CHAPTER 6

c0006 # Portfolio Analysis of the Future Dutch Generating Mix

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s0010 **Abstract**

p0010 This chapter presents results of an application of Markowitz Portfolio Theory (MPT) to the future portfolio of electricity generating technologies in the Netherlands in the year 2030. Projections of two base-case generating mixes and general scenario assumptions have been taken from two specific scenarios designed by the Dutch Central Planning Office, i.e. 'Strong Europe' (SE) and 'Global Economy' (GE). This chapter focuses on the electricity cost–risk dimension of the Dutch portfolio of generating technologies and the potential for additional deployment of renewable generating technologies to enhance the efficiency of base-case generating mixes in year 2030. The major results of this study are as follows. (1) In both scenarios, the base-case generating mix is not very efficient. Graphical analysis suggests that diversification may yield up to 20% risk reduction at no extra cost. (2) Promotion of renewable energy can greatly decrease the portfolio risk. Defining mixes without renewables results in significantly riskier mixes with relatively small impact on portfolio costs. (3) Because of its relative low risk and high potential, large-scale implementation of offshore wind can reduce cost risk of the Dutch generating portfolio. Only in the GE scenario is a (small) upward effect on the expected Dutch electricity cost in year 2030 foreseen. In an SE world large-scale implementation of offshore wind is projected to have a downward effect on Dutch electricity prices in 2030.

s0130 ## Acknowledgements

p0840 The authors gratefully acknowledge financial support for this study from the Dutch Ministry of Economic Affairs (EZ). With the usual disclaimer, the authors, who during the period 2002–2006 collaborated intensively with Shimon in a range of portfolio-related research activities, would like to put

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on record the great intellectual inspiration bestowed on them by Shimon Awerbuch.

s0020 ## 6.1 Introduction

p0020 The Dutch Ministry of Economic Affairs (EZ) has been assessing the socio-economic impact of the Dutch renewables stimulation targets and policies over the period up to the year 2020. To that effect, the Dutch Central Planning Office (CPB), in association with the Energy Research Centre of the Netherlands (ECN), has performed a social cost–benefit analysis of possible large-scale implementation of offshore wind in the Dutch continental shelf (Verrips et al., 2005). This study arrived at generally negative conclusions on the merits of early implementation of large-scale offshore wind in the Dutch continental shelf.

p0030 This chapter considers the merits of large-scale implementation of offshore wind and other renewables-based generation technologies over a longer period, up to the target year 2030. The CPB scenario assumptions from the report mentioned above are used, without any adjustments but for a longer time-horizon. As an appraisal approach, portfolio analysis, i.e. Markowitz Portfolio Theory (MPT), is applied instead of conventional cost–benefit analysis. Application of portfolio analysis, as against cost–benefit analysis, allows the portfolio price risk dimension to be integrated in a quantitative fashion into the appraisal of distinct generating mixes.

p0040 The MPT approach is applied to future Dutch generating mixes for the year 2030, evaluating risk against two CPB scenarios, i.e. Strong Europe (SE) and Global Economy (GE). For each scenario, three policy variants are evaluated:

u0010 • the base or 'zero' variant, which does not include wind power, but includes small shares of other renewables
u0020 • an alternative variant articulating offshore wind power
u0030 • another alternative broad-based renewables variant.

s0030 ## 6.2 Theoretical framework

p0080 Financial portfolio analysis, based on MPT (Markowitz, 1952), builds on the premise that a portfolio of well-chosen assets has reduced risk characteristics when no perfect mutual correlations between the return on each of pair of assets exist. In a similar line of argument, portfolio (cost) risk may be reduced in a portfolio of well-chosen generating technology options as a result of less than perfect correlations between their cost characteristics.

p0090 Earlier studies, such as Awerbuch (2000), Awerbuch and Berger (2003) and Berger (2003), suggest that introducing renewables in the generating portfolio may significantly affect overall holding-period return (HPR) risk. This chapter proposes some adjustments in the theoretical framework, among others the introduction of the concept of (portfolio) 'price risk', or rather 'cost risk' replacing the expected returns concept applied in the studies referred to above. In a newly developed model the present authors have developed a *risk–cost-efficient frontier*. This type of efficient frontier shows a graph of risk (expressed in €/MWh) and cost of electricity (COE, expressed in €/MWh) for all efficient portfolios. A portfolio is efficient when a marginal increment in the output of any generation technology does not reduce portfolio cost without increasing risk (or does not reduce portfolio risk without increasing cost). Underlying efficient portfolios are energy based (i.e. based on shares of constituent electricity generating technologies in terms of electricity generation, e.g. in GWh or TWh, instead of MW capacity). The concept of 'portfolio risk' will be further explained later.

p0100 The transformation from a risk–return to a risk–cost-efficient frontier is proposed for the following main reasons:

u0040 • 'Return' has quite a different prevailing (financial or physical 'profit') connotation from just the reciprocal value of cost per unit of energy.

u0050 • From a mathematical perspective, the reciprocal of portfolio cost is not the same as portfolio return, if the latter is properly defined.

u0060 • The conversion from portfolio cost to a parameter defined as its reciprocal (dubbed 'portfolio return') makes the link to portfolio risk problematic: the latter cannot be expressed in the same dimensions as the reciprocal parameter of portfolio COE (hereafter expressed in MWh).

p0140 Efficient frontiers resulting from applying MPT to portfolios of financial assets depict in a forward-looking way a set of points, each of which corresponds to a particular efficient portfolio. Such an efficient frontier representation brings out two dimensions of underlying efficient portfolios: the projected *portfolio return* in percentage terms per period (*y*-axis coordinate) and *portfolio risk* (*x*-axis coordinate), i.e. the projected standard deviation of portfolio return, both expressed in the same dimension (% per period). Underlying efficient portfolios are composed of a certain efficient, linear combination of individual financial assets from a certain asset universe, with their respective shares in the projected portfolio value as weights. The essential feature of an efficient portfolio is that its (projected) portfolio return cannot be improved without, at the same time, higher portfolio risk exposure. Note that the aforementioned risk concept, as brought out by efficient frontiers of financial portfolios, is quite transparent.

p0150 From a societal point of view the crucial question is considered: Which portfolios can yield the lowest expected energy costs at given, acceptable levels of expected risk? To answer this question, ways in which to construct an efficient frontier are sought, showing for the set of efficient portfolios the relationship between the expected portfolio COE (stated briefly: *portfolio cost*) and the expected portfolio COE risk, i.e. *portfolio risk*. Values of portfolio risk should have a transparent interpretation to enable the projection of confidence intervals of portfolio cost. To achieve this, the following three-stage procedure was pursued.

