

Evaluation of Cyprus' Electricity Generation Planning Using Mean-Variance Portfolio Theory

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Abstract

This paper utilises Mean-Variance Portfolio (MVP) theory, originally developed for financial portfolios, to evaluate the planned electricity generation mix for the country of Cyprus. The current generation mix, which consists entirely of oil, was found to be highly inefficient, exposing the country to unnecessary price risk and higher costs. Results show that if 60% of the oil in the generation mix is replaced with natural gas, the cost of electricity generation will be reduced by 30% and the variability of the cost will be reduced by 15%. The addition of a 10% share of wind to the oil-gas portfolio was found to reduce the overall risk by up to 8%, without imposing any extra cost. The potential diversification into coal was deemed to be doubtful due to its sensitivity to the price of carbon dioxide (CO₂) and its environmental impact.

Keywords: Mean-variance portfolio, electricity generation, energy policy, Cyprus.

1. Introduction

Cyprus is the third largest island in the Mediterranean with an area of 9,250 square kilometres and a population of about 877,600 inhabitants¹ [Cyprus Statistical Service, 2007]. Cyprus has a strong and prosperous economy characterised by macroeconomic stability. It relies mainly on the tourism and services sectors and depends greatly on imports of raw materials and capital goods.

Indigenous energy sources on the island include wind, biomass and solar energy. The Cyprus Ministry of Commerce, Industry and Tourism (MCTI) considers the development of wind farms on the island to be "the most effective and economically efficient way of achieving the target" of 6%

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¹ The population does not include the illegal settlers from Turkey (currently estimated at around 160,000) residing in the Turkish occupied part of Cyprus.

contribution of RES to the total electricity production by 2010 [Gogakis, 2007].

Towards meeting this objective the Cyprus Energy Regulatory Authority (CERA) granted, by the end of 2007, 22 licences for the construction of wind farms on the island with a total generating capacity of 454.7MW [CERA, 2007]. At that time, there were also a number of other licences under review by the CERA, which amounted to an additional 228.4MW of generating capacity. It should be noted that the actual construction of the first wind park (maximum capacity 82MW) has only very recently been commissioned (in July 2009) and should be completed by the end of 2010.

The production of energy from biomass in Cyprus refers mainly to the exploitation of agricultural residues and municipal waste. The cultivation of energy crops to produce biofuels is not a viable option on the island due to the lack of irrigation water and inadequate land plot area. Nevertheless, by the end of 2007, CERA had granted 14 licences for the generation of electricity from biomass with a total generating capacity of approximately 9MW [CERA, 2007].

Energy generation from the sun is also a very attractive choice for Cyprus due to the sunny climate of the island. However, the cost of producing electricity from solar energy through photovoltaics (PV) remains a very expensive option, so their application is very limited in Cyprus, as is the case worldwide. The situation has improved since the Electricity Authority of Cyprus (EAC) adopted a renewable energy subsidisation scheme in 2005. Under this scheme, 55% of the initial PV installation cost is subsidised and the produced electricity is bought by the authority at a fixed price of 0.12£/kWh (in Cypriot Pounds) or 0.21€/kWh. Nevertheless, their application remains on a small-scale basis.

Energy from the sun is utilised in Cyprus, however not for electricity generation, but for heating water. In fact, Cyprus is the world leader in solar thermal energy usage with an estimated 0.9m² installed collector area per inhabitant or 63MWth per 100,000 inhabitants [Weiss, Bergmann, Faninger, 2006]. This has earned the island the 2006 Ali Sayigh World Renewable Energy Congress (WREC) Trophy.

In addition to these established energy sources, there has recently been a discovery of oil and/or gas reserves off the south coast of the island. In 2008 the Cyprus government launched a first round of Hydrocarbon Exploration licences for 11 of the exploration blocks within the exclusive economic zone of the Republic [MCIT, 2009]. Cyprus has also signed deals with Egypt and Lebanon on mutual exploitation of hydrocarbon deposits that cross their boundaries.

Although Cyprus is a world leader in solar thermal energy, electricity generation on the island is based exclusively on oil. Up to now electricity has been provided solely by the EAC, which is a semi-governmental organisation. However, in order to comply with EU regulations the electricity generation markets will be completely liberalised by the end of 2013 [MCIT, 2009]. The distribution of electricity, however, will be done through the existing network of the EAC. The EAC owns and operates three power stations with a total nominal capacity of 1118MW.

