore, this paper was an attempt to apply an alternative tool for electricity planning – the MVA approach – in relation to the traditional least cost methodology. This allowed addressing both the expected return and the RES portfolio risk, taking into account both the standard deviation of each technology output and the correlation coefficient between technology outputs.

The major findings of the study were that less risky solutions are characterised by a mix of RES technologies and that both the 2010 production mix and the 2022 forecasted scenario are far from the efficient frontier.

Though recognising the usefulness of the MVA approach for electricity generation planning, the results obtained seem to indicate that this approach should be enriched with additional technical, legal and economic constraints given the different nature of financial assets (for which the MVA approach was initially proposed) and real assets (as is the case of power plants). Therefore, future work envisages the development of a new model combining the MVA approach with generation expansion models for electricity power planning.

ACKNOWLEDGMENT

This work was financed by: the QREN – Operational Programme for Competitiveness Factors, the European Union – European Regional Development Fund and National Funds-Portuguese Foundation for Science and Technology, under Project FCOMP-01-0124-FEDER-011377 and Project Pest-OE/EME/UI0252/2011.

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