o0010 **1.** For each cost component considered making up the COE of a certain electricity generating technology, determine the expected value and the upper limit value of the two-sided 95% confidence interval.

o0020 **2.** For each generating technology considered, determine the expected value and the upper limit value of the two-sided 95% confidence interval based on results of step 1.

o0030 **3.** Determine the efficient frontier, based on results of step 2.

p0190 Although this procedure does not use the notion of a holding period return, in its elaboration it is fully compatible with MPT applications to portfolios of financial assets.

p0200 The portfolio risk indicator emerging from this exercise can be interpreted in a transparent way: it is simply the (expected) standard deviation of portfolio cost. For a specific portfolio cost value it is approximately half the difference between the upper bound value of the projected portfolio cost interval and projected portfolio cost. Moreover, upper bounds of portfolio cost intervals can enable users, e.g. policy makers, to define their risk aversion preferences. For example, if a user wishes to accept, say, 90 €/MWh as a maximum COE with an overshoot risk of 2.5% (on average one case in the right-hand tail rejection area out of 40 cases), the portfolio with the lowest (expected) portfolio cost meeting this condition can be determined.

p0210 Hence, by including portfolio COE risk, the MPT approach as applied in this chapter enables policy makers to integrate the *trias energetica* (competitive energy prices, energy supply security, mitigation of adverse environmental impacts) in a quantitative framework. The proposed approach enables policy makers to monitor electricity cost–risk developments using an energy supply security norm as a yardstick, i.e. a preset upper bound to the real COE.

p0220 To improve flexibility and overcome obstacles found in earlier spreadsheet-based models, ECN developed a new generic optimization model for determining efficient frontiers. The new model uses the AIMMS[1] dedicated mathematical modelling framework.

p0230 For the analysis of cost and risk for a portfolio of electricity generating options, the graphical presentation as shown in Figure 6.1 is used, combined with a table containing some key indicators for cost, risk and composition.

p0240 The dotted elliptical area indicates the range of feasible portfolios and the solid line indicates the cost-efficient frontier, comprising all Pareto-efficient[2] combinations of risk and return. Note that the elliptical feasible area is formed under constraints on the different generating options. In an unconstrained world, the feasible area would resemble the well-known boomerang shape also found in financial applications.

p0250 Mix *Q* typically is the global minimum-cost portfolio and mix *P* is the global minimum-risk portfolio. Mix *A* represents a target mix for a certain target year. Generating mix *A* is clearly not efficient, since rearranging could:

u0070 • reduce portfolio risk at the same portfolio cost (moving from A to point *N*), or
u0080 • reduce portfolio cost at the same risk (moving from point A to point *S*), or

[1] AIMMS is a dedicated optimization modelling framework developed by Paragon Decision Technology Inc. (http://www.aimms.com).
[2] Pareto efficiency in this context indicates that no improvement in return can be attained without increasing risk and vice versa.

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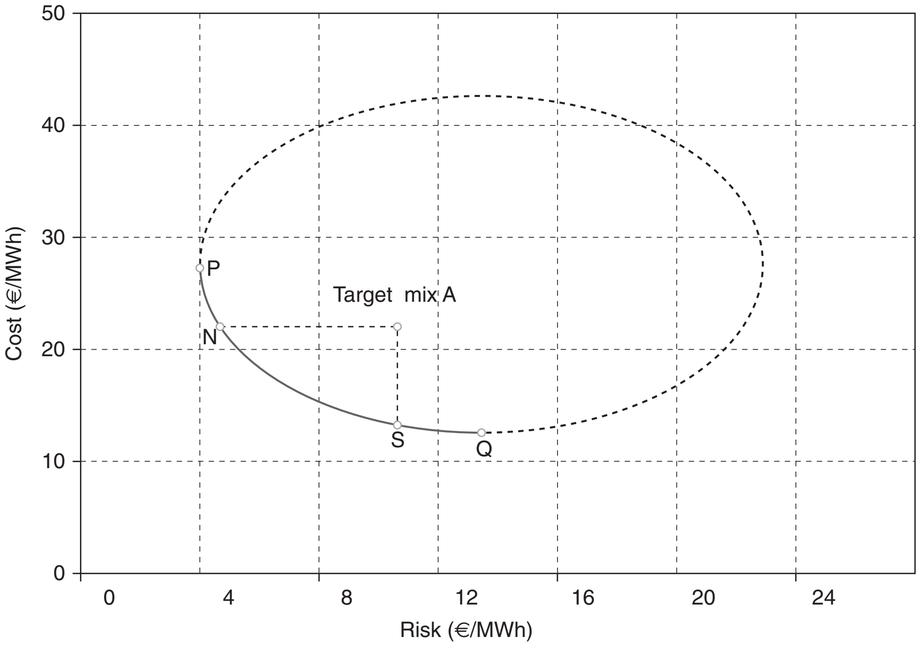

f0010 **FIGURE 6.1** Example: cost-efficient frontier.

u0090 • reduce both (all combinations between point A exclusive and arc NS inclusive, excluding those on lines AN and AS).

p0290 An example of characteristic points A, N, S, P and Q is presented in Table 6.1. This table denotes an illustrative example and is not based on real data. Assuming that the costs are distributed independently random, for each portfolio – characterized by its expected portfolio cost and portfolio risk – its maximum portfolio cost within a set probability can be calculated. This figure is presented as 'upper bound at 2.5%' and may be interpreted as the maximum cost that will occur with 97.5% certainty. Examples are given by the figures in the third row.

p0300 Policy makers may wish to set norms for maximum portfolio cost in certain milestone years. These norms can be taken as the point of departure for monitoring the evolution of the actual electricity mix and actual technology costs. Based on updated technology costs (cost projections), the maximum portfolio cost in milestone years can be estimated (projected). 'Market failure' (e.g. the predilection of incumbent generators for CCGT with attendant high fuel cost risk) may render a country exposed to a supply security risk, considered unduly high by its policy makers. At least for the power sector, portfolio analysis can be used as a tool to monitor the level of energy supply security. Should the estimated portfolio cost in a milestone year exceed the preset norm, this may trigger policies by the public sector to bring about new (replacement or expansive) investments in generating capacity, with – from a socioeconomic cost perspective – low-risk technologies. In a liberalized market, adjustment of market framework conditions can bring this about.

