SAVi Sustainable Asset Valuation

Sustainability Assessment of an Onshore Wind Portfolio in Germany

An Application of the Sustainable Asset Valuation (SAVi) for B Capital Partners, Zurich

SUMMARY OF RESULTS

IISD International Institute for Sustainable Development

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B CAPITAL PARTNERS

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Sustainability Assessment of an Onshore Wind Portfolio in Germany: An Application of the Sustainable Asset Valuation (SAVi) for B Capital Partners, Zurich

March 2020

Written by David Uzsoki, Laurin Wuennenberg, Oshani Perera, Andrea M. Bassi, and Georg Pallaske.

This SAVi assessment was commissioned by B Capital Partners AG, Zurich, Switzerland.

B Capital Partners AG is a partner-owned investment house, established in 2003 in Zurich. We exclusively focus on core sustainable infrastructure. Since 2010, we have invested and advised capital in excess of EUR 2.4bn across Europe. Our goal is to select superior infrastructure assets for our clients, while adhering to the highest corporate ethic as well as to state-of-the-art ESG standards. We are a signatory to UNPRI and a member of GRESB. B Capital is currently deploying capital for the Luxemburg-based B Capital Energy Transition Infrastructure Fund as well as for its institutional clients and large family offices via direct mandates.

We have demonstrated our commitment to integrating ESG aspects into the industry's traditional investment and monitoring processes via several industry initiatives and publications. Most importantly, we have developed an ESG DD tool for direct infrastructure investing together with GRESB.

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About SAVi

SAVi is a simulation service that helps governments and investors value the many risks and externalities that affect the performance of infrastructure projects.

The distinctive features of SAVi are:

- Valuation: SAVi values, in financial terms, the material environmental, social and economic risks and externalities of infrastructure projects. These variables are ignored in traditional financial analyses.
- Simulation: SAVi combines the results of systems thinking and system dynamics simulation with project finance modelling. We engage with asset owners to identify the risks material to their infrastructure projects and then design appropriate simulation scenarios.
- Customization: SAVi is customized to individual infrastructure projects.

For more information on SAVi:

www.iisd.org/savi

Executive Summary

B Capital Partners invited the International Institute for Sustainable Development (IISD) to conduct a sustainability assessment on one of their onshore wind portfolios, located in the central part of Germany. The portfolio consists of 14 onshore wind turbines of 2.05 megawatts (MW) capacity each, with a total capacity of 28.7 MW. The objective of the assessment is to improve transparency and provide evidence of how environmental, social, and economic costs and benefits (externalities) resulting from the onshore wind asset, as well as potential costs for the asset induced by climate change risks, would alter its asset valuation. IISD customized and applied the Sustainable Asset Valuation (SAVi) methodology to conduct a comparative sustainability assessment of this onshore wind portfolio and a hypothetical gas-fired power plant with the same power generation capacity.

The sustainability assessment consists of the following steps:

1. **Valuing, in financial terms, the environmental, social, and economic costs and benefits (externalities)** caused by the two energy generation assets. The following externalities are valued in this assessment:
    - Income spending from maintenance of energy capacity
    - Income spending from road construction
    - Income spending from construction of energy capacity
    - Land use
    - Real estate value depreciation
    - Road construction
    - Biodiversity management costs
    - Social cost of carbon (alternative 1 for valuing the cost of emissions)
    - Health costs of air pollution (alternative 2 for valuing the cost of emissions).
2. **Assessing the potential costs induced by climate change risks** and how the implied costs affect the financial performance of the energy generation assets if those risks materialize.
    - Air temperature increase (physical climate risk)
    - A carbon tax (transitional climate risk).
3. **Integrating the valued externalities and climate risk-related costs** into the three components of the SAVi assessment:
    - Cost-benefit analysis (CBA)
    - Levelized cost of electricity (LCOE)
    - Financial analysis, generating performance results for the equity and project internal rate of return (IRR).

