

Hollandse Kust Zuid Levelised Cost of Energy Baseline and Scenarios



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Project number: WIENL16053

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Filename 20160704_REP_RVO_Hollandse Kust LCOE_v1_FINAL.docx
Pages 31
Status Final

Version	Author	Date	Remarks/Change
1.0	A Crockford	20 June 2016	Final
2.0			
3.0			

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Netherlands Enterprise Agency (RVO: Rijksdienst voor Ondernemend Nederland)

Executive Summary

For the Hollandse Kust Zuid offshore wind zone, RVO is currently making key decisions regarding the sites ("kavels"), possible export cable routes and position of grid connection platforms. RVO is also making decisions regarding the feasibility of cost-saving measures, such as changing a telecom cable route.

RVO has commissioned Ecofys to model the costs for various scenarios of the future Hollandse Kust offshore wind farms, in order to provide additional insight into the cost reduction potential of different measures. RVO defined four scenarios, which are compared to an agreed Baseline, with relative differences presented for discussion purposes. The comparisons are based on relative differences in Levelised Cost of Energy (LCOE) calculations between scenarios. The LCOE calculations were performed with the Ecofys Offshore Wind Cost Model with input data from Ecofys and RVO.

The four investigated options could individually lead to reductions in overall LCOE of 0.1 to 1.1% for the Hollandse Kust Zuid zone, as shown in Table 1. Note that the precision shown in these results does not reflect the level of uncertainty.

Table 1 – Differences in calculated costs and LCOE for each Alternative Scenario, relative to Baseline
(reductions are highlighted in green, increases are highlighted in red)

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Summary	Modified connections to the offshore hubs: Site I & IV to Northern OHVS; Site II & III to Southern OHVS	Telecom cables running between sites I and sites II/III relocated outside wind farm zone	Export cables exit the zone from the east	Additional areas within zone are added to Site 1
Total DEVEX	0.0%	0.0%	0.0%	0.0%
Total CAPEX	-0.11%	0.02%	-1.42%	0.18%
Total Annual OPEX	-0.08%	0.0%	-0.23%	0.04%
Decommissioning	-0.10%	0.02%	0.37%	0.28%
LCOE Developer	-0.14%	-0.77%	-0.26%	-0.86%
- Contributing factors	Shorter infield cable length: lower costs and lower losses	Lower wake losses: more yield Fewer infield cable crossings Longer infield cables at some sites: higher costs, higher electrical losses	Shorter export cables: lower electrical losses Otherwise similar layouts, same costs	Some wind turbines in less windy regions, but also decreased wake losses: more yield Shallower average water depth: lower foundation costs Longer infield cables: higher costs, higher electrical losses More cable crossings: higher costs
LCOE Tennet	-0.03%	-0.33%	-7.64%	-1.03%
- Contributing factors	Minor change due to small increase in yield; No change to overall TenneT infrastructure	Lower wake losses: more yield Longer export cable to northern hub: higher costs, higher electrical losses	Shorter export cables: lower costs, lower electrical losses Fewer export cable crossings: lower costs	Decreased wake losses: more yield Same costs
LCOE Overall	-0.13%	-0.72%	-1.10%	-0.88%

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1 Introduction

1.1 Goal of the study

The Dutch Energy Agreement requires a 40% cost reduction for offshore. Realisation of this cost reduction is expected to require a combination of measures, such as standardisation of the offshore electrical infrastructure and larger capacity wind turbines within larger wind farms. In September 2014, the Minister of Economic Affairs decided on the "Routekaart" for offshore wind in the Netherlands, where a total of 3.5 GW of offshore wind energy will be realised before 2023, by developing 5 large concentrated wind areas (of 700 MW each).

For the Hollandse Kust Zuid offshore wind zone, RVO is currently making key decisions regarding the sites ("kavels"), possible export cable routes and position of grid connection platforms. RVO is also making decisions regarding the feasibility of cost-saving measures, such as changing a telecom cable route.

To provide additional insight into the cost reduction potential of different measures, RVO has commissioned Ecofys to perform comparisons between a baseline concept and various different scenarios defined by RVO. The comparisons are based on relative differences in Levelised Cost of Energy (LCOE) calculations between scenarios. The LCOE calculations were performed with the Ecofys Offshore Wind Cost Model with input data from Ecofys and RVO.

1.2 Approach

This report summarises the evaluation of four alternative scenarios, according to the following approach:

1. Design Baseline Case

Ecofys evaluated the wind resource of all sites and provide baseline layouts for yield calculations and cost estimation. This allowed the calculation of a Baseline LCoE. The Baseline Scenario is described in Chapter 2.

2. Evaluate New Scenarios

a. Create wind farm layouts and provide yield and wake assessments

For each new scenario, Ecofys designed corresponding wind farm layouts, based on the scenario definitions from RVO and using best-practice principles.

b. Provide cost price analysis for comparison of different offshore wind farm sites

For each new layout, Ecofys calculated the corresponding costs, in order to determine the Scenario LCoE. The relative difference compared to the Baseline LCoE allows for easy comparison between scenarios.

The four alternative scenarios were defined by RVO. A brief description is provided in Table 2, with further details of the scenarios and results in Chapters 3 to 6. The scenarios are compared together in Chapter 7.

Table 2 – Overview of Alternative Scenarios

Alternative	Summary
Alternative 1	Modified connections of the windfarms to the offshore hubs: connecting Site I & IV to the Northern OHVS and Site II and III to the Southern OHVS
Alternative 2	Telecom cables running from west to east between sites I and sites II/III relocated outside the wind farm zone
Alternative 3	Export cables exit the zone from the east
Alternative 4	Additional areas within zone are added to Site 1

2 Baseline Scenario

2.1 Design Assumptions

The primary design assumptions for the Baseline and Alternative Scenarios are shown in Table 3, as agreed with RVO. The primary settings of the Ecofys Offshore Cost Model were confirmed with RVO, although the details are not presented here since the model remains confidential.