t0010 **Table 6.1** Example: aggregated results mix A

	Mix P	Mix N–A	Mix A	Mix S–A	Mix Q
Portfolio cost (€/MWh)	28.0	22.0	22.0	13.5	12.5
Portfolio risk σ (€/MWh)	4.0	4.5	10.5	10.5	13.5
Upper bound at 2.5% (€/MWh)	36.0	31.0	43.0	34.5	39.5
Gas CHP (%)	25	30	35	25	25
Coal (%)	25	25	40	30	25
Nuclear (%)	5	5	5	5	5
Renewable wind (%)	20	25	10	30	25
Renewable biomass (%)	25	15	10	10	20

CHP: combined heat and power.

s0040 6.3 The Dutch generating mix in 2030

p0310 CPB developed long-term scenarios for Europe and uses these scenarios for analysis of energy markets and climate policy (Bollen et al., 2004). Two of these scenarios, GE and SE, have been used by CPB as a basis for a social cost–benefit analysis of large-scale implementation of offshore wind in the Dutch continental shelf (Verrips et al., 2005). Aligning with the latter CPB study, this chapter also uses the long-term CPB scenarios 'Strong Europe (SE)' and 'Global Economy (GE)' as a starting point for long-term portfolio analysis. This section describes a number of input assumptions and presents two alternative policy variants. Furthermore, for scenarios SE and GE, the efficient frontier and risk characteristics are analysed.

p0320 In this analysis of future costs and risks there is a clear distinction between how the world may look like *without* major policy changes and *after* specified changes of policy packages. The first aspect is translated into *scenarios*, which are plausible consistent descriptions of the future. Scenarios may be regarded as external to the model. As mentioned, this study builds on scenarios constructed by the CPB. The policy aspect is less external, since it defines different approaches or strategies for dealing with external changes. Different policy strategies, including 'business-as-usual' are translated into *policy variants*.

p0330 This chapter uses CPB scenarios SE and GE. For each scenario, three variants are considered:

u0100

- Reference (0): a reference variant assuming continuation of renewables stimulation policy as currently implemented or whose implentation has already been officially announced (SE0 and GE0). This variant is also referred to as the base case.

u0110 • Wind (p1): an intensification of renewables stimulation policy, with the emphasis put on offshore wind energy stimulation (SEp1 and GEp1).
u0120 • Biomass (p2): an intensification of renewables stimulation policy, with the emphasis put on a broad variety of relatively cost-effective renewable technologies (SEp2 and GEp2).

p0370 In addition to identifying scenarios and policy variants, the model will need some prior information setting the initial situation and restricting possible outcomes. This prior information is translated into a set of *input assumptions*. All input data used in this study have been obtained from, and are consistent with, the data used in CPB's cost–benefit analysis for offshore wind (Verrips et al., 2005). Constraints imposed on the model relate, inter alia, to the assumed technical potentials of the distinct renewable generating technologies, because of, for example, resource or authorization (notably, wind power) constraints.

p0380 Most technology cost assumptions are similar for both SE and GE. Only onshore wind and offshore wind have distinct cost assumptions. Cost-reducing technical progress for these technologies is assumed to occur at a faster rate (as captured by a lower progress ratio) under SE than under the GE scenario. However, since SE and GE have quite divergent assumptions on carbon dioxide (CO_2) price developments, the resulting total generating costs differ for many, notably fossil-fuel-based, technologies. Furthermore, total electricity demand is assumed to be higher under GE than under SE. Other assumptions are listed below. The feasible range of generating capacities, called energy bounds (see Appendix C), are largely identical in energy terms, except for existing nuclear and coal. The bounds do, however, differ relatively, owing to the higher energy demand in the GE scenario.

s0050 6.3.1 The Strong Europe (SE) scenario

p0390 Strong international cooperation and important public institutions are key characteristics of the Strong Europe (SE) scenario. In this scenario, European integration proceeds successfully – politically, economically and geographically. Welfare distribution is valued over economic growth and cooperation will result in a stringent climate policy. Up to 2020 a CO_2 price of 11 $€_{2003}$/tonne is assumed, thereafter increasing to 55 $€_{2003}$/tonne in 2030. For gas a price of 4.7 $€_{2003}$/GJ is assumed in 2030. Until 2030, primary energy demand is assumed to increase at a (very) modest rate and CO_2-related emissions would decrease in absolute terms.

s0060 6.3.1.1 The SE0 base case

p0400 One of the key graphical results of portfolio analysis is construction of the efficient frontier (EF), a graph on which each point represents an efficient portfolio. Portfolio efficiency in this context means that no portfolio with lower costs (in terms of €/MWh) can be obtained without increasing risk.

p0410 For the SE0 variant the efficient frontier is depicted in Figure 6.2. Details characterizing special points in this figure are presented in Table 6.2.

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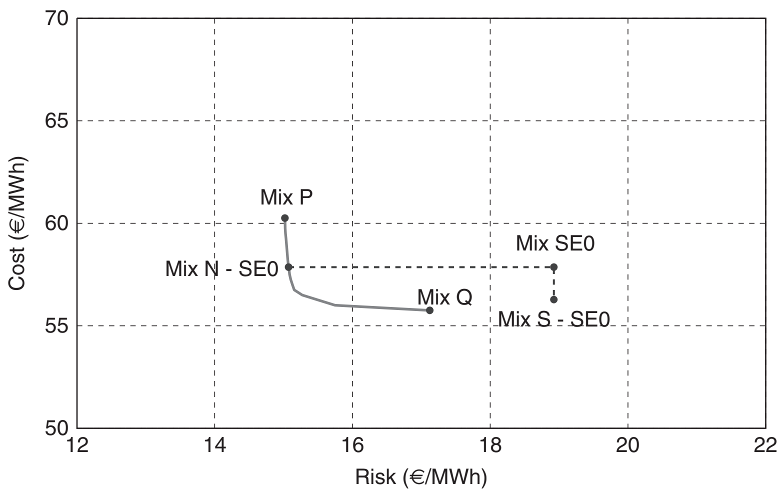

f0020 **FIGURE 6.2** Efficient frontier for SE0.

t0020 **Table 6.2** Aggregated results SE0

	Mix P	Mix N–SE0	Mix SE0	Mix S–SE0	Mix Q
Portfolio cost (€/MWh)	60.2	57.9	57.9	56.3	55.7
Portfolio risk σ (€/MWh)	15.0	15.1	18.9	18.9	17.1
Upper bound at 2.5% (€/MWh)	89.7	87.4	95.7	93.4	89.3
Gas CC (%)	18.4	18.4	38.6	41.0	34.4
Gas CHP (%)	37.2	37.2	37.2	38.1	38.1
Coal (%)	12.1	12.7	21.7	11.5	1.5
Nuclear (%)	0.0	0.0	0.0	0.0	0.0
Renewable wind (%)	20.0	20.0	0.0	4.2	20.0
Renewable biomass (%)	10.5	10.5	1.5	4.2	4.9
Renewable other (%)	1.7	1.1	1.0	1.1	1.1