Assessment Components and Results

Integrated Cost-Benefit Analysis (CBA)

The results of the integrated CBA are displayed in Table E1 and cover cost and benefit factors that occur over the lifetime of each asset. For the gas-fired power plant, a lifetime of 40 years is assumed, while the lifetime of the onshore wind farm amounts to only 23 years. The analysis reveals that both assets generate positive economic returns if only conventional cost and revenue factors are measured. The gas-fired power plant yields EUR 16.4 million positive net results, and the onshore wind farm generates EUR 25.16 million.

The SAVi net results include the potential costs induced by climate change risks and the value of environmental, social, and economic costs and benefits (externalities) caused by each respective asset. The two SAVi net results of the onshore wind farm remain at approximately EUR 21 million—irrespective of whether emissions caused by the wind portfolio are valued as social cost of carbon (3a) or as health cost of air pollution (3b). Therefore, the SAVi net results of the onshore wind farm are roughly 15% lower than the conventional net results (1). Assessed climate change risks have no cost implications for the onshore wind farm.

The integrated CBA indicates a positive net result of EUR 2.46 million (4b) for the gas-fired power plant if potential costs induced by climate change risks materialize and the value of externalities, including the health cost of air pollution (part of externality result 3b), are integrated into the calculation. If emissions of the gas-fired power plant are valued as social cost of carbon (3a) and are integrated into the CBA, total costs outweigh the benefits. The gas-fired power plant yields a negative net result of EUR -2.87 million (4a). In both instances, the SAVi net results of the gas-fired power plant are much poorer than in the conventional net results and are significantly poorer than the SAVi net results of the onshore wind portfolio.

Table E1. Net results of the integrated CBA – Comparison of a gas-fired power plant vs. the onshore wind portfolio (in EUR million)

Cost and benefit position	Gas-fired power plant (in EUR million)	Onshore wind (in EUR million)
Conventional costs: CAPEX and OPEX	(65.73)	(49.89)
Revenues	82.13	75.05
(1) Net results (conventional)	16.40	25.16
(2) Potential costs induced by climate change risks	(7.57)	0.00
(3a) Externalities	(11.70)	(3.58)
(3b) Externalities	(6.37)	(4.02)
(4a) SAVi net results (1 + 2 + 3a)	(2.87)	21.58
(4b) SAVi+ net results (1 + 2 + 3b)	2.46	21.14

Integrated Levelized Cost of Electricity Generation (LCOE)

The Levelized Cost of Electricity Generation (LCOE) is a measure of the unit cost of electricity generation (EUR/MWh). It provides a full breakdown of cost components. The LCOE is a useful indicator for comparing the unit cost of different technologies over their lifetime. It is hence suitable for comparing the onshore wind portfolio and the gas-fired power plant, as they are characterized by varying lifetimes.

When considering only the conventional cost positions for calculating the LCOE, both assets are almost on par and account for approximately EUR 64/MWh, as indicated by the (1) Subtotal in Table E2. The LCOE of the two assets increasingly diverge the more potential costs induced by climate change risks materialize and the more valued externalities are integrated into the calculation. The total integrated LCOE results for the gas-fired power plant ranges between EUR 76.21/MWh (4b) and EUR 81.48/MWh (4a), depending on which methodology for valuing emissions is chosen. The total integrated LCOE for the onshore wind farm amounts to approximately EUR 69/MWh, irrespective of the methodology for valuing emissions. The integration of potential costs induced by climate change risks and the value of externalities increases the LCOE of the onshore wind farm slightly by approximately 7% compared to the (1) Subtotal. In comparison, the LCOE of the gas-fired power plant increases more significantly between 15% (4b) and more than 20% (4a) compared to the (1) Subtotal.