Table 3 – Key Assumptions for Site Design

Parameter	Input
Wind farm size	4 x 350 MW
OHVS	2 x 700 MW offshore substations Locations defined by RVO
Wind turbine type	Representative 7 MW (164 m rotor)
Wind turbine spacing	6.5-7 rotor diameters (approx.)
Wind turbine power curve	Estimated based on rotor diameter and rated capacity
Water depths	18-24 m RWS bathymetry map
Foundations	Monopiles
Export cable	Export cable route defined by TenneT – to Wateringen 220 kV cables
Infield cable voltage	66 kV
Nearest port	IJmuiden
Weather downtime	33%
Soil conditions	Primarily sand (piling is possible)
Wind speeds	9.5 – 9.6 m/s at 107 m hub height Based on combination of datasets from KNMI Noordzee Wind mesoscale model and OWEZ and Meteomast IJmuiden met masts
Yield	Wake losses: calculated using NO Jensen model, with correction for deep-array effects Electrical losses: calculated for infield and export cables, OHVS and onshore converter station Wind turbine availability: 96% Balance of plant availability: 98.5%
Debt/equity	Developer WACC = 7.4% TenneT WACC = 4% Project lifetime = 24 years
All other inputs	Standard Ecofys Offshore Cost Model settings

2.2 Site Design

To form the basis for comparison, Ecofys designed a baseline layout for the Hollandse Kust Zuid zone, as shown in Figure 1. The site-specific inputs for the baseline layouts of the four individual sites within the zone are presented in Table 4.

Table 4 – Site-specific Inputs for Baseline Layouts

	Baseline HKZ1	Baseline HKZ2	Baseline HKZ3	Baseline HKZ4	Baseline Hollandse Kust Zuid zone
Wind turbine rated capacity [MW]	7	7	7	7	7
Number of wind turbines	50	50	50	50	200
Wind farm rated capacity [MW]	350	350	350	350	1400
Average water depth [m]	22	22	21	20	21
Distance to port (Ijmuiden) [km]	44	48	49	40	45
Export cable length offshore [km]	45	45	39	39	42
Export cable length onshore [km]	11	11	11	11	11
Number of cable crossings - export cable [-]	3	3	3	3	3
Export cable voltage [kV]	220	220	220	220	220
Array cable length [km]	75	60	62	73	270
Array cable voltage [kV]	66	66	66	66	66
Number of cable crossings - array cables [-]	19	0	4	2	25
Average annual wind speed at 107 m [m/s]	9.6	9.6	9.5	9.5	9.6
Wake losses [%]	12.6%	14.0%	12.8%	13.5%	13.2%
Non-availability losses [%]	5.4%	5.4%	5.4%	5.4%	5.4%
Electrical losses [%]	2.8%	2.6%	2.5%	2.6%	2.7%
Net annual yield [GWh]	1314	1296	1302	1289	5201

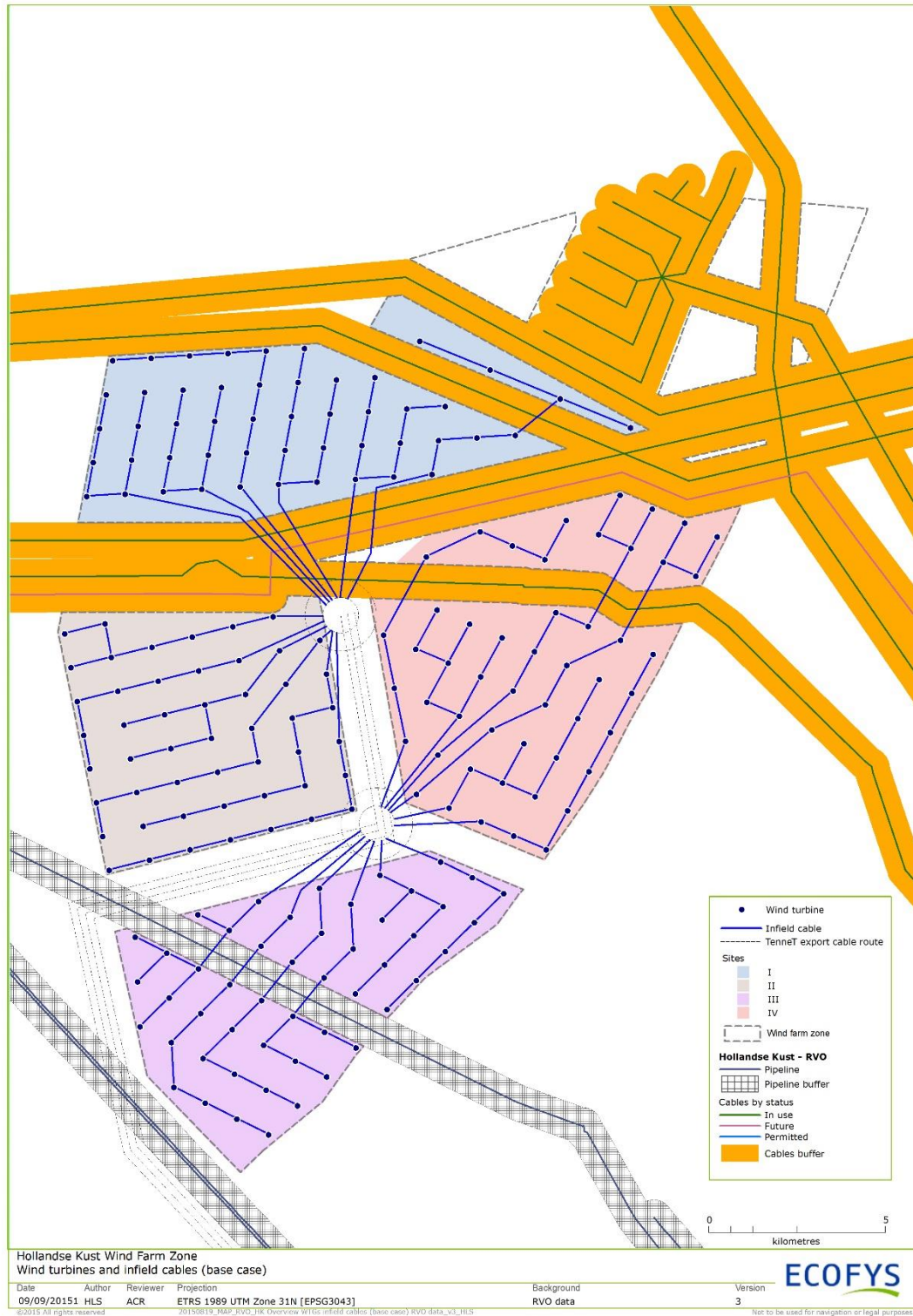


Figure 1 – Baseline layouts for Hollandse Kust Zuid sites (boundaries defined by RVO and Ecofys; layouts designed by Ecofys)

2.3 LCOE

Table 5 and Table 6 present the relative comparisons between sites. The differences in calculated costs are shown relative to the average between the four Baseline sites. The differences in LCOE are shown relative to the LCOE of the complete zone (Baseline scenario).