Cyprus's energy policy is perfectly aligned with the energy policy of the European Union. The main objectives aim at ensuring an adequate, secure and sustainable energy supply, and increasing the competitiveness of the economy, while respecting the country's environment.

The measures taken to meet these objectives include the deregulation of the energy markets as well as the promotion of sustainable development in the energy sector by promoting the efficient use and conservation of energy. However, the two main measures, which are more the concern of this investigation, are the government's decision to diversify into other forms of energy, primarily natural gas and Renewable Energy Sources (RES).

Natural gas will be transported to Cyprus by ships in the form of Liquefied Natural Gas (LNG). This was deemed to be the most economic and the safest means of transporting the fuel due to the island's isolated geographic position with regards to other European gas networks. On the other hand, RES in Cyprus have to make up 6% of the total electricity generation by the year 2010 so as to comply with EU regulations (Directive 2001/77/EC). The new EU Directive 2009/28/EC sets a legally binding target for RES on the island of 13% of the total final energy consumption by 2020.

Since electricity generation on the island is currently done solely through oil, almost any form of energy diversification would be beneficial. However, to what extent should the government diversify using natural gas? To what degree will the addition of RES, in the form of wind energy, prove to be economically beneficial? Should the government diversify only into natural gas and RES or should it consider other forms such as coal? What would be the benefits of diversification in terms of cost and risk reduction, when taking into consideration physical constraints, such as the RES potential for the island? This report addresses all the above questions by applying MVP theory to the electricity generation of the island.

2. Literature review

2.1 Energy security

Energy security issues are often perceived as matters that deal with the abrupt disruption in the supply of energy sources to a particular country. A recent example of this was the interruption of natural gas supplies to Ukraine by Russia in January 2009, after a dispute between the two countries. The dispute also affected gas supplies to many other European countries.

This paper, however, deals with another equally important aspect of energy security: the risk of an unexpected rise in the cost of electricity in a particular country [Awerbuch, Berger, 2003]. This effect is made more profound when the country's electricity generation mix is not efficiently diversified and hence is needlessly exposed to cost price fluctuations.

2.2 Previous work on energy planning using MVP

In finance, investors use portfolio theory to minimise the risk and maximise the return of their portfolio by diversification. A perfectly diversified portfolio will eliminate the stand-alone or idiosyncratic risk of each stock while maximising the overall return. This idea was first proposed by Nobel Laureate Harry Markowitz in 1952 and is widely known as Mean-Variance Portfolio (MVP) theory.

MVP theory can be used in electricity generation planning to evaluate the addition of each new alternative on the basis of its contribution to the overall risk and cost of the generation mix and not on its stand-alone cost. For example, the idea that adding a more costly alternative, such as wind, can actually serve to reduce the portfolio-generating cost, derives from the fact that wind-generating costs do not correlate or co-move with fossil prices. Therefore, the addition of wind can help to diversify the generating mix and enhance its cost-risk performance [Awerbuch. 2006]. In layman's terms the theory supports the phrase: "Don't put all your eggs in one basket".

Oil prices have been shown to have a negative impact on economic activities in fossil-fuel importing nations. With the increase in fossil-fuel prices in the last 20 years, a growing volume of literature has emerged on the Oil-GDP relationship. Awerbuch and Sauter (2006) argue that the economic losses brought about by the Oil-GDP relationship can be reduced by increasing the share of RES or other fixed-cost technologies in the generation mix. Furthermore, they estimate that the cost of installing RES

to meet national targets can be partly or completely offset by avoided GDP losses.

Awerbuch and Berger (2003) performed an analysis of the EU electricity generation policy by applying MVP theory. The results indicated that the existing and projected EU mixes are sub-optimal from a risk-return perspective, meaning that feasible portfolios with lower cost and risk exist. A subsequent study by Awerbuch and Yang (2007) further analyses the projected 2020 EU generation mix. Their results also suggest that greater shares of non-fossil technologies, primarily nuclear and wind, can help to reduce the cost and risk of the EU generating portfolio as well as its CO₂ emissions.

Other case studies of smaller generation mixes have been performed using MVP for countries such as the Netherlands [Jansen, Beurskens, van Tilburg, 2006], Ireland [Doherty, Outhred, O'Malley, 2005] and Scotland [Awerbuch, Kansen, Beurskens, 2005]. All these studies have yielded similar results to support the deployment of fixed-cost RES such as wind. The inclusion of a CO₂ cost in these investigations serves to fortify the result even further, as it makes alternatives with zero emissions more attractive. This investigation is essentially a case study along the same lines for the country of Cyprus.