Table E2. **LCOE of a gas-fired power plant and the onshore wind portfolio (in EUR/MWh)**

Cost and benefit position	Gas-fired power plant (in EUR million)	Onshore wind (in EUR million)
(1) Subtotal: Conventional LCOE for the producer	64.75	64.23
Potential costs induced by climate change risks	5.19	0.00
(2) Subtotal: LCOE for the producer, incl. potential costs induced by climate change risks	69.94	64.23
(3a) Total value of externalities, incl. social cost of carbon	11.54	4.53
(3b) Total value of externalities, incl. health costs of air pollution	6.27	5.10
(4a) Subtotal: LCOE for the society (1 + 2 + 3a)	81.48	68.76
(4b) Subtotal: LCOE for the society (1 + 2 + 3b)	76.21	69.33

Financial Analysis

The purpose of the financial analysis is to assess (a) the financial impact of potential costs induced by climate change risks and (b) the financial implications if the monetary values of environmental, social, and economic costs and benefits (externalities) are internalized. These two factors are integrated into the financial models of both assets as a change in cash flows in the cash flow (CF) statement. The scope of this financial analysis deviates from CBA and

LCOE calculation in one dimension. The financial analysis of the onshore wind portfolio is conducted from the investor's perspective. Hence, it captures the asset's performance from the point of acquisition onwards and not the entire asset lifecycle, whereas for the gas-fired power plant comparator, the entire asset life cycle is considered in the financial analysis.

The onshore wind portfolio yields a project internal rate of return (IRR) of 4.93% and an equity IRR of 6.7% if no climate change risks materialize and externalities are not internalized. Under the same condition, the gas-fired power plant yields a slightly lower project IRR of 3.27% and a much lower equity IRR of 3.57%. Consequently, the baseline results confirm that both projects are financially viable, while the onshore wind portfolio is the more attractive investment alternative.

Tables E3 and E4 summarize the results of the financial analysis. The analysis and presentation of results explicitly distinguish between internalizing potential costs induced by climate change risks and the monetary value of environmental, social, and economic costs and benefits (externalities). Internalizing the assessed externalities into the CF statement is rather hypothetical. In the near future, these externalities don't imply costs for the project and hence don't have cash flow impacts for the two assets. The situation is different when considering climate change risks. Physical impacts such as air temperature increases are a reality of climate change and are beginning to materialize. Likewise, regulatory changes with cost implications such as a carbon tax are becoming a reality in several jurisdictions, including Germany.

Integrating the additional costs of a carbon tax (transitional climate change risk) into the CF statement would impair the cash flows of the gas-fired power plant and yield a negative equity IRR and a negative project IRR. Costs induced by air temperature increases (physical climate change risks) have less severe implications for that asset but would still lower the equity IRR to 0.63% and the project IRR to 1.24%, as shown in Table E3. Therefore, if the assessed climate change risks materialize, the gas-fired power plant would no longer be financially viable. Materialization of these climate change risks has no implications for the equity and project IRR of the onshore wind portfolio.

Table E3. Financial impact of climate risks on project IRR and equity IRR of a gas-fired power plant and the onshore wind portfolio

	Gas-fired power plant		Onshore wind	
	Project IRR	**Equity IRR**	**Project IRR**	**Equity IRR**
IRR baseline = potential costs induced by climate risks not included	3.27%	3.57%	4.93%	6.70%
IRR, incl. potential costs induced by physical climate risks	1.24%	0.63%	4.93%	6.70%
IRR, including carbon tax (transitional climate risk)	Negative	Negative	4.93%	6.70%

The project IRR of the onshore wind farm decreases from 4.93% to approximately 4% if the value of all measured externalities is internalized. Likewise, the equity IRR decreases from 6.7% to 5.23% and 5.05% respectively, depending on the methodology for valuing emissions of the asset. Despite the overall detrimental effects of externalities, the asset yields positive IRR results. The financial performance of the gas-fired power plant, on the other hand, is more adversely affected if the value of all measured externalities is internalized. If certain externalities, such as the social cost of carbon or the health costs of air pollution are internalized, the IRRs of the asset would shrink to zero or even become negative.