The four individual sites are similar in terms of water depths, wind speeds, energy yield and infrastructure requirements. As a result, the sites are each relatively equal in terms of costs and LCOE.

Table 5 – Difference in calculated costs, relative between Sites (reductions are highlighted in green, increases are highlighted in red)

	Baseline HKZI	Baseline HKZ2	Baseline HKZ3	Baseline HKZ4
Baseline scenario for comparison	Average of 4 Baseline Sites	Average of 4 Baseline Sites	Average of 4 Baseline Sites	Average of 4 Baseline Sites
Total DEVEX	0.00%	0.00%	0.00%	0.00%
Total CAPEX	1.24%	0.09%	-0.62%	-0.71%
Total Annual OPEX	0.13%	0.07%	-0.13%	-0.08%
Decommissioning	0.04%	-0.21%	-0.05%	-0.21%

Table 6 – Difference in calculated LCOE, relative between Sites (reductions are highlighted in green, increases are highlighted in red)

	Baseline HKZI	Baseline HKZ2	Baseline HKZ3	Baseline HKZ4
Baseline scenario for comparison	Baseline Hollandse Kust Zuid zone	Baseline Hollandse Kust Zuid zone	Baseline Hollandse Kust Zuid zone	Baseline Hollandse Kust Zuid zone
LCOE Developer	-0.25%	0.10%	-0.39%	0.56%
LCOE Tennet	1.52%	1.52%	-1.53%	-1.53%
LCOE Overall	-0.05%	0.26%	-0.52%	0.32%

3 Alternative 1

This section presents the key results from “Alternative 1”, based on the following scenario description from RVO:

Modify the connections of the windfarms to the offshore hubs: connect Site I & IV to the Northern OHVS and Site II and III to the Southern OHVS.

The infield cable layouts were modified according to the scenario description, as shown in Figure 2.

The relative changes in LCOE due to changes for this scenario are shown in Table 7 and Figure 3. There is a slight overall decrease in LCOE for the developers, due to shorter infield cables in this layout. The relative differences in site designs and costs are shown in bold in Table 8 and Table 9.

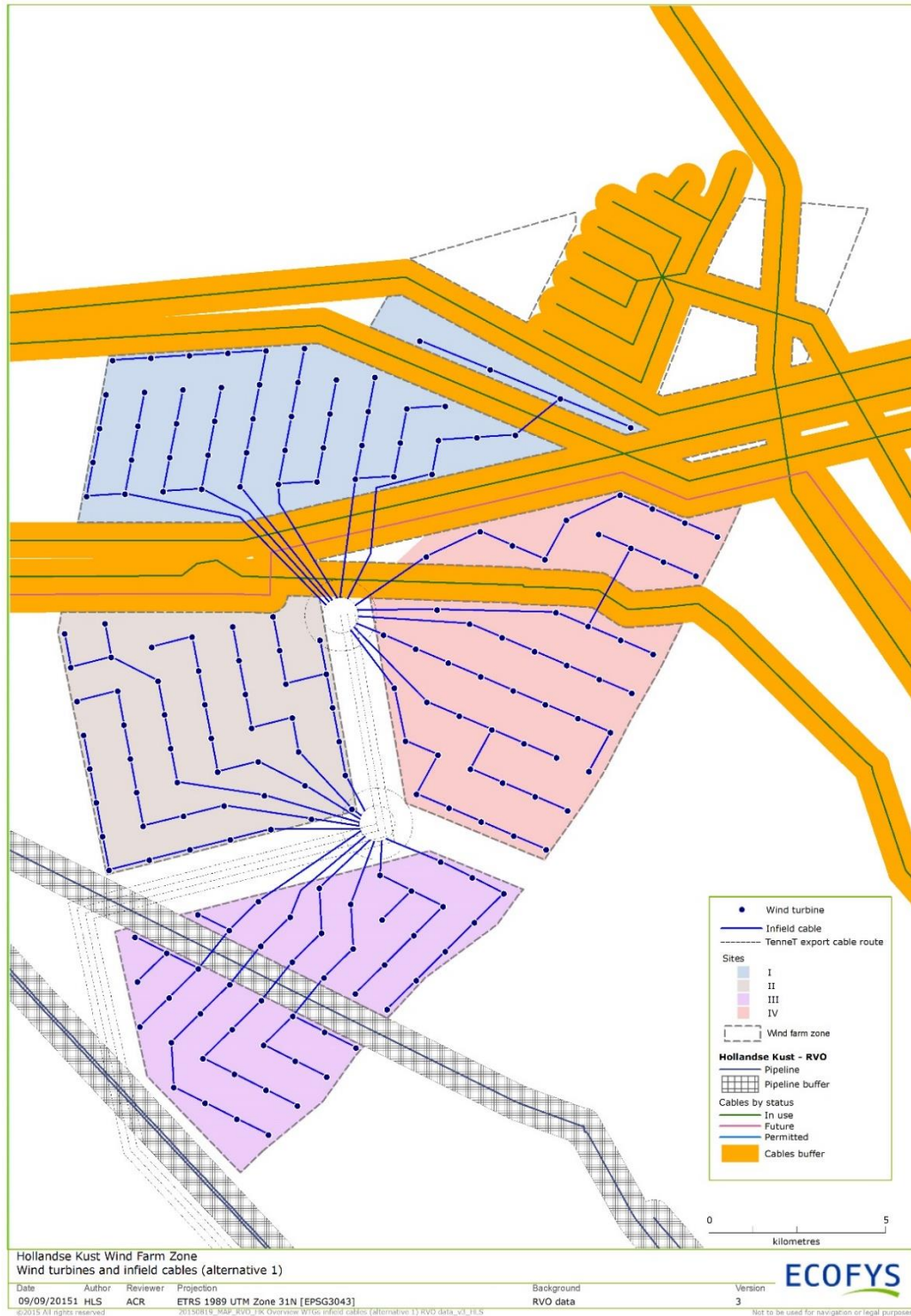


Figure 2 – Alternative 1 layouts for Hollandse Kust Zuid sites (boundaries defined by RVO and Ecofys; layouts designed by Ecofys)

Table 7 – Changes in LCOE for Alternative 1 including explanations

Result	Impacts on LCOE	Cause
Zone - Developer	Decrease of -0.14%	Shorter infield cable length: lower costs and lower losses
Zone – TenneT	Decrease of -0.03%	Minor change due to small increase in yield; No change to overall TenneT infrastructure
Zone - Overall	Decrease of -0.13%	See above