3. Methodology

The alternatives used in this investigation were Oil, Natural Gas, Coal and Wind. Oil is now the only means of generating electricity on the island, however the infrastructure to import natural gas in the form of LNG is currently under construction. Wind is the most economically feasible and the fastest growing RES both in Cyprus and in Europe. Coal was considered as an alternative in order to investigate its potential for further diversification into other conventional sources of electricity generation. Solar energy was not considered in this report due to its high generating cost as compared to the other alternatives.

The generating cost for each alternative was partitioned into five sub-groups, namely: Fuel cost, Operating and Maintenance (O&M) cost, Capital or Construction cost, CO₂ cost and System Integration cost. The System Integration cost was included in the overall cost for wind, since wind is considered to be a variable-output technology. For this reason some level of back-up generation capacity is required to balance the system when the output is reduced.

Details of the equations used in the report can be found in the Appendix.

3.1 Expected electricity generating cost and return

The first step in the methodology was the determination of the expected electricity generating costs and returns. The generating cost was measured in €/kWh. The relevant return is simply the inverse of the generating cost, measured in kWh/€ [Berger, 2003]. In other words, the return represents the amount of electricity (kWh) generated, for every unit of currency (€) spent.

3.2 Expected portfolio risk

Then the expected portfolio risk for each generation mix was quantified using the expected year-to-year fluctuation in the generating cost of the mix. This required the use of Holding-period returns (HPR). Holding-period returns are a measure of the rate of change in a particular cost stream from one year to the next.

3.3 Data required for calculating the optimal generating portfolios

To calculate the optimal generating portfolios of every sub-category of each alternative, three sets of data are required: The generating cost (kWh/€), the HPR standard deviation and the correlation coefficients.

3.3.1 Generating costs

Table 1 below shows the levelised generation costs for the four technologies, using a discount rate of 5%. The time series of expenditures were discounted to their present values by applying a discount rate, which takes into account the time value of money.

The fuel, O&M and capital cost for gas, wind and coal were obtained from a report on the Projected Costs of Generating Electricity produced by the International Energy Agency (IEA) [IEA, 2005]. The average of each cost category was calculated from data of power plants in 21 countries around the world. The report also used a 5% discount rate and 2010 as the base year. Electricity generation for natural gas was assumed to be produced only using Combined Cycle Gas Turbines (CCGT), for coal using only Steam Turbines and for wind using only onshore wind farms.

The fuel and O&M costs for oil were estimated by taking a historical average from data published in the EAC Annual Reports for the years 1990-2008. No sufficient data could be found for the capital cost of oil-fuelled generation from the EAC or any other international report since electricity generation using oil is nearly extinct. Therefore, it was assumed

that the capital cost for the coal-fired steam turbine is equal to the capital cost of the oil-fired steam turbine [IEA, 1998] and similarly the cost of the gas-fired CCGT to be equal to the oil-fired Gas Turbine.

TABLE 1
Levelised Generation Costs (€/kWh)

	OIL	NATURAL GAS	WIND	COAL
Fuel Cost (€/kWh)	0.0584	0.0325	0.0000	0.0147
O&M Cost (€/kWh)	0.0140	0.0031	0.0102	0.0056
Capital Cost (€/kWh)	0.0091	0.0057	0.0447	0.0098
CO2 Cost (€/kWh)	0.0117	0.0055	0.0000	0.0130
System Integration (€/kWh)	0.0000	0.0000	0.0100	0.0000
TOTAL COST (€/kWh)	0.0932	0.0468	0.0649	0.0431
RETURN (kWh/€)	10.7348	21.3541	15.4057	23.1861

The cost of CO₂ can be interpreted as the economic cost of abatement strategies to reduce GHG emissions. This cost was calculated on the basis of the average emissions of each alternative, in tCO₂/kWh, [IEA 2005, WEC 2004]. The CO₂ price used in the cost calculation was €15/tCO₂ [IEA, 2007].

A System Integration cost was included in the overall cost for wind, since wind is considered to be a variable-output technology. System integration cost depends on the amount of back-up generation capacity required. Calculating this amount is a complex issue and largely depends on the share of wind generation in the overall mix. Dale et al. (2004) estimated the intermittency costs for the UK to be in the vicinity of 0.02€/kWh for up to 20% wind penetration. However a more recent investigation by the UKERC (2006), has estimated intermittency costs to be around 0.01€/kWh. The latter estimate was used for the purpose of this report.