Table E4. Implications of internalizing project externalities on project IRR and equity IRR of a gas-fired power plant and the onshore wind portfolio

	Gas-fired power plant		Onshore wind	
	Project IRR	**Equity IRR**	**Project IRR**	**Equity IRR**
IRR baseline = no externalities internalized	3.27%	3.57%	4.93%	6.70%
Project IRR, internalizing the total value of externalities, incl. social cost of carbon	Negative	Negative	4.09%	5.23%
Project IRR, internalizing the total value of externalities, incl. health costs of air pollution	Negative	Negative	3.98%	5.05%

Conclusions

Altogether, the results across all three components of the SAVi assessment (CBA, LCOE, Financial Analysis) demonstrate that the performance and investment attractiveness of the onshore wind portfolio remains relatively stable while the gas-fired power plant loses its investment attractiveness once potential costs induced by climate change risks and the value of monetized externalities are integrated into the assessment. This is evidenced by the gas-fired power plant's poor SAVi net results in the CBA, which range around zero, and the sharp decrease of project IRR and equity IRR once the potential costs induced by climate change risks or the value of externalities are internalized. Likewise, the LCOE of this plant is affected and significantly increases once these factors are internalized.

The onshore wind portfolio, on the other hand, is resilient to the assessed climate change risks, which is why these risk factors do not alter the asset performance across any of the three components of the SAVi assessment. The assessment results of this asset diminish if environmental, social, and economic costs and benefits (externalities) are monetized and internalized into the CBA, the LCOE, or the financial analysis. Still, the SAVi CBA results of the onshore wind portfolio remain considerably positive; the LCOEs increase only slightly once externalities are included in the calculation, and the equity IRR remains positive at approximately 5% and project IRR at around 4%. Therefore, compared to a gas-fired power plant, the assessed wind farm is the more resilient and more profitable investment choice as well as the more beneficial (less costly) energy generation asset from a societal point of view.

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Abbreviations

BAU	business as usual
CAPEX	capital expenditure
CBA	cost-benefit analysis
CF	cash flow
CLD	causal loop diagram
EBITDA	earnings before interest taxes, depreciation, and amortization
FTE	full-time equivalent
GDP	gross domestic product
HCAP	health costs of air pollution
IRR	internal rate of return
LCOE	levelized cost of electricity
LVOE	levelized value of externalities and climate risks
MW	megawatt
MWh	megawatt hours
NPV	net present value
O&M	operation and maintenance
OPEX	operation and maintenance expenditure
P&L	profit and loss
SAVi	sustainable asset valuation tool
SD	system dynamics
SCC	social costs of carbon

Glossary

Discounting: A finance process to determine the present value of a future cash value.

Externality: An externality is a negative or positive impact, often referred to as a cost or benefit, that affects a third party who did not play a role in determining such impact. The third party, who can be private (individual, organization) or the society as a whole, did not choose to incur the cost or to receive the benefit. Hence, an externality is not reflected in the market price of a good or service (Kenton, 2019).

Econometrics: A methodology that measures the relation between two or more variables, running statistical analysis of historical data and finding correlation between specific selected variables.

Equity Internal Rate of Return (IRR): IRR is the discount rate that makes the net present value (NPV) of all cash flows equal to zero. The equity IRR indicates the expected rate of return for equity investors, including the financing cash flows.

Feedback loop: "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts et al., 1983).

Health costs of air pollution: Health costs resulting from air pollution due to power generation. This includes health impacts from $PM_{2.5}$, SO_2, and NO_x emissions.

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (UNEP, 2014).

Internal rate of return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net present value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Optimization: A stream of modelling that seeks to identify the policy or set of policies that deliver the best possible outcome from a set of alternatives, given a set of criteria (i.e., parameters to optimize) and/or constraints (i.e., available budget) (UNEP, 2014).

Project Internal Rate of Return (IRR): IRR is the discount rate that makes the net present value (NPV) of all cash flows equal to zero. The project IRR is the expected rate of return for the whole project, including both equity and debt capital, thus excluding financing cash flows.

Risk: A risk in the context of infrastructure finance refers to the chance that a factor outside the direct control of an asset owner or operator materializes as a cost for an asset. Materiality of a risk is considered in relation to the asset under assessment. Risks can be of social, environmental (physical), economic, or regulatory origin. An externality caused by the same asset under assessment may or may not turn into a risk.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

Social costs of carbon: The economic cost caused by an additional ton of carbon dioxide emission or its equivalent through the carbon cycle (Nordhaus, 2017).