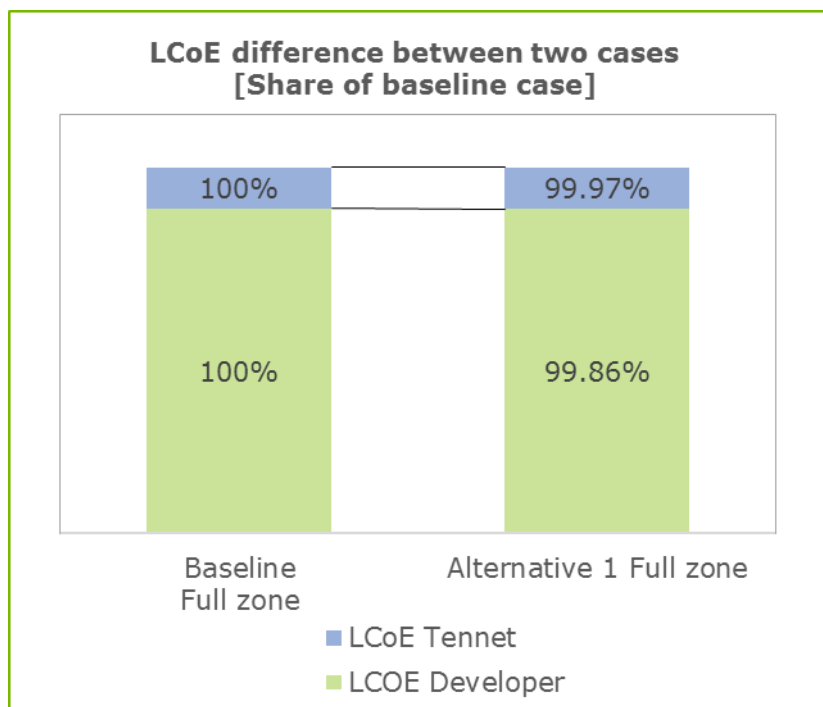


Figure 3 – Relative Difference in LCOE for Alternative 1

Table 8 – Site-specific Inputs (differences from Baseline are highlighted in bold)

	Baseline HKZ1	Alternative 1 - HKZ2	Baseline HKZ3	Alternative 1 - HKZ4	Alternative 1 - Hollandse Kust Zuid zone
Wind turbine rated capacity [MW]	7	7	7	7	7
Number of wind turbines	50	50	50	50	200
Wind farm rated capacity [MW]	350	350	350	350	1400
Average water depth [m]	22	22	21	20	21
Distance to port (Ijmuiden) [km]	44	48	49	40	45
Export cable length offshore [km]	45	39	39	45	42
Export cable length onshore [km]	11	11	11	11	11
Number of cable crossings - export cable [-]	3	3	3	3	3
Export cable voltage [kV]	220	220	220	220	220
Array cable length [km]	75	60	62	63	260
Array cable voltage [kV]	66	66	66	66	66
Number of cable crossings - array cables [-]	19	0	4	2	25
Average annual wind speed at 107 m [m/s]	9.6	9.6	9.5	9.5	9.6
Wake losses [%]	12.6%	14.0%	12.8%	13.5%	13.2%
Non-availability losses [%]	5.4%	5.4%	5.4%	5.4%	5.4%
Electrical losses [%]	2.8%	2.5%	2.5%	2.7%	2.6%
Net annual yield [GWh]	1314	1298	1302	1289	5203

Table 9 – Difference in calculated costs, relative to Baseline (reductions are highlighted in green, increases are highlighted in red)

	Alternative 1 - Hollandse Kust Zuid zone
Baseline scenario for comparison	Baseline Hollandse Kust Zuid zone
Total DEVEX	0%
Total CAPEX	-0.11%
Total Annual OPEX	-0.08%
Decommissioning	-0.10%
LCOE Developer	-0.14%
LCOE Tennet	-0.03%
LCOE Overall	-0.13%

4 Alternative 2

This section presents the key results from “Alternative 2”, based on the following scenario description from RVO:

Calculate the effect on the wind farm LCOE if the telecom cables running from west to east between sites I and sites II/III would be relocated outside the wind farm zone. The boundaries of the sites should then be changed to get sites of the same size, boundaries between sites must always be at least 1,000 m. The OHVS’ may be relocated to optimize length of infield cables.

The site boundaries were modified and new wind turbine, infield and export cable layouts were created according to the scenario description, as shown in Figure 4. The revised layout increases the spacing between wind turbines to about 6.8 rotor diameters (6.8D) from around 6.5D in the Baseline scenario.

Note that the costs of relocating the telecom cables is not included in this analysis.

The relative changes in LCOE due to changes for this scenario are shown in Table 10 and Figure 5. There are minor additional costs, which are offset by higher yields. There are significantly fewer cable crossings for Site 1, and the other benefits are relatively equally spread over the four sites. The relative differences in site designs and costs are shown in bold in Table 11 and Table 12.