3.3.2. Technology risk estimates

The risk of each technology was quantified by the standard deviation of the holding-period returns, based on historical data for each sub-category. Table 2 summarises the values used in the investigation. The values for the standard deviation for fuel and O&M costs for oil were estimated using the data obtained from the EAC Annual Reports. The rest of the risk estimates were obtained from Awerbuch and Yang (2007). Fuel cost risks have been estimated using annual historic data, in order to eliminate seasonal

variations in prices. As can be observed in the table below, wind is essentially riskless with respect to fuel.

TABLE 2

Holding-period returns standard deviations (%) for technology generating costs

Technology	Fuel	O&M	Capital	CO ₂
OIL	0.253	0.132	0.230	0.260
NATURAL GAS	0.190	0.105	0.150	0.260
WIND	0.000	0.080	0.050	0.000
COAL	0.140	0.054	0.230	0.260

3.3.3. Correlation Coefficients

The fuel, CO₂, and O&M holding-period return correlation coefficients between the different alternatives were obtained from Awerbuch and Yang (2007). According to Awerbuch and Berger (2003), the correlation between capital and O&M cost is assumed to be small, so a coefficient of 0.1 was used, whilst the value between the capital costs of two alternatives is high, so a coefficient of 0.7 was used [Awerbuch, Berger 2003]. The correlation coefficient between CO₂ and capital as well as O&M costs was assumed to be zero.

4. Results

4.1 Decision to diversify into natural gas and wind

First the effect of adding natural gas to the current Cyprus generation mix was investigated by constructing a portfolio consisting of oil and natural gas in various proportions. The resulting efficient frontier is shown in Figure 1 below.

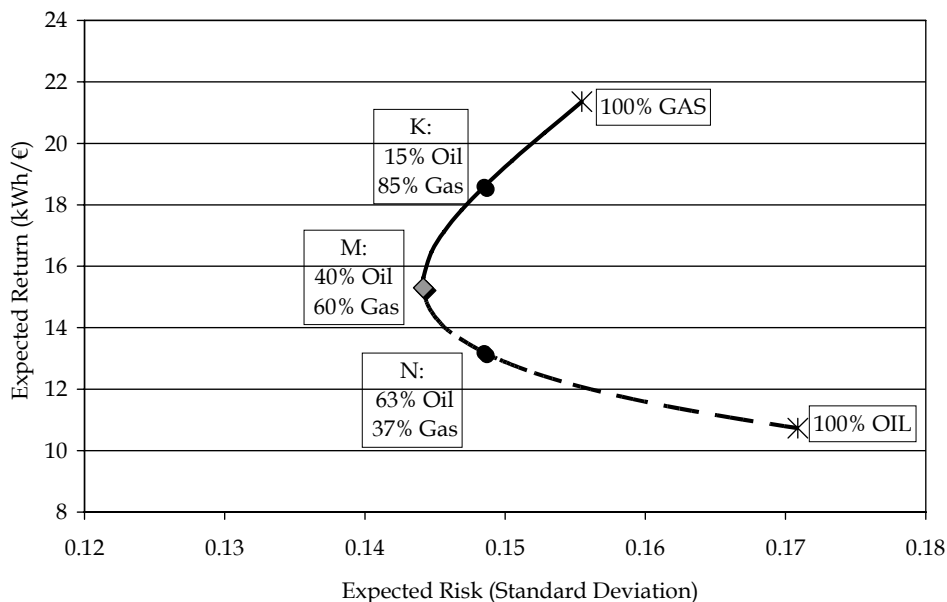
Starting from the current scenario of 100% electricity generation through oil, the return yielded is 10.73 kWh/€, with a standard deviation of 17.09%. Adding natural gas to the mix serves to increase the return and reduce the risk of the overall generating portfolio until point M is reached.

Point M is the combination of alternatives that provides the minimum risk. In this case it consists of 40% oil and 60% natural gas, and offers a return of 15.30kWh/€ at a 14.17% standard deviation. Any further addition of natural gas to the mix beyond point M will serve to raise both the risk and return of the overall portfolio and depends on the “risk appetite” of the

planning authority. Therefore, it is not possible to determine a single optimal portfolio combination. Instead, a range of efficient choices exists, made up of the combinations above the minimum variance portfolio M.

FIGURE 1

Efficient frontier for generation mix consisting only of oil and natural gas



Source: Own calculations.