Spatial aggregation/disaggregation: Aggregated simulation models provide a single value for any given simulated variable (e.g., population and agricultural land). Spatial models instead generate results at the human scale and present them on a map, e.g., indicating how population and agricultural land would be geographically distributed within the boundaries of the country.

Stock and flow variables: "A stock variable represents accumulation and is measured at one specific time. A flow variable is the rate of change of the stock and is measured over an interval of time" (United Nations Environment Programme [UNEP], 2014, p. 51)

System dynamics (SD): A methodology developed by Forrester in the late 1950s (Forrester, 1961) to create descriptive models that represent the causal interconnections between key indicators and indicate their contribution to the dynamics exhibited by the system as well as to the issues being investigated. The core pillars of the system dynamics method are feedback loops, delays, and non-linearity emerging from the explicit capturing of stocks and flows (UNEP, 2014).

Vertical/horizontal disaggregation of models: Vertically disaggregated models contain a high level of detail at the sectoral level (i.e., energy), while horizontally disaggregated models focus on capturing the interconnections between several sectors and contain less detail at the sectoral level (UNEP, 2014).

1.0 Introduction

B Capital Partners invited the International Institute for Sustainable Development (IISD) to conduct a sustainability assessment on one of their onshore wind portfolios located in the central part of Germany, using IISD's Sustainable Asset Valuation (SAVi) methodology. The portfolio consists of 14 onshore wind turbines of 2.05 MW capacity each, with a total capacity of 28.7 MW. Information on the onshore wind portfolio from B Capital Partners was reviewed and combined with data from technical and scientific literature to parametrize and calibrate the SAVi assessment model.

B Capital Partners commissioned this sustainability assessment to better understand how their onshore wind portfolio performs if environmental, social, and economic costs, and benefits (externalities), as well as potential costs induced by climate change risks are integrated into an asset valuation. The application of SAVi provides this holistic view for infrastructure projects and portfolios by conducting three steps:

- Valuing, in financial terms, the environmental, social, and economic externalities of infrastructure projects/portfolios. An externality is a negative or positive impact that affects a third party who did not play a role in determining such impact. The third party, who can be private (individual, organization) or the society as a whole, did not choose to incur the cost or to receive the benefit.
- Assessing how environmental, social, economic and regulatory risks will impose costs and hence affect the financial performance of the infrastructure asset/portfolio if those risks materialize.

  For this assessment, two risk factors evoked by climate change are assessed: air temperature increase (physical climate risk) and the introduction of a carbon tax (transitional climate risk).
- Integrating the valued externalities and risk-related costs into the three components of the SAVi assessment:
  - Cost-benefit analysis (CBA)
  - Levelized cost of electricity (LCOE) calculation
  - Financial analysis.

To put the performance results of the onshore wind portfolio into perspective and allow B CAPITAL PARTNERS to evaluate the financial and sustainability competitiveness of this investment, a comparative assessment approach was defined. Performance results of the onshore wind portfolio generated by SAVi are compared to the performance results of a hypothetical gas-fired power plant in Germany. This was considered a meaningful comparator as it allows the comparison of investments into two widely used technologies for electricity generation in Germany: a renewable energy technology and a fossil fuel-based energy technology. Moreover, natural gas is considered essential for the energy transition in Germany and hence is expected to be present in Germany's energy mix in the coming decades. It is assumed that the gas-fired power plant has an operating capacity of 15.21 MW at a 43.7% load factor to match the annual electricity generation provided by the wind portfolio and hence make conventional costs of externalities caused by the asset comparable.[1] The assumed lifetimes of the wind and gas assets are 23 years and 40 years, respectively.

Section 2 of this report presents the results of the integrated CBA and the LCOE for both assets. In this part of the report, the costs of technology for each respective asset are used to conduct the analysis. The quantified and valued externalities are integrated into the CBA and the LCOE calculations. Likewise, the potential costs induced by climate change risks (air temperature increase and carbon tax) are incorporated. CBA results are presented as cumulative discounted numbers over the lifetime of each asset. The LCOE results are presented as costs per MWh of electricity generated. Calculating the LCOE of both assets serves to make the costs (as well as the valued externalities and risk-imposed costs of the two energy generation technologies) comparable despite their varying lifetimes. Section 2 closes by highlighting the results of biophysical parameters of both assets, which provide the underlying data for the monetary valuation.