CC: combined cycle; CHP: combined heat and power.

p0420 Let us consider each characteristic point:

u0130 • Table 6.2 column Mix SE0. The *target mix* set for the SE0 is characterized by (expected) portfolio cost of 57.9 €/MWh and portfolio risk of 18.9 €/MWh. The odds are 1 to 40 (=2.5%) that the target mix will end up in a portfolio electricity

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cost level exceeding 95.7 €/MWh (two sigma from the mean). As already explained in Section 6.2, the latter type of information may assist policy makers to define levels of cost risk that they consider acceptable. Renewables are poorly represented in the target mix: wind 0%, biomass 2% and other renewables 0%.

u0140 • *Point S–SE0* is on the efficient frontier vertically below the target mix. The mix S–SE0 has the same risk as the target mix but its expected electricity costs are lower (56.3 €/MWh). As the target mix is rather risky, point S is situated on the inefficient part of the efficient frontier (not shown in Figure 6.1). Somewhat counter-intuitively, more renewables-based electricity is represented in portfolio S–SE0. Coal (which is costly in the SE0 scenario owing to the CO_2 price) is substituted by gas technologies, wind power and biomass options.

u0150 • *Point N–SE0* is on the efficient frontier horizontally to the left of the target mix. The mix N–SE0 has the same cost as the target mix but its expected risk level is much lower (15.1 €/MWh versus 18.9 €/MWh). Renewables are well represented in this low-risk portfolio: wind 20% (representing the total onshore and offshore potential), biomass 10% (also the full potential) and other renewables 1%.

u0160 • *Point Q* is the lowest point of the efficient frontier. This point stands for the lowest expected cost portfolio (55.7 €/MWh). Note that its expected risk is appreciably lower than that of the target mix (17.1 €/MWh versus 18.9 €/MWh). As renewables tend to be less cost risky than fossil-fuel-based electricity, while under SE their costs are assumed to come down importantly by 2030, renewables are represented rather well in mix Q: wind 20% (full potential), biomass 4% and other 1%.

u0170 • *Point P* is the highest point of the efficient part of the efficient frontier. This point stands for the lowest expected risk portfolio (15.0 €/MWh), but its expected cost is higher than that associated with the target mix (60.2 €/MWh versus 57.9 €/MWh). However, the upper bound at the 2.5% percentile in mix P (89.7 €/MWh) is lower than for the target mix (95.7 €/MWh). As renewables tend to be less cost risky than fossil-fuel-based electricity, renewables are represented quite well in portfolio P: wind 20%, biomass 10% and other 2% (the total renewable potential).

p0480 The relatively high expected carbon cost under the SE scenario (55 €/tCO_2 in target year 2030) has a strong impact on costs: even along the efficient frontier no portfolios can be found in the base-case variant with lower expected electricity cost than 55.7 €/MWh. Furthermore, the shape of the efficient frontier is rather hollow, so that over a wide range from bottom right (point Q) to left, large (expected) risk reductions can be obtained at relatively small cost sacrifices (hence slightly higher expected costs), up to a point where the efficient frontier bends steeply upwards. The explanation of this shape may relate to almost 'free lunches' that can be obtained initially by moving from Q to the left along the efficient frontier, notably by substitution of gas with coal and biomass co-firing.

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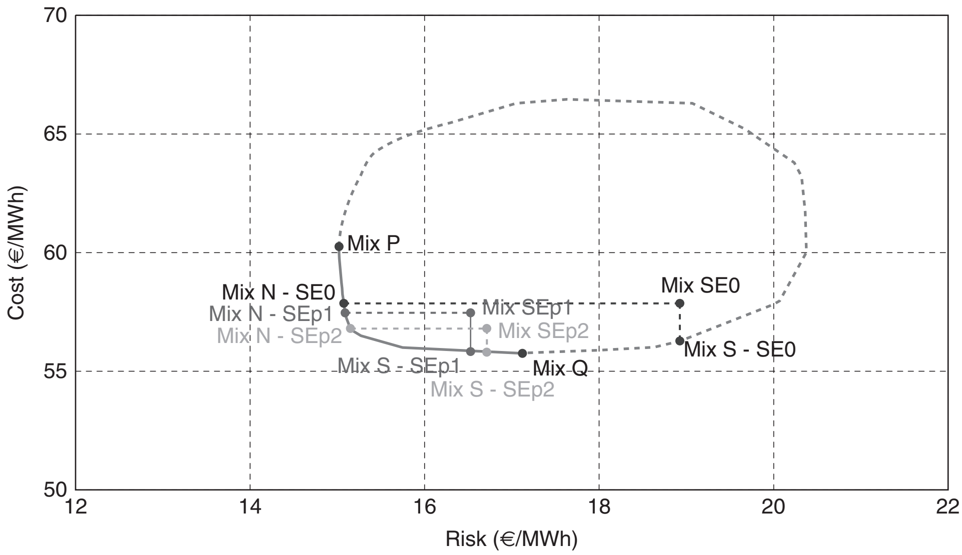
6.3.1.2 Variants SEp1 and SEp2

p0490 A striking feature under SE is that the target mixes for variants p1 (renewables with offshore wind focus) and p2 (broad-based renewables) are not only much



f0030 **FIGURE 6.3** Efficient frontier for SE0, SEp1 and SEp2.

less risky than for the base-case policy variant, but also characterized by slightly lower expected electricity cost. The carbon factor under SE appears to have a rather high impact, rendering the economics of renewables-based technology vis-à-vis fossil-fuel-based ones much better for renewable electricity generators AUQ1 (RES-E generators). Furthermore, the (expected) portfolio cost–risk differences between target mixes p1 and p2 are rather small: SE-p1 has slightly higher costs on the one hand, but slightly lower risk on the other (Figure 6.3, Tables 6.3 and 6.4).

s0080

6.3.2 The Global Economy (GE) scenario

p0500 The Global Economy (GE) scenario is characterized by strong international cooperation and an important role for individual responsibility. Economic growth is valued over government interference beyond providing a limited amount of public service. Integration is limited to the economic sphere and cooperation in non-trade issues, such as effective climate policy, fails. Up to 2020 a CO_2 price of 11 €/tonne is assumed, and from 2021 the carbon market is assumed to collapse under the GE scenario with a 0 €/tonne price for CO_2 emission allowances. For gas a price of 4.7 $€_{2003}$/GJ is assumed in 2030. Until 2030, primary energy demand will increase at a steady 2.3%, as will emissions.