It makes little sense for a country to have a generating portfolio that lies below point M, since at the same level of risk there exists another portfolio that provides a higher return. For example, point N, which consists of 63% oil and 37% gas, provides a return of 13.18kWh/€ with a standard deviation of 14.85%. However, at exactly the same level of risk, point K, consisting of 15% oil and 85% gas, gives a return of 18.59kWh/€.

Wind was then added to the generation mix and the combined efficient frontier for oil, natural gas and wind was constructed to investigate the effect. However, in this case an additional constraint was included in the optimisation procedure, to limit the share of wind in the overall mix to 10%. This was done in order for the model to reflect more realistic generation mix options for policy makers given the wind energy potential on the island.

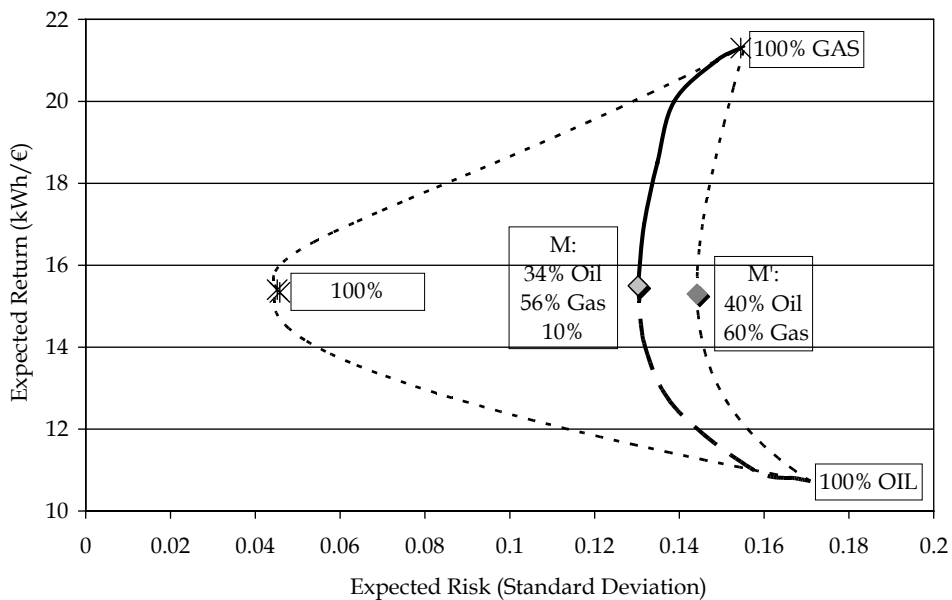
The 10% wind penetration is considered to be an achievable target, given that the first wind park to be completed by the end of 2010 will have a generating capacity of 82MW. Although this capacity corresponds to 7.3%

of the total installed capacity in Cyprus, it is estimated to provide only around 3% of the island's electricity requirements as per the company undertaking the project [Reuters, 2009]. This is consistent with the typical wind capacity factors of 20-40% [Boccard, 2008].

The resulting graph of the practical efficient frontier is shown in Figure 2. The addition of a 10% share of wind to the oil and gas portfolio mix, presented in the previous section, shifts the minimum variance portfolio (M) to the left, reducing the level of risk from a standard deviation of 14.42% to 13.02%, without imposing any additional cost. In this case, portfolio M consists of 34% oil, 56% natural gas and 10% wind.

FIGURE 2

Practical efficient frontier consisting of oil, gas and wind
(capped at 10% penetration)



Source: Own calculations,

4.2 Possibility of future diversification into coal

Coal was added to the mix as a fourth technology, in order to evaluate the possibility of further diversification using this technology. Figure 3 shows the resulting practical efficient frontier for all four alternatives with wind being capped at 10% penetration. Once again the thinner dotted lines represent the various two-technology portfolios between the four alternatives.