Section 3 presents the methodology and the results of the financial analysis conducted for the onshore wind portfolio and the hypothetical gas-fired power plant. The P&L and CF statements of B CAPITAL PARTNERS are used to conduct the financial analysis for the onshore wind portfolio while the cost of technology is used to conduct the same for the gas-fired power plant. The financial analysis serves to assess how climate change risks affect the financial performance (if they materialize) and how the valued economic, environmental, and social costs and benefits (externalities), would change the financial performance if they are incorporated into the financial analysis as well. Specifically, the financial analysis conducted by SAVi reveals how the project internal rate of return (IRR) and the equity IRR of both assets change if climate change risks, on one hand, and externalities, on the other hand, are internalized.

The report closes with a conclusion in Section 4 that highlights the key takeaways for B CAPITAL PARTNERS.

Annex 1 summarizes methodological considerations of the two modelling approaches that constitute SAVi: system dynamics and financial modelling. The chapter outlines how the SAVi energy model was applied for this assessment and presents two different approaches for internalizing risks and externalities into the financial model of an asset.

Annex II provides details on assumptions, data sources, and how various risks and externalities are valued.

Figure 1 shows a generalized systems diagram presenting the systemic approach used for this sustainability assessment to estimate the societal contribution of electricity generation from onshore wind and natural gas, and on the other hand, to estimate how elements of the system affect the infrastructure assets under assessment. The diagram shows how the asset is embedded in the system (energy in this case) and how it affects a variety of social, economic, and environmental indicators. The system dynamics and financial models used for this assessment include indicators of capacity and generation, employment, and fuel consumption.

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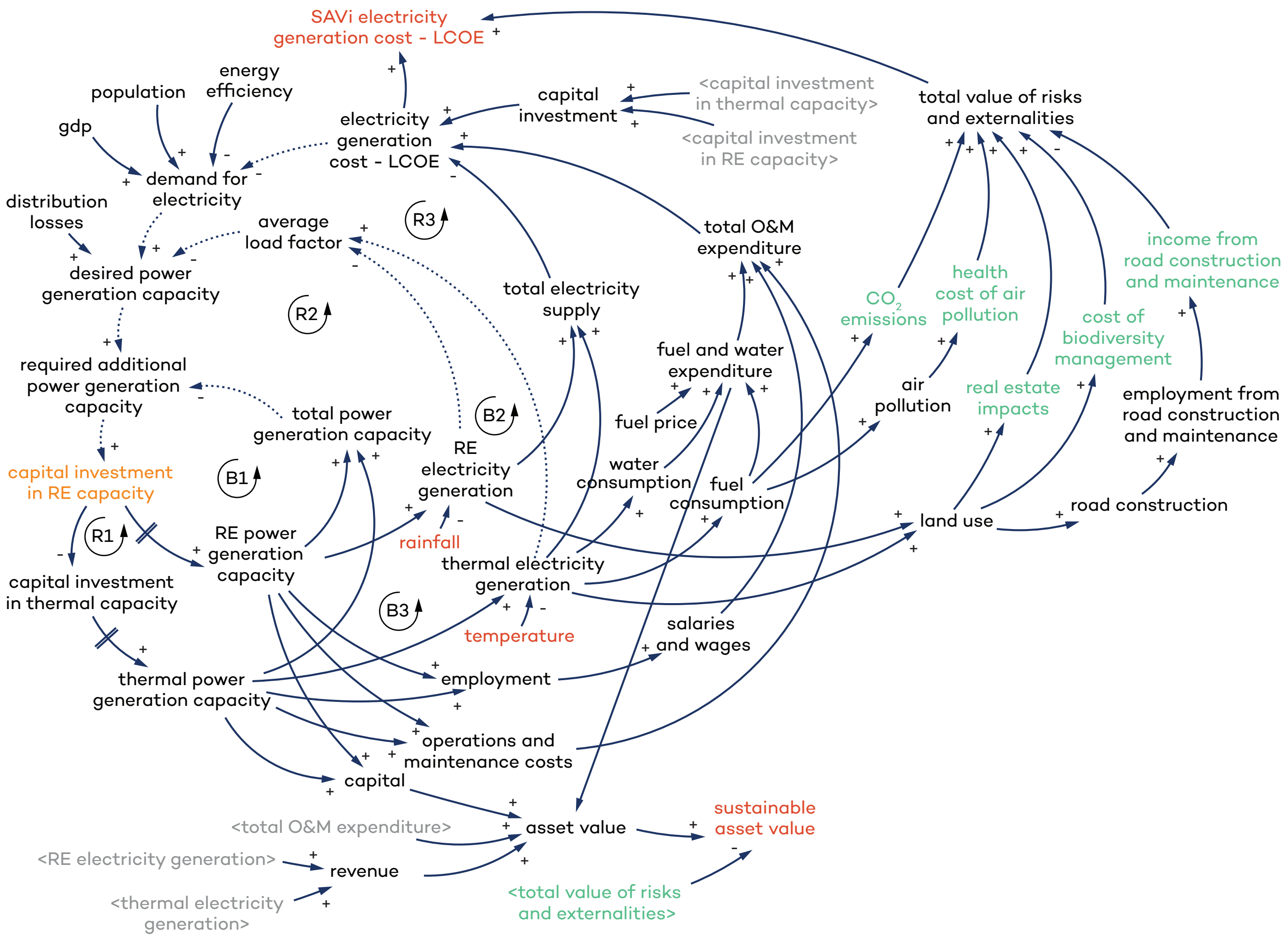
[1] The annual generation of electricity is the same for both technologies. Given that the gas-fired power plant has a higher load factor, the number of MW of capacity required for gas is lower than the MW of wind.