s0090

6.3.2.1 The GE0 base case

p0510 The shape of the efficient frontier under the GE scenario is less concave than under SE, and the frontier is situated lower, particularly with respect to cost. The carbon factor (expected carbon cost in target year 2030 of 0 €/tCO_2) is a major underlying factor accounting for the latter feature. As the economics t0030 **Table 6.3** Aggregated results SEp1

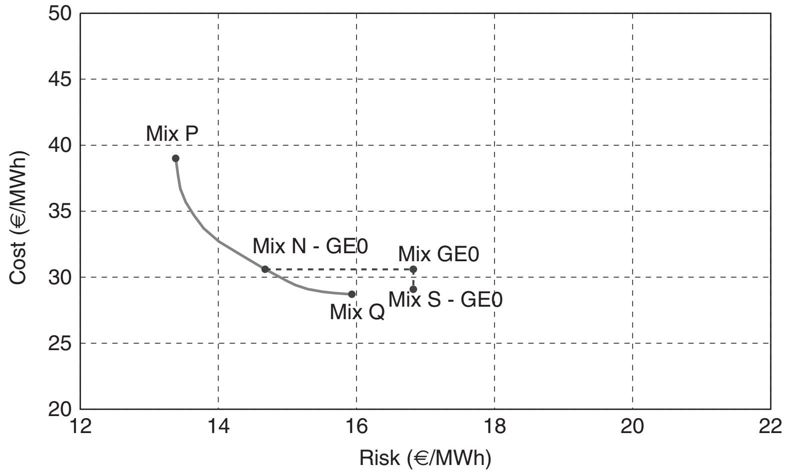
	Mix P	Mix N–SEp1	Mix SEp1	Mix S–SEp1	Mix Q
Portfolio cost (€/MWh)	60.2	57.5	57.5	55.8	55.7
Portfolio risk σ (€/MWh)	15.0	15.1	16.5	16.5	17.1
Upper bound at 2.5% (€/MWh)	89.7	87.0	89.9	88.2	89.3
Gas CC (%)	18.4	18.4	24.2	28.7	34.4
Gas CHP (%)	37.2	37.2	37.4	38.1	38.1
Coal (%)	12.1	12.7	21.7	7.2	1.5
Nuclear (%)	0.0	0.0	0.0	0.0	0.0
Renewable wind (%)	20.0	20.0	14.0	20.0	20.0
Renewable biomass (%)	10.5	10.5	1.5	4.9	4.9
Renewable other (%)	1.7	1.1	1.1	1.1	1.1

CC: combined cycle; CHP: combined heat and power.

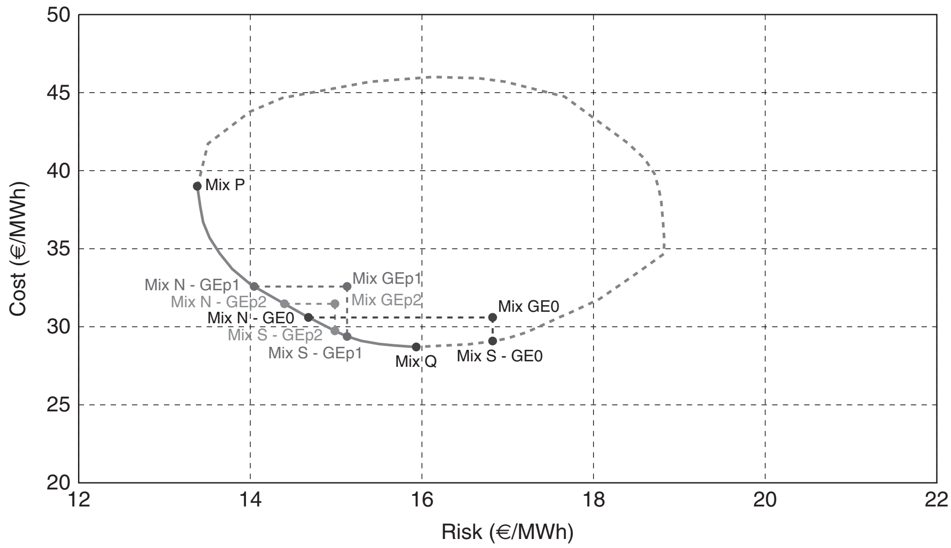
t0040 **Table 6.4** Aggregated results SEp2

	Mix P	Mix N–SEp2	Mix SEp2	Mix S–SEp2	Mix Q
Portfolio cost (€/MWh)	60.2	56.8	56.8	55.8	55.7
Portfolio risk σ (€/MWh)	15.0	15.2	16.7	16.7	17.1
Upper bound at 2.5% (€/MWh)	89.7	86.5	89.6	88.6	89.3
Gas CC (%)	18.4	18.4	24.2	30.5	34.4
Gas CHP (%)	37.2	37.2	38.1	38.1	38.1
Coal (%)	12.1	13.5	21.7	5.4	1.5
Nuclear (%)	0.0	0.0	0.0	0.0	0.0
Renewable wind (%)	20.0	20.1	13.4	20.1	20.0
Renewable biomass (%)	10.5	9.7	1.5	4.9	4.9
Renewable other (%)	1.7	1.1	1.1	1.1	1.1

CC: combined cycle; CHP: combined heat and power.



f0040 **FIGURE 6.4** Efficient frontier for GE0.



f0050 **FIGURE 6.5** Efficient frontier and feasible mixes GEp1 and GEp2.

of renewables are much less favourable under GE (again on account of the assumed negligible carbon costs, but for wind also because of assumed slower technological progress), penetration of RES-E is projected to be much slower. The information contained on the special points in Figures 6.4 and 6.5 bears this out.

p0520 Only mix N on the efficient frontier, horizontally left from the base-case target mix GE0, and even more so mix P (the least risky portfolio feasible under scenario GE) have an appreciable uptake of RES-E. Under GE RES-E technology tends to be much more expensive than fossil-fuel technology if at typically much lower risk. Hence the Sharpe ratio (cost change per unit of risk change: the slope of the efficient frontier) is initially much less favourable, when moving along the efficient frontier to the left departing from Q. However, in GE the constraints to RES-E deployment imposed upon the model are reached at a much later phase when moving upwards along the efficient frontier from Q (bottom right) to P (top left). Hence, on the least risky (upper left) part RES-E is better placed to accommodate risk aversion by moving leftwards under GE than under SE.

p0530 Compare, for example, mix N under GE (in Table 6.5) with mix N under SE (in Table 6.2) and check the corresponding RES-E shares. The shares of wind (20%) and biomass (10%) in N under SE appear to have increased to their (model-imposed) upper limits, while under GE (wind 7%, biomass 4%) this is clearly not the case. This emphasizes the fact that under GE renewables can accommodate risk reduction at low risk levels better than under SE, where they are already stretched to the limit at low risk levels.