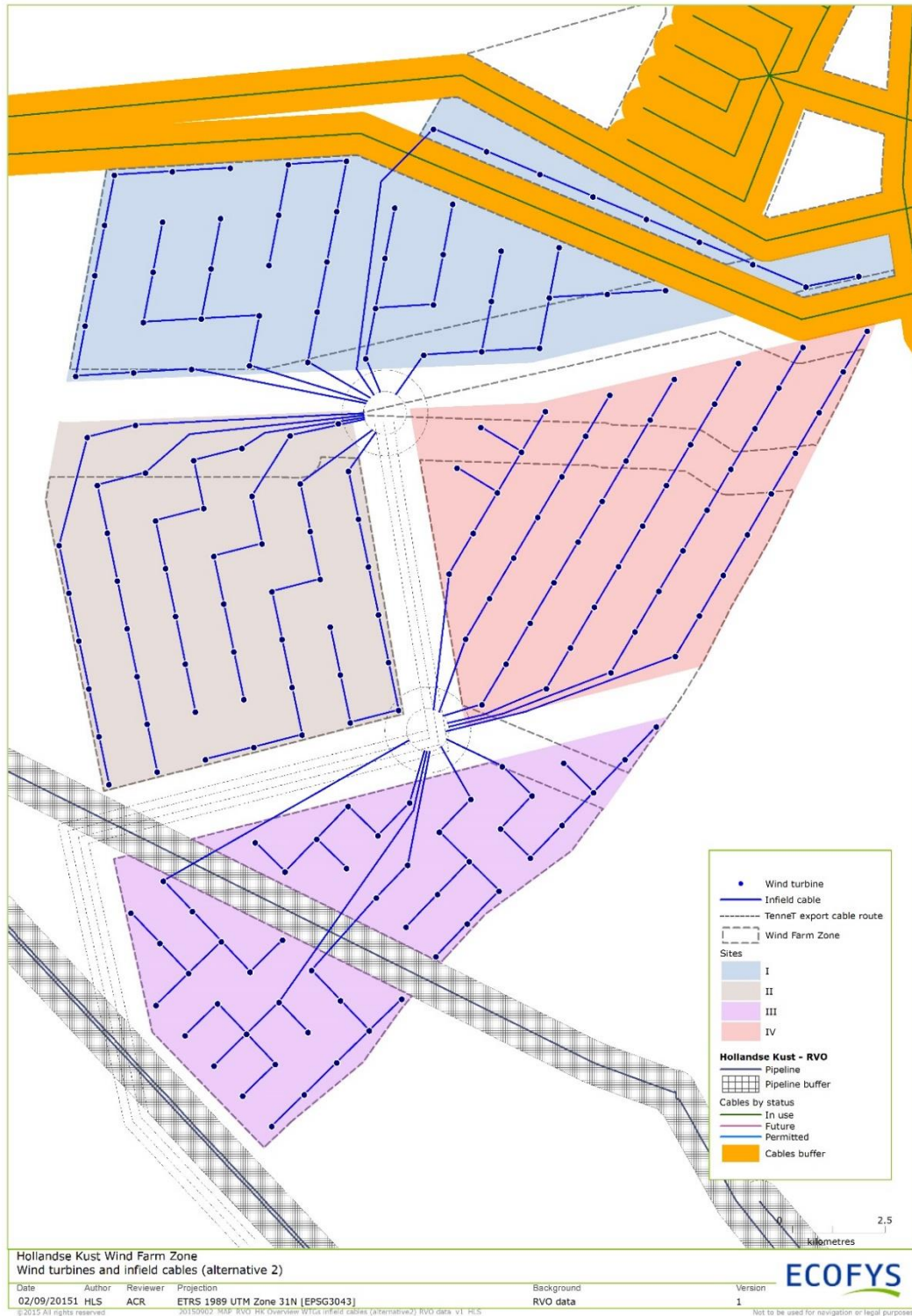


Figure 4 – Alternative 2 layout for Hollandse Kust Zuid zone (boundaries defined by RVO and Ecofys; layouts designed by Ecofys)

Table 10 – Changes in LCOE for Alternative 2 including explanations

Result	Impacts on LCOE	Cause
Zone - Developer	Decrease of -0.77%	Lower wake losses: more yield Fewer infield cable crossings (especially Site 1) Longer infield cables at some sites (more spacing between wind turbines): higher costs, higher electrical losses
Zone – TenneT	Decrease of -0.33%	Lower wake losses: more yield Longer export cable to northern hub: higher costs, higher electrical losses
Zone - Overall	Decrease of -0.72%	See above Some extra costs and higher electrical losses, offset by lower wake losses

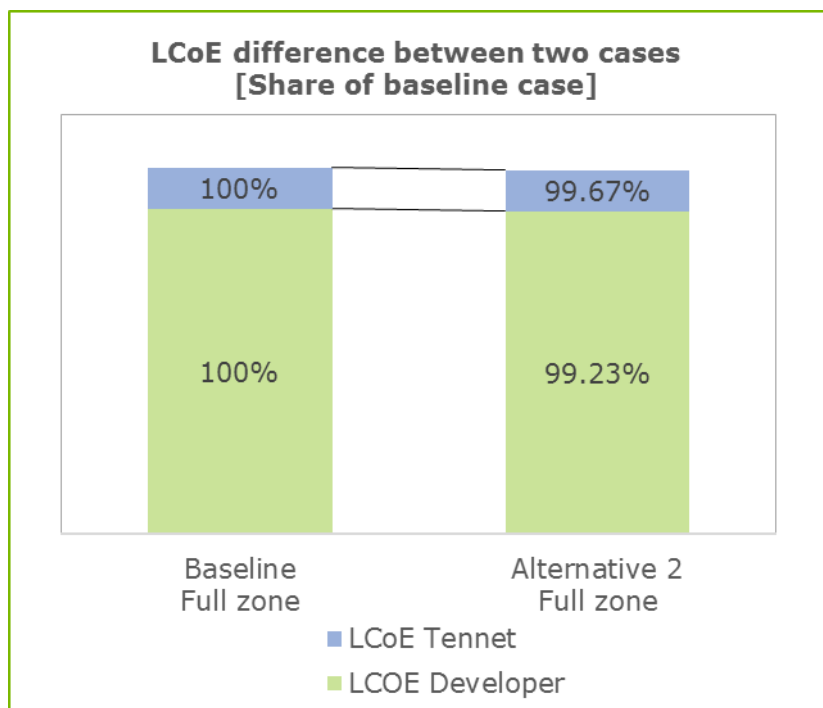


Figure 5 – Relative Difference in LCOE for Alternative 2

Table 11 – Site-specific Inputs (differences from Baseline are highlighted in bold)

	Alternative 2 - Hollandse Kust Zuid zone
Wind turbine rated capacity [MW]	7
Number of wind turbines	200
Wind farm rated capacity [MW]	1400
Average water depth [m]	21
Distance to port (Ijmuiden) [km]	45
Export cable length offshore [km]	43
Export cable length onshore [km]	11
Number of cable crossings - export cable [-]	3
Export cable voltage [kV]	220
Array cable length [km]	276
Array cable voltage [kV]	66
Number of cable crossings - array cables [-]	4
Average annual wind speed at 107 m [m/s]	9.6
Wake losses [%]	12.6%
Non-availability losses [%]	5.4%
Electrical losses [%]	2.7%
Net annual yield [GWh]	5239

Table 12 – Difference in calculated costs, relative to Baseline (reductions are highlighted in green, increases are highlighted in red)

	Alternative 2 - Hollandse Kust Zuid zone
Baseline scenario for comparison	Baseline Hollandse Kust Zuid zone
Total DEVEX	0.0%
Total CAPEX	0.02%
Total Annual OPEX	0.0%
Decommissioning	0.02%
LCOE Developer	-0.77%
LCOE Tennet	-0.33%
LCOE Overall	-0.72%

5 Alternative 3

This section presents the key results from “Alternative 3”, based on the following scenario description from RVO:

Calculate the effect on the LCOE if the export cables exit the zone from the east. This would also possibly mean moving the southern OHVS, considering the possibility that it can be placed within 10-12nm zone. This change will include minor changes to sizes and divisions of Sites.