As a result, CAPEX and OPEX can be estimated for the analysis. In addition, various externalities caused by the assets are estimated, being a negative or positive impact that affects a third party in the system who did not play a role in determining such impact. Finally, risks that will likely materialize as a cost for an energy asset are estimated. An example of a material risk is the reduced power generation efficiency caused by rising air temperatures, being a physical impact of climate change. The main climate-related variables for the assessment of climate change impacts on power generation capacity are (i) precipitation (affects water availability for cooling purposes) and (ii) temperature (affects generation efficiency and hence fuel use, and in turn emissions). Future variations of precipitation and temperature are externally defined and affect the load factor and efficiency of gas-fired generation, which in turn affect generation costs and revenues. The feedback of GHG emissions caused by the gas-fired power plant under analysis on future variations in climate is not accounted for in this assessment due to the negligible share of this plant in global GHG emissions.

Figure 1. Conceptual representation of the systemic analysis performed with (i) a System Dynamics and (ii) a Financial model.



Legend: red variables represent exogenous climate-related assumptions; green variables represent externalities; orange variables are investment decisions (e.g., investment in a specific asset).

The diagram shows that circular causal relations between variables form causal feedback loops. Causal loop diagrams include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or –) on each link, indicating a positive or negative causal relation (see Table 8 in Annex 1). Positive causal links are reinforcing relations that amplify change over time, while negative links imply balancing effects that reduce change over time and lead to equilibriums.

2.0 SAVi Assessment Results – Cost-benefit analysis and levelized costs of electricity

This chapter presents the results of the integrated CBA and the LCOE for the two energy assets: The onshore wind portfolio and a hypothetical gas-fired power plant. The calculations of the CBA results and the LCOE are based on system dynamics modelling and consider the entire life cycle of both assets. For this purpose, assumptions for the cost of technology were used for both assets. This was necessary because the available P&L and CF statements of the client did not provide sufficient information to assess the entire life cycle of the assets.