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6.3.2.2 Variants GEp1 and GEp2

p0540 A remarkable difference between the location of target mixes under the GE variants p1 (wind) and p2 (biomass) and those of their SE counterparts is that under GE their associated expected electricity cost is somewhat higher than the corresponding zero (base-case) target mix. This can be gleaned from Figure 6.4 as well

t0050 **Table 6.5** Aggregated results GE0

	Mix P	Mix N–GE0	Mix GE0	Mix S–GE0	Mix Q
Portfolio cost (€/MWh)	39.0	30.6	30.6	29.1	28.7
Portfolio risk σ (€/MWh)	13.4	14.7	16.8	16.8	15.9
Upper bound at 2.5% (€/MWh)	65.2	59.4	63.6	62.1	59.9
Gas CC (%)	11.4	11.4	25.1	26.4	15.3
Gas CHP (%)	31.1	31.1	32.8	32.8	32.8
Coal (%)	29.4	45.1	40.0	37.6	48.3
Nuclear (%)	1.1	1.1	1.1	1.1	1.1
Renewable wind (%)	16.8	6.6	0.0	1.3	1.7
Renewable biomass (%)	8.8	3.7	0.1	0.0	0.0
Renewable other (%)	1.4	0.9	0.9	0.9	0.9

CC: combined cycle; CHP: combined heat and power.

t0060 **Table 6.6** Aggregated results GEp1

	Mix P	Mix N–GEp1	Mix GEp1	Mix S–GEp1	Mix Q
Portfolio cost (€/MWh)	39.0	32.6	32.6	29.4	28.7
Portfolio risk σ (€/MWh)	13.4	14.0	15.1	15.1	15.9
Upper bound at 2.5% (€/MWh)	65.2	60.1	62.2	59.0	59.9
Gas CC (%)	11.4	11.4	18.5	11.4	15.3
Gas CHP (%)	31.1	31.1	32.2	31.1	32.8
Coal (%)	29.4	38.3	35.4	49.8	48.3
Nuclear (%)	1.1	1.1	1.1	1.1	1.1
Renewable wind (%)	16.8	13.4	11.7	2.0	1.7
Renewable biomass (%)	8.8	3.7	0.1	3.7	0.0
Renewable other (%)	1.4	0.9	0.9	0.9	0.9

CC: combined cycle; CHP: combined heat and power.

as from Tables 6.6 and 6.7. Evidently, the costs of deliberate market forcing of RES-E are much higher under GE, where there is no help from the carbon factor.

s0110 6.4 Policy implications

p0550 In the previous section the reference policy variant and two 'renewables promotion' policy variants were analysed for MPT efficiency, using the Strong Europe (SE) and Global Economy (GE) scenarios. In line with the assumptions underlying the scenarios, both COE and associated risk are generally lower in GE than in SE, owing to learning rates in technological development and the content of future climate policy. Differences in scenarios are clearly reflected in the shape and position of the feasible areas.

p0560 Results of portfolio analysis indicate that:

u0180 • In both scenarios, the base variant is not very efficient and graphical analysis suggests that diversification may yield up to 20% risk reduction at no extra cost.

u0190 • Stimulation of renewable energy, as described in policy variants p1 and p2, can greatly improve the cost risk. Even in the GE scenario – the one that is rather unfavourable to a takeoff of renewables-based technology – this can

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t0070 **Table 6.7** Aggregated results GEp2

	Mix P	Mix N–GEp2	Mix GEp2	Mix S–GEp2	Mix Q
Portfolio cost (€/MWh)	39.0	31.5	31.5	29.7	28.7
Portfolio risk σ (€/MWh)	13.4	14.4	15.0	15.0	15.9
Upper bound at 2.5% (€/MWh)	65.2	59.7	60.8	59.1	59.9
Gas CC (%)	11.4	11.4	16.3	11.4	15.3
Gas CHP (%)	31.1	31.1	32.3	31.1	32.8
Coal (%)	29.4	42.1	37.6	48.3	48.3
Nuclear (%)	1.1	1.1	1.1	1.1	1.1
Renewable wind (%)	16.8	9.6	11.2	3.4	1.7
Renewable biomass (%)	8.8	3.7	0.7	3.7	0.0
Renewable other (%)	1.4	0.9	0.9	0.9	0.9

CC: combined cycle; CHP: combined heat and power.

be achieved at little additional cost. For the SE scenario, portfolio cost in the renewables policy variants is lower than that in the zero variant.

u0200 • Defining mixes without intensification of renewables stimulation (i.e. the zero variant target mixes) would result in riskier mixes (about 10% risk reduction is possible compared to the alternative policy variants 1 and 2), while portfolio costs would not be materially affected (about 6% cost increase for GEp1, 3% cost increase for GEp2, small cost reduction of 1–2% for SEp1 and SEp2).

u0210 • Further optimization beyond the variants evaluated is possible. However, the largest increase has already been realized with the relatively straightforward policy options p1 or p2.

u0220 • All in all, the results indicate that intensification of renewables stimulation policy can be justified from a socioeconomic perspective. In the SE scenario, the choice between p1 and p2 depends on risk aversion preferences: p1 is indicated to be slightly less risky but also slightly costlier. In the GE scenario the results presented above indicate that policy variant p2 would be socioeconomically slightly more favourable than p1.

p0620 The effects of variation of a number of input parameters on the cost and risk of the generating mixes have been investigated in sensitivity analyses. Owing to uncertainty surrounding cost and risk, the results of this study should be treated with caution. To put these in due perspective, sensitivity analysis is a quite valuable tool. To keep this chapter to a reasonable length, details of the sensitivity

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analyses are not given, but the main results are presented in the following paragraphs.[3]

p0630 The price of carbon (CO_2) is of key importance to the additional cost at which the security of supply in the power sector can be improved by moving towards an increasing share for renewables-based options. A higher carbon price dramatically improves the market position of renewables. An increase in the price of carbon tilts and shifts the efficient frontier upwards.

p0640 Owing to the large share of natural gas in the SE0 generating mix, expected portfolio cost and risk increase considerably. Under the assumption of 'high' gas prices (high compared to the CPB SE and GE scenarios), the risk mitigating potential for renewables-based generating options is highly amplified. Hence, the sensitivity of renewables-based generation technologies for the gas price is quite high.