The site boundaries were modified and new wind turbine, infield and export cable layouts were created according to the scenario description, as shown in Figure 6. The revised layout maintains similar site areas and spacing between wind turbines (around 6.5D) as in the Baseline scenario.

The relative changes in LCOE due to changes for this scenario are shown in Table 13 and Figure 7. There are cost savings due to a significantly shorter export cable, which also reduces the electrical losses. The LCOE is reduced for TenneT, but is relatively unchanged for the developers. The relative differences in site designs and costs are shown in bold in Table 14 and Table 15.

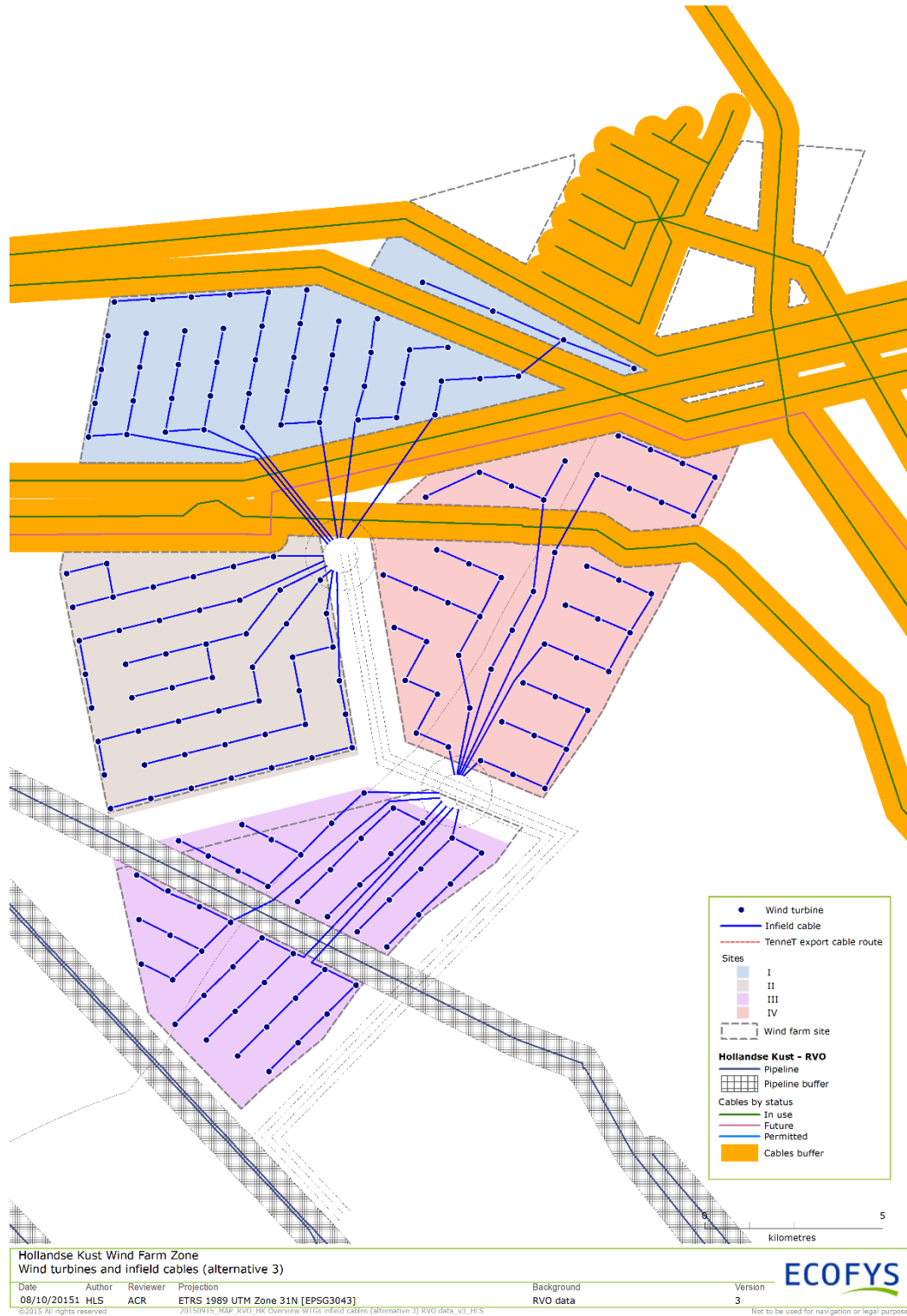


Figure 6 – Alternative 3 layout for Hollandse Kust Zuid zone (boundaries defined by RVO and Ecofys; layouts designed by Ecofys)

Table 13 – Changes in LCOE for Alternative 3 including explanations

Result	Impacts on LCOE	Cause
Zone - Developer	Decrease of -0.26%	Shorter export cables: lower electrical losses Otherwise similar layouts, same costs
Zone – TenneT	Decrease of -7.64%	Shorter export cables: lower costs, lower electrical losses Fewer export cable crossings: lower costs
Zone - Overall	Decrease of -1.10%	See above

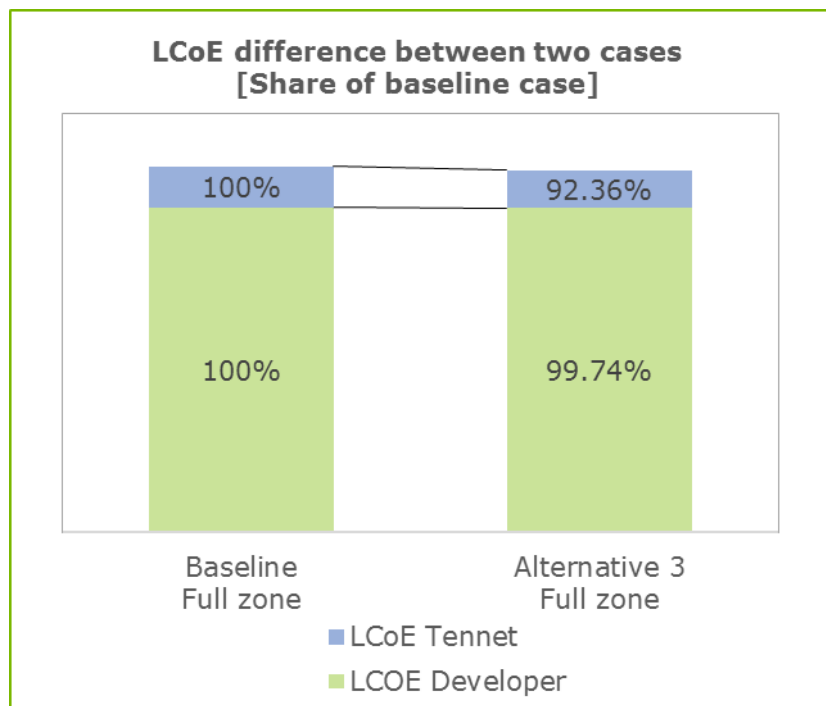


Figure 7 – Relative Difference in LCOE for Alternative 3

Table 14 – Site-specific Inputs (differences from Baseline are highlighted in bold)