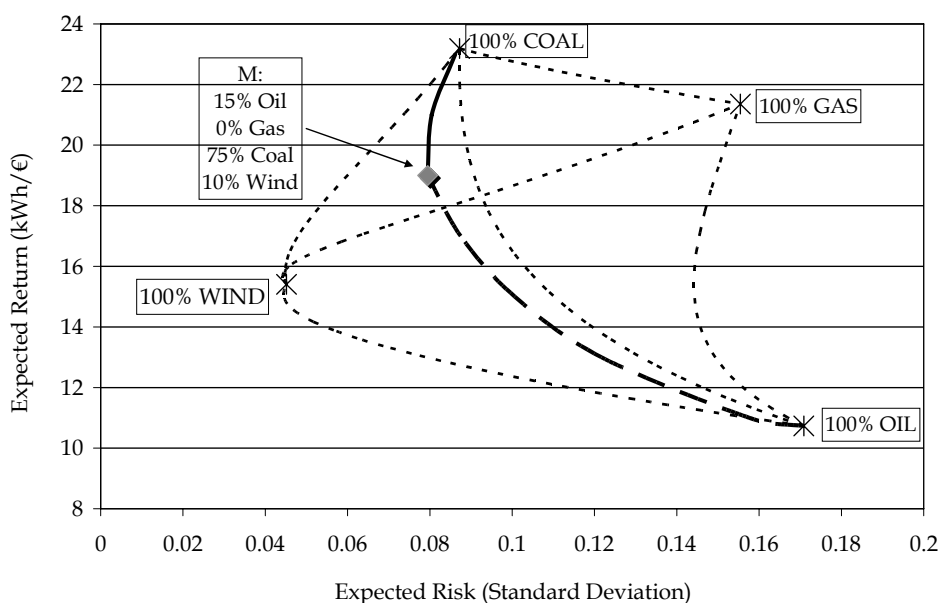
Coal offers a much higher return out of the four technologies and a significantly lower risk than any of the other two conventional fossil-fuel technologies. Its addition to the mix serves to shift the points of the efficient frontier towards the north-west side of the graph with portfolios of higher return and lower risk. This essentially is a 43% decrease in the generation cost and a 53% decrease in its variability, as compared to the current generation cost using only oil.

The addition of coal in the mix has almost entirely displaced the contribution of gas in the portfolios of the efficient frontier, as can be seen from the sample points K and N provided. This is because coal provides higher return at a much lower risk than gas. However, it should be noted that coal-fired generation is much more sensitive to the price of CO₂ prevailing in the markets.

The effect of an increase in the price of CO₂ was investigated by assuming a rise in price from 15€/tCO₂ to 35€/tCO₂. This new price is well within the estimates of the European Investment Bank which predicts a price of 45€/tCO₂ by 2030. Figure 4 shows the practical efficient frontier, which again includes a 10% constraint for wind generation. The portfolio consisting of 100% coal at a CO₂ price of 15€/tCO₂ is also included for comparison.

FIGURE 3

Practical efficient frontier consisting of oil, gas, coal and wind
(capped at 10% penetration)

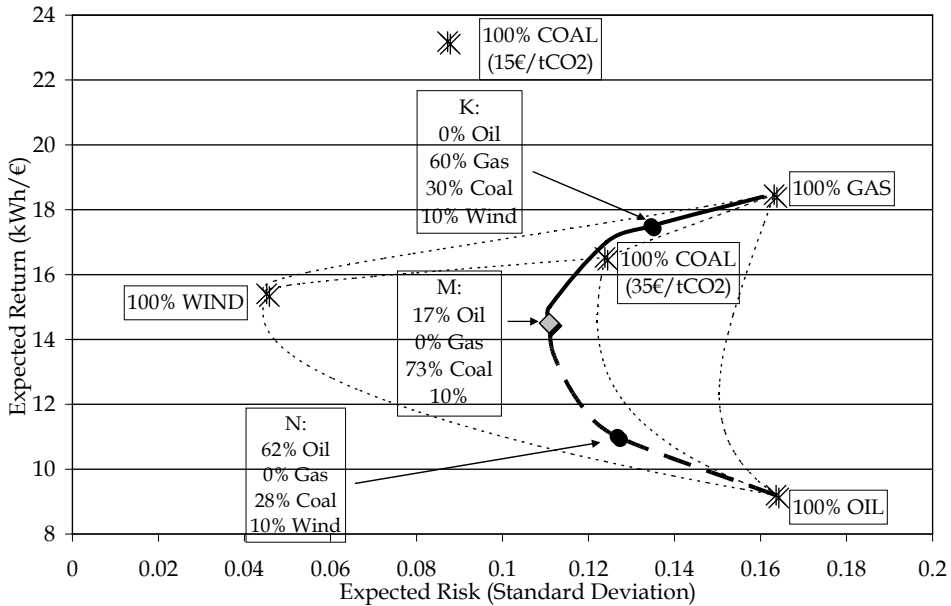


Source: Own calculations

It can be seen from the graph that the return of coal is dramatically reduced, from 23.18kWh/€ to 16.52 kWh/€, due to the increase in the price of CO₂. In addition, there is a noticeable increase in the risk of coal, from a standard deviation of 8.72% to 12.38%. This is due to the fact that more weight is placed on the cost of CO₂, which, like fuel, also carries a substantial amount of risk. The other three generating technologies remain fairly unchanged by the CO₂ price change, as compared to coal. The composition of the minimum variance portfolio, M, did not change by much as compared to the case of 15€/tCO₂. However its return decreased from 19kWh/€ to 14.5kwh/€ and its risk increased from 7.95% to 11.08% holding-period returns standard deviation.