p0650 Since biomass is only considered in co-firing and the share is limited, variations in the price have little effect on either costs or risk. With an increasing biomass price, the mix shifts towards a larger share of coal.

p0660 Finally, the sensitivity analysis shows that offshore wind – because of its relatively low risk and high potential – can significantly reduce portfolio risk. Under the SE scenario assumptions, tightening the technical offshore wind constraints results in higher coal shares. Also, from 1 GW up to 6 GW every discrete relaxation of the offshore wind constraint by 1 GW increments has the same marginal risk reduction potential.

p0670 The results of sensitivity analyses that have been shown in this section indicate that the characteristic of renewables-based technology to reduce portfolio risk is rather robust. This holds not only for broad-based renewables stimulation strategy but also for strategies with a certain focus on offshore wind. Further, the economics of renewables-based generating technologies are quite sensitive to the evolution of the gas price. In this respect, recall that both the GE and the SE scenario assume a rather moderate gas price evolution.

p0680 A general observation is that the large distances of target mixes from their corresponding efficient frontier under the distinct scenario variants and the uncertainties underlying the technology cost and potential assumptions suggest that it is difficult for policy makers to impose the right framework conditions to the market that lead to socially optimal portfolios. Nevertheless, under scenarios of rising real-term fossil fuel prices and increasingly binding carbon constraints, it would seem appropriate to reduce long-term (electricity) cost risk and long-term cost rises by renewables R&D and market stimulation.

s0120

6.5 Conclusions

p0690 Technology costs have been chosen in accordance with the cost–benefit analysis study for offshore wind (Verrips et al., 2005). Input data have been composed with utmost attention and care, but the true future costs remain highly dependent

[3] For sensitivity analyses see Jansen et al. (2006).

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on external factors. Scenario parameters such as reference mixes, CO_2 price and gas price assumptions have been chosen in line with the above-mentioned study and could be the subject of discussion.

p0700 Risk estimates were derived following a predefined methodology, and projections of long-term cost and risk for generating options specifically and portfolios at large remain difficult, even under the most up-to-date approaches. Furthermore, fuel correlations and technology parameter correlations are indicative and based on expert judgements.

p0710 Of all predefined target portfolios for the year 2030, none is efficient in the sense deployed in this study: for each portfolio, reductions in either cost or risk, or both, are possible. In most cases, risk reductions and cost reductions can be obtained by increasing the share of renewable generating options (notably wind power and biomass). These opportunities can be quantified as a 20% risk reduction and a 4% cost reduction (Tables 6.8 and 6.9). Defining mixes without renewables results in riskier mixes (about 10% risk reduction is possible) (Tables 6.10 and 6.11).

p0720 The outcome is very sensitive to CO_2 price assumptions. In the SE scenario, with prices of 55€/tonne, the renewable options become much more competitive than in the GE scenario, with zero carbon costs. The relative importance of gas-fuelled power plants (58% in GE0 and 76% in SE0) poses a quite serious cost risk for the Dutch electricity sector. Renewables can considerably reduce cost risk of

t0080 **Table 6.8** Potential diversification effect GE0

	GE0	Minimum	Reduction (%)
Portfolio risk	16.8	13.4 (mix P)	20
Portfolio cost	30.6	28.7 (mix Q)	6

t0090 **Table 6.9** Potential diversification effect SE0

	SE0	Minimum	Reduction (%)
Portfolio risk	18.9	15.0 (mix P)	21
Portfolio cost	57.9	55.7 (mix Q)	4

t0100 **Table 6.10** Potential diversification effect GEp1/GEp2

	Mix GE0	Mix GEp1	Reduction (%)	Mix GEp2	Reduction (%)
Portfolio risk	16.8	15.1	10	15.0	11
Portfolio cost	30.6	32.6	−6	31.5	−3

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t0110 **Table 6.11** Potential diversification effect SEp1/SEp2

	Mix SE0	Mix SEp1	Reduction (%)	Mix SEp2	Reduction (%)
Portfolio risk	18.9	16.5	13	16.7	12
Portfolio cost	57.9	57.5	1	56.8	2

the generating portfolio. The impact on risk and cost is strongly dependant on the scenario assumptions (notably the CO_2 price, the gas price and, to a lesser extent, the coal price) and the cost assumptions of renewables.

p0730 The analysis approach set out in this report is based on the methodology explained in Berger (2003) and Awerbuch and Berger (2003), and pioneered by Shimon Awerbuch in the 1990s. Several methodological refinements have been proposed. These have been implemented in this study, and some also in other ongoing or recently concluded research projects. The following contributions have been presented in this report:

u0230 • the introduction of an advanced notion of the efficient frontier based on cost
u0240 • the use of energy-based instead of generating capacity-based portfolios
u0250 • the expression of risk in terms of costs instead of a percentage rate
u0260 • consistent determination of risk associated with generating costs for distinct technologies.

p0780 This chapter has documented some major improvements in one-period analysis of generating technology portfolios through the application of MPT. Focal research issues to enhance the reliability further and widen the scope of applications for the MPT approach in the domain of electricity and energy mix portfolios include:

u0270 • improving the use of historical cost information to derive projections of future risk values, such as incorporating generalized autoregressive conditional heteroscedastic (GARCH) techniques (e.g. Humphreys and McClain, 1998)
u0280 • improving the methodology to derive the projected correlation matrix, showing the assumed interrelationships between portfolio cost components
u0290 • improving the allowance made for the cost impacts of penetration of intermittent renewable resources, which warrants, *inter alia*, a segmentation of the power market (into peak, intermediate and base load categories) and renewable resources (e.g. average wind speed categories, average insolation categories), and specification of contributions to ancillary power provision services
u0300 • expanding the cost component on pollutant emissions with inclusion of the cost of non-GHG polluting emissions such as NO_x and SO_2. In the cost projections presented in this paper only the cost of CO_2 are considered
u0310 • conversion from one-period analysis to multiperiod analysis, permitting not only the identification of efficient portfolios in a certain target year but also the determination of optimal trajectories for rebalancing portfolios from the base year to the target year. This would warrant specification of generation plant

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vintage years. Some leads are presented in Steinbach (2001)and Kleindorfer and Li (2005).