	Alternative 3 - Hollandse Kust Zuid zone
Wind turbine rated capacity [MW]	7
Number of wind turbines	200
Wind farm rated capacity [MW]	1400
Average water depth [m]	21
Distance to port (Ijmuiden) [km]	45
Export cable length offshore [km]	29
Export cable length onshore [km]	11
Number of cable crossings - export cable [-]	1
Export cable voltage [kV]	220
Array cable length [km]	276
Array cable voltage [kV]	66
Number of cable crossings - array cables [-]	24
Average annual wind speed at 107 m [m/s]	9.6
Wake losses [%]	13.2%
Non-availability losses [%]	5.4%
Electrical losses [%]	2.3%
Net annual yield [GWh]	5218

Table 15 – Difference in calculated costs, relative to Baseline (reductions are highlighted in green, increases are highlighted in red)

	Alternative 3 - Hollandse Kust Zuid zone
Baseline scenario for comparison	Baseline Hollandse Kust Zuid zone
Total DEVEX	0.0%
Total CAPEX	-1.42%
Total Annual OPEX	-0.23%
Decommissioning	0.37%
LCOE Developer	-0.26%
LCOE Tennet	-7.64%
LCOE Overall	-1.10%

6 Alternative 4

This section presents the key results from “Alternative 4”, based on the following scenario description from RVO:

Calculate the effect on the LCOE if the additional areas in the north of the zone (triangle and parallelogram, shown in white in Baseline map) are added to Site 1 boundary.

The site boundaries were modified and new wind turbine and infield cable layouts were created according to the scenario description, as shown in Figure 8. The revised layout for Site 1 allows greater spacing between wind turbines than in the Baseline scenario.

The relative changes in LCOE due to changes for this scenario are shown in Table 16 and Figure 9. There are additional costs for Site 1, due to longer infield cables and more cable crossings. However, the extra costs are offset by lower wake losses (more yield) which results in lower LCOE for the developer and TenneT. The relative differences in site designs and costs are shown in bold in Table 17 and Table 18.

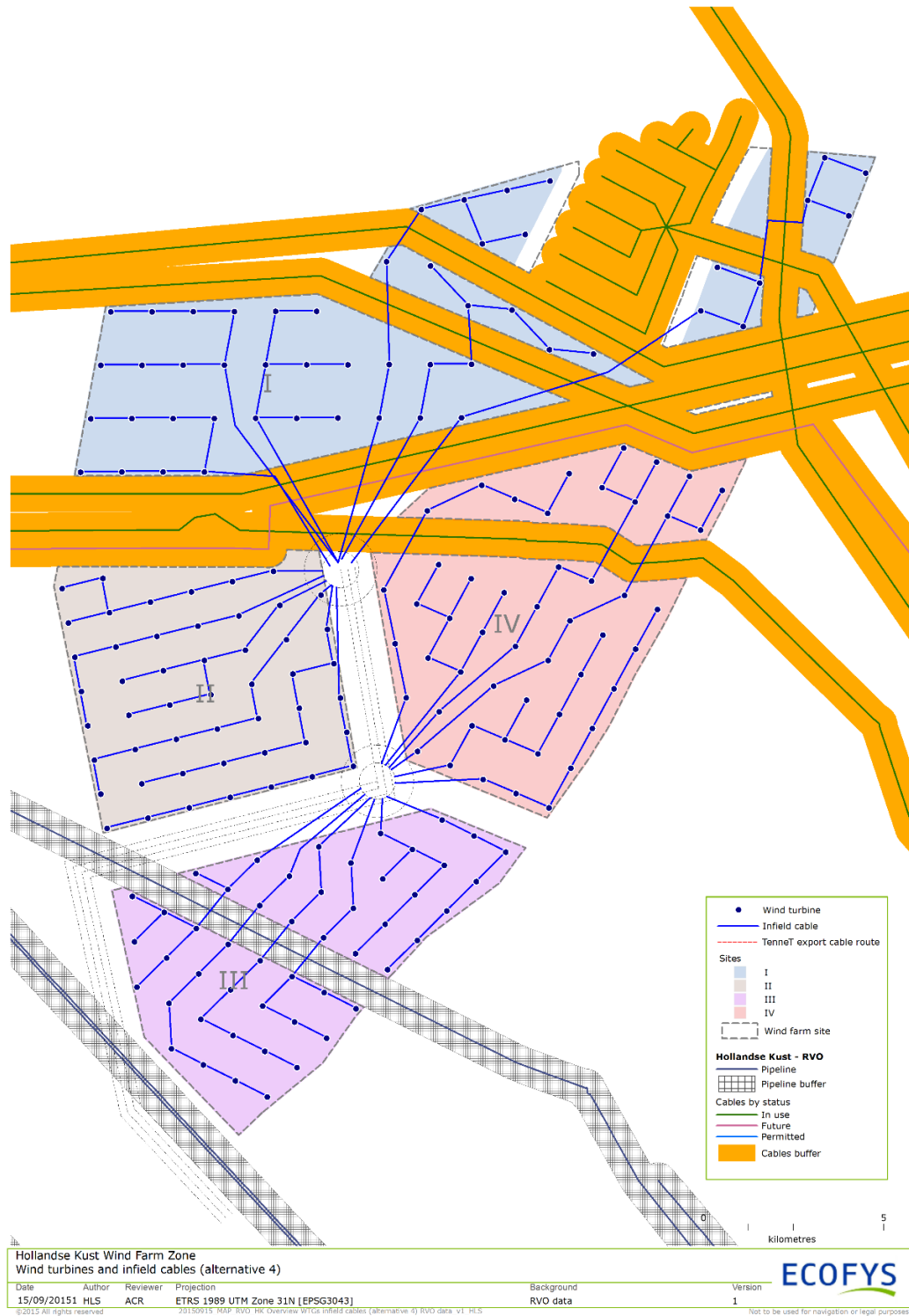


Figure 8 – Alternative 4 layout for Hollandse Kust Zuid zone (boundaries defined by RVO and Ecofys; layouts designed by Ecofys)