FIGURE 4

Practical efficient frontier consisting of oil, gas, coal and wind (capped at 10% penetration) with an assumed CO₂ price of 35€/tCO₂



Source: Own calculations,

4.3 Discussion

The decision of the Cyprus government to diversify into natural gas has been correct from a risk-return perspective, since any addition of gas into the mix will only serve to increase return (i.e. reduce generation cost) and decrease the variability in the cost of electricity. Just to illustrate this point, if 60% of the oil generation is replaced with natural gas (i.e. move to the

minimum variance portfolio M for the oil-gas efficient frontier), the cost of generation will be reduced by approximately 30% and the variability in the cost will be reduced by approximately 15%. Furthermore, the move towards natural gas is environmentally beneficial as well, since gas is a “cleaner” fuel, with less carbon and sulphur emissions than oil. This is why natural gas is currently by far the fastest growing method of electricity generation, amongst conventional fossil-fuel technologies, both in Europe and the rest of the world. However, the Cyprus government should not be quick to entirely replace oil as fuel from the generating portfolio before the results of the oil exploration in its national waters is complete.

The results of section 4.2 show that the decision to incorporate wind energy to the generation mix does not simply help Cyprus to meet its EU national targets for RES. The addition of a fixed-cost technology to the mix serves to reduce the overall risk of the portfolio without increasing the cost. This is because wind is essentially riskless with respect to fuel and CO₂. This result is important since there is a general misconception that all RES have a high generation cost (i.e. low return), with respect to fossil-fuel technologies, and are therefore economically feasible only through subsidies.

In electricity generation planning, authorities usually evaluate alternatives such as natural gas, oil and coal, based purely on their stand-alone costs. This *least-cost* approach, however, is inherently biased towards cheaper, fossil-fuel technologies. At the same time this method fails to consider the merits of fixed-cost, low-risk, passive, capital-intensive alternatives such as wind [Awerbuch et al, 2005]. For this reason, a least-cost approach to electricity generation would almost never choose wind energy over natural gas or coal. However, the portfolio approach, followed in this paper, has shown that the addition of wind energy to the mix is indeed desirable since it brings price stability, without raising the overall portfolio cost. The importance of price stability in the cost of electricity has implications for the general economic growth of the country.

Cyprus’s first wind park will be completed by the end of 2010 and will have a generating capacity of 82MW. It is estimated that the average wind speed at the site is 6 m/s for 1,600 hours annually [Reuters, 2009]. This would make up around 3% of Cyprus’ current total electricity generation, and therefore will help reduce the country’s carbon emissions by a substantial amount. The general interest in wind energy electricity production is evident through the numerous licences that CERA has granted to individual corporations for the construction of wind parks on the island. However, care should be taken both by individual companies and the relevant authorities, when planning and commissioning such

projects, to avoid overinvestment in a sector bound by physical constraints.

Diversification into coal has never been included in the energy policy targets of the Cyprus government. However, according to the results of this investigation, its addition to the oil-gas-wind portfolio would reduce the risk and greatly increase the return of the portfolio. Coal-fired electricity generation has traditionally been one of the cheapest forms of generation. In a time when the cost of CO₂ was not taken into consideration, the cost would have been even less. Coal is more of a capital-intensive technology with fuel cost making up only a third of its total cost. Furthermore, the price of coal fuel is the least volatile out of the three fossil-fuel alternatives considered.

When looking at the problem purely from an economic perspective, the addition of coal rather than natural gas to the current generation mix would have been more beneficial. To observe this, one needs to refer to Figures 3 and 4 and in each case focus on the two-technology efficient frontiers for oil-gas and oil-coal. At a CO₂ price of 15€/kWh the diversification into coal gives a much higher return and lower risk than the diversification into gas. At 35€/kWh, some oil-gas combinations give a higher return, however diversification into coal reduces the risk to a greater extent for all portfolio combinations.