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b0010 **Appendix A**

s0160 Input assumptions

p0870 This appendix presents a concise overview of the assumptions used in this chapter. Tables 6.A1 to 6.A5

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t0120 **Table 6.A1** Technology specific upper and lower bounds of electricity generation (TWh, 2030)

	SE		GE	
	Lower bound	Upper bound	Lower bound	Upper bound
Gas CC	35.3	96.1	11.4	46.8
Gas CHP	71.3	72.9	31.1	32.8
Coal	0.0	83.3	0.0	55.7
Nuclear	0.0	0.0	1.1	1.1
Renewable wind	0.0	38.4	0.0	16.8
Renewable biomass	0.0	20.1	0.0	8.8
Renewable other	0.0	3.4	0.0	1.5

CC: combined cycle; CHP: combined heat and power.

t0130 **Table 6.A2** Estimated fuel costs (€/GJ, 2030)

	Mean	High
Gas	4.70	10.00
Coal	1.70	3.00
Uranium	2.22	3.00
Biomass (co-firing)	5.00	7.00
Biogas (co-firing)	0.00	2.00
Biomass small	4.00	6.00

t0140 **Table 6.A3** Correlations fuel costs, expert opinions

	Gas	Coal	Uranium	Biomass	Renewable
Gas	1.0	0.7	0.2	0.4	0.0
Coal	0.7	1.0	0.4	0.4	0.0
Uranium	0.2	0.4	1.0	0.1	0.0
Biomass	0.4	0.4	0.1	1.0	0.0
Renewable	0.0	0.0	0.0	0.0	1.0

t0150 **Table 6.A4** Correlations non-fuel costs, expert opinions

	Investment	Variable O&M	Fixed O&M	CO_2
Investment	0.5	0.0	0.0	0.0
Variable O&M	0.0	0.5	0.0	0.0
Fixed O&M	0.0	0.0	0.5	0.0
CO_2	0.0	0.0	0.0	1.0

O&M: operation and maintenance.

t0160 **Table 6.A5** CO2 costs/emission estimates

	CO_2 emission (kg/GJ)	Mean (€/t)	High (€/t)
Gas	56.1		
Coal	94.7		
CO_2 price SE		55.0	85.0
CO_2 price GE		0.0	30.0

b0020

Appendix B

s0170

Technology characteristics

p0880 Figure 6.B1 and Figure 6.B2

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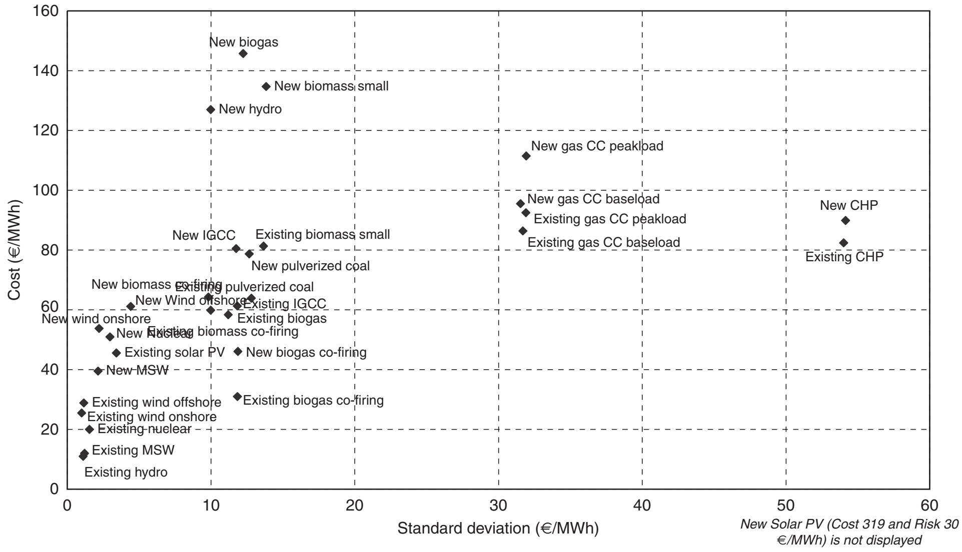
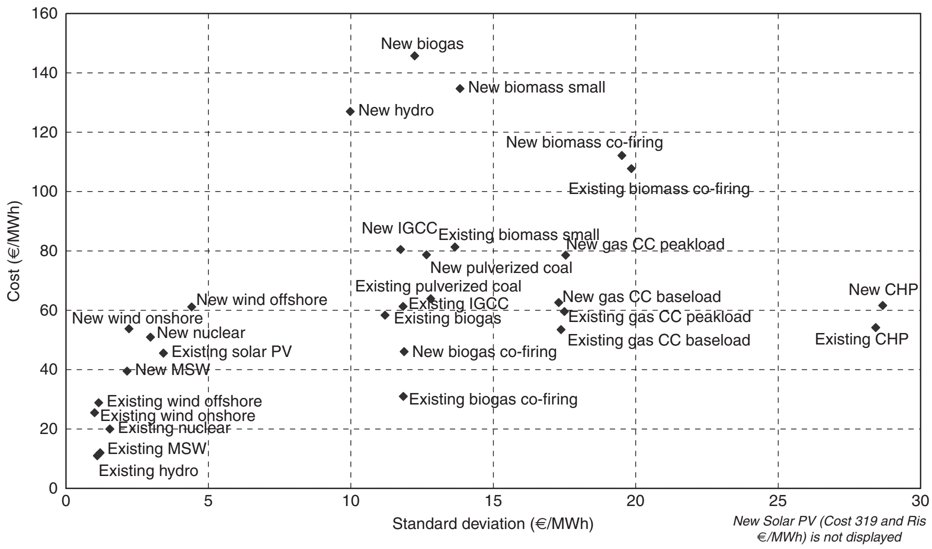


f0060 **FIGURE 6.B1** Technology characteristics SE (high gas). New solar PV (cost 319 and risk 30 €/MWh) is not displayed. CC: combined cycle; CHP: combined heat and power; MSW: municipal solid waste; PV: photovoltaics.



f0070 **FIGURE 6.B2** Technology characteristics SE (high biomass). New solar PV (cost 319 and risk 30 €/MWh) is not displayed. CC: combined cycle; CHP: combined heat and power; IGCC: integrated gasification combined cycle; MSW: municipal solid waste; PV: photovoltaics.

b0030 Appendix C

s0180 Energy bounds

p0890 Table 6.C1

t0170 **Table 6.C1** Aggregate overview of technology bounds (TWh)

	SE (%)		GE (%)	
	Lower bound	Upper bound	Lower bound	Upper bound
Gas CC	35.3	96.1	11.4	46.8
Gas CHP	71.3	72.9	31.1	32.8
Coal	0.0	83.3	0.0	55.7
Nuclear	0.0	0.0	1.1	1.1
Renewable wind	0.0	38.4	0.0	16.8
Renewable biomass	0.0	20.1	0.0	8.8
Renewable other	0.0	3.4	0.0	1.5

CC: combined cycle; CHP: combined heat and power.