Table 16 – Changes in LCOE for Alternative 4 including explanations

Result	Impacts on LCOE	Cause
Zone - Developer	Decrease of -0.86%	Decreased wake losses: more yield Some wind turbines in less windy regions: less yield Lower average water depth: lower foundation costs Longer infield cables: more costs; higher electrical losses More cable crossings: more costs
Zone – TenneT	Decrease of -1.03%	Decreased wake losses: more yield Same costs
Zone - Overall	Decrease of -0.88%	See above

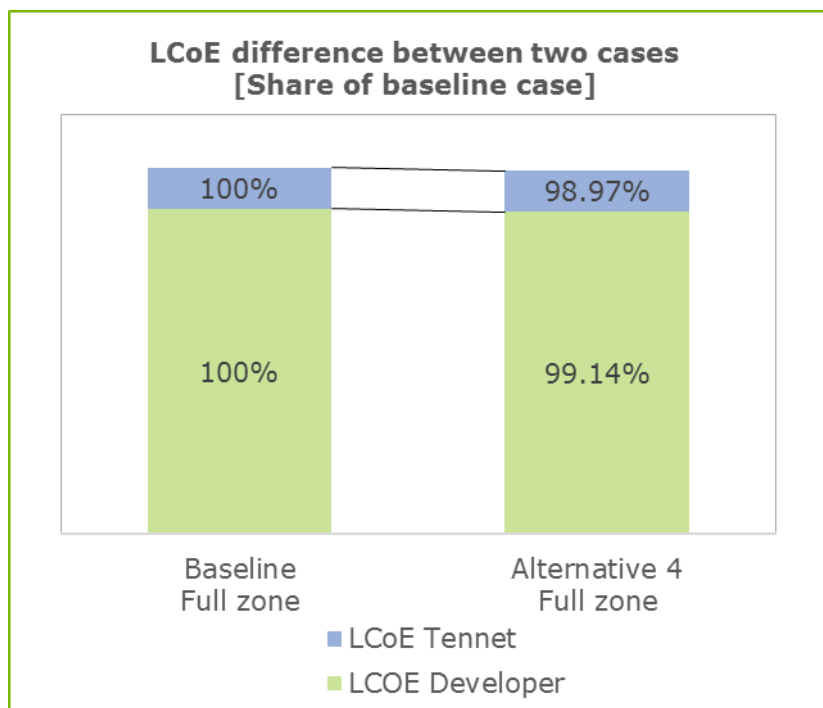


Figure 9 – Relative Difference in LCOE for Alternative 4

Table 17 – Site-specific Inputs (differences from Baseline are highlighted in bold)

	Alternative 4 - Hollandse Kust Zuid zone
Wind turbine rated capacity [MW]	7
Number of wind turbines	200
Wind farm rated capacity [MW]	1400
Average water depth [m]	21
Distance to port (Ijmuiden) [km]	45
Export cable length offshore [km]	42
Export cable length onshore [km]	11
Number of cable crossings - export cable [-]	3
Export cable voltage [kV]	220
Array cable length [km]	289
Array cable voltage [kV]	66
Number of cable crossings - array cables [-]	31
Average annual wind speed at 107 m [m/s]	9.6
Wake losses [%]	12.3%
Non-availability losses [%]	5.4%
Electrical losses [%]	2.7%
Net annual yield [GWh]	5255

Table 18 – Difference in calculated costs, relative to Baseline (reductions are highlighted in green, increases are highlighted in red)

	Alternative 4 - Hollandse Kust Zuid zone
Baseline scenario for comparison	Baseline Hollandse Kust Zuid zone
Total DEVEX	0.0%
Total CAPEX	0.18%
Total Annual OPEX	0.04%
Decommissioning	0.28%
LCOE Developer	-0.86%
LCOE Tennet	-1.03%
LCOE Overall	-0.88%

7 Comparison of Alternatives

The four alternative scenarios are directly comparable in Table 19, in terms of differences infrastructure and yields. In Table 20, the resulting differences in costs and LCOE are shown. The differences relative to the Baseline Scenario are highlighted in bold.

Table 19 – Comparison of Site-specific Inputs for each Alternative Scenario (differences from Baseline are highlighted in bold)

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Summary	Modified connections to the offshore hubs: Site I & IV to Northern OHVS; Site II & III to Southern OHVS	Telecom cables running between sites I and sites II/III relocated outside wind farm zone	Export cables exit the zone from the east	Additional areas within zone are added to Site 1
Wind turbine rated capacity [MW]	7	7	7	7
Number of wind turbines	200	200	200	200
Wind farm rated capacity [MW]	1400	1400	1400	1400
Average water depth [m]	21	21	21	21
Distance to port (Ijmuiden) [km]	45	45	45	45
Export cable length offshore [km]	42	43	29	42
Export cable length onshore [km]	11	11	11	11
Number of cable crossings - export cable [-]	3	3	1	3
Export cable voltage [kV]	220	220	220	220
Array cable length [km]	260	276	276	289
Array cable voltage [kV]	66	66	66	66
Number of cable crossings - array cables [-]	25	4	24	31
Average annual wind speed at 107 m [m/s]	9.6	9.6	9.6	9.6
Wake losses [%]	13.2%	12.6%	13.2%	12.3%
Non-availability losses [%]	5.4%	5.4%	5.4%	5.4%
Electrical losses [%]	2.6%	2.7%	2.3%	2.7%
Net annual yield [GWh]	5203	5239	5218	5255

Table 20 – Differences in calculated costs for each alternative scenario, relative to Baseline
(reductions are highlighted in green, increases are highlighted in red)

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Summary	Modified connections to the offshore hubs: Site I & IV to Northern OHVS; Site II & III to Southern OHVS	Telecom cables running between sites I and sites II/III relocated outside wind farm zone	Export cables exit the zone from the east	Additional areas within zone are added to Site 1
Total DEVEX	0%	0.0%	0.0%	0.0%
Total CAPEX	-0.11%	0.02%	-1.42%	0.18%
Total Annual OPEX	-0.08%	0.0%	-0.23%	0.04%
Decommissioning	-0.10%	0.02%	0.37%	0.28%
LCOE Developer	-0.14%	-0.77%	-0.26%	-0.86%
LCOE Tennet	-0.03%	-0.33%	-7.64%	-1.03%
LCOE Overall	-0.13%	-0.72%	-1.10%	-0.88%

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