However, from an environmental perspective, coal is the “dirtiest” out of the four technologies considered. It has the highest amount of carbon emissions per kWh, which also means that it is the most susceptible to changes in the market price of CO₂. Furthermore, coal fired power stations are also associated with increased local air pollution with the emission of pollutants such as SO₂, NO_x, CO and particulate matter. Due to the increasing interest in environmental impacts, and especially in the effects of global warming, there is growing political pressure on governments around the world to adopt greener energy policies. All these factors act against the addition of coal in electricity generation, both in Cyprus and throughout the EU.

4.4 Model limitations

The purpose of this investigation was not to provide specific fractional shares and combinations of alternatives, which would give the optimal generating portfolio for Cyprus. This would require a much more detailed and in-depth investigation. The paper is limited to providing a direction for electricity generation planners at the policy level, by evaluating strategic decisions based on the portfolio cost and risk.

Mean-variance portfolio as applied to financial assets relies on some explicit assumptions, which may not directly apply to the case of electricity generation planning. The first assumption is that financial securities are infinitely divisible. In the case of energy planning, this is not entirely true, since the commissioning of power plants represents large, indivisible unit investments. This is particularly important for the case of Cyprus, where the total generating capacity is quite small. The problem becomes less significant when dealing with generating portfolios for large national territories, since the addition of an extra power plant seems minimal, as compared to the total capacity. Another important assumption is that past prices can be used to predict future market behaviour. However, this assumption does not account for any new, unexpected events that might cause unprecedented effects in the market.

5. Conclusion

This investigation used MVP theory to assess the electricity generation policy for the country of Cyprus. The current method of electricity generation in Cyprus is highly inefficient, with the generating portfolio consisting of 100% oil. This results in higher generation costs and exposes the country to unnecessary risk, in terms of fluctuations in the cost of electricity. It has been shown that diversification into natural gas in the form of LNG and wind energy, will serve to minimise the risk and increase the return (i.e. reduce the cost) of the overall generating portfolio. Diversification into coal was found to be economically beneficial, however its deployment is highly doubtful mainly due to environmental considerations.

The fact that Cyprus has been, for almost 50 years now, a nation almost entirely dependent on oil-imports, for all forms of energy production (not just electricity), means that the economy must have endured the full impact of the negative relationship between oil and GDP. Careful planning of electricity generation and energy diversification will be a key step, in reducing the effect of oil price fluctuations on the economic activity of the island.

Appendix

- The Expected Generation Cost for each alternative $E(C_m)$ is given by the following equation,

$$\text{Expected Generation Cost for each alternative} = E(C_m) = \sum_{n=1}^N x_n E(c_n) \quad (\text{Equation.1})$$

where x_n = fractional share of each sub-group in the total generation cost of the alternative

$E(c_n)$ = expected cost per kWh for each sub-group.

- The Expected Portfolio Cost for each alternative $E(P)$, is given by the following equation,

$$\text{Expected Portfolio Cost} = E(P) = \sum_{m=1}^M X_m E(C_m) \quad (\text{Equation.2})$$

where X_m = fractional share of each alternative in the total generation cost of the mix

$E(C_m)$ = expected levelised cost per kWh for each alternative calculated using Equation 1.

- The Expected Portfolio Risk $E(\sigma_p)$, is given by Equation 3 below,

$$\text{Expected Portfolio Risk} = E(\sigma_p) = \sqrt{\sum_{n=1}^N W_n^2 \sigma_n^2 + 2 \sum_{n_i < n_k} W_{n_i} W_{n_k} \rho_{n_i, n_k} \sigma_{n_i} \sigma_{n_k}} \quad (\text{Equation.3})$$

where W_n = product of X_m and x_n

σ_n = standard deviation of the holding-period returns of the annual costs (see below) for

each technology sub-group, and

ρ = correlation coefficient between two sub-group costs.

- Holding-period returns are given by Equation 4 below,

$$\text{Holding-Period Returns} = \frac{\text{Cost in year (t + 1)} - \text{Cost in year (t)}}{\text{Cost in year (t)}} \quad (\text{Equation.4})$$

- The formula used to calculate the levelised electricity generation costs (ECG), as applied by the IEA is the following:

$$ECG = \frac{\sum \left[\frac{(I_t + M_t + F_t)}{(1+r)^t} \right]}{\sum \left[\frac{E_t}{(1+r)^t} \right]} \quad (\text{Equation.5})$$

where EGC = Average lifetime levelised electricity generation cost

I_t = Investment expenditures in the year t

M_t = Operations and maintenance expenditures in the year t

F_t = Fuel expenditures in the year t

E_t = Electricity generation in the year t

r = Discount rate.

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