The CBA integrates both the potential costs induced by climate change risks and the monetary values of the economic, environmental, and social costs and benefits (externalities) of the two assets. The CBA results are presented in Section 2.1 as cumulative values over the lifetime of each asset. Subsequently, Section 2.2 presents the results of integrating the potential costs induced by climate change risks and the valued externalities into the calculation of the LCOE. Section 2.3 presents the results of assessed biophysical parameters. These are the underlying parameters for valuing the risks and externalities that are integrated into the CBA and the LCOE.

2.1 Integrated Cost-Benefit Analysis

In this section, environmental, social, and economic costs and benefits (externalities) of the onshore wind portfolio, and potential costs induced by climate change impacts—also referred to as climate change risks—are integrated into a comparative CBA. Results of the onshore wind farm portfolio are compared to the results of a gas-fired power plant of the same amount of electricity generation. Tables 1 to 4 on the following pages present the performance results of the integrated CBA, indicating cumulative numbers over the lifetimes of each of the two assets. The two assets have varying capacity lifetimes. The lifetime of the wind farm is 23 years, while a gas-fired power plant typically operates for 40 years.

The CBA covers conventional cost positions for constructing and operating each of the assets (Table 1), integrates potential costs induced by climate change impacts (Table 2) as well as environmental, social, and economic costs and benefits (externalities) caused by each asset (Table 3). Finally, the revenues from selling generated electricity are calculated, and the net results for both assets are presented (Table 4). All values are displayed in EUR million and are discounted[2] at an interest rate of 4.5%. Cost figures are indicated using a minus sign, while revenues and positive externalities are displayed without a minus sign. The right column in the tables serves to define the respective cost position/risk/externality, explain assumptions and methods applied to calculate monetary values and highlight the performance results.

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[2] Discounting is applied to estimate the value of the project considering the declining value of money (or purchasing power) in the future. Discounting captures the effects of inflation and the potential return of investment alternatives (opportunity costs). A discount factor of 4.5% implies that the value of money next year allows the purchase of 4.5% less than in the current year.

Table 1. Conventional lifecycle costs of the Integrated CBA – Comparison of a gas-fired power plant vs. the onshore wind farm (EUR million)

Discounted cost by position (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**[3]
Capital and O&M expenditure	-10.92	-43.12	Capital and operational expenditures for generating electricity over the lifetime of each asset based on the weighted average technology cost (Barclays, 2016; International Energy Agency [IEA], 2014).
Cost of financing	-0.675	-5.21	The cost of financing includes interest rate payments and financing fees charged by financing institutions that provide capital for different phases of the asset.
Fuel costs	-53.62	0.00	Cost for fuel necessary to generate electricity. This cost item only applies for generating 58,214 MWh electricity annually by the gas-fired power plant (YCharts, 2019).
Compensation payments	0.00	-0.61	Compensation payments of EUR 42,400 occur annually for the onshore wind farm to establish, maintain, supervise, and report on new hunting grounds for birds. Birds would otherwise be adversely affected if they would continue hunting on the territory of the wind farm. Compensation is paid by the asset owner of the onshore wind farm to farmers in proximity to the wind farm to grow specific crops and treat the agriculture land in particular ways that allow the provision of a new habitat for birds. Such compensation payments are not assumed for the gas-fired power plants, as there is no evidence for effective mitigation strategies to reduce bird kills (see detailed comments below, next to “biodiversity management”).

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[3] Detailed explanations and quantitative assumptions are indicated in Section 2.3 of this chapter and Annex I.

Discounted cost by position (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**[3]
Decommissioning	-0.51	-0.96	EUR 36,000 per MW decommissioning costs for wind were assumed. This value is indicated in the project proposal and permission documents (LVA Sachsen-Anhalt, 2007). For the gas-fired power plant decommissioning costs of EUR 20,000 per MW were assumed, which are average costs for a plant below 500 MW of capacity in the U.S. power sector (Raimi, 2017).
Subtotal (1)	**-65.73**	**-49.89**	Subtotal (1) is the sum of all conventional cost positions for each of the two assets.

The calculation of conventional cost positions in Table 1 demonstrates that the onshore wind farm is more capital-intensive. However, the longer lifetime of the gas-fired power plant, combined with the high annual fuel costs, contribute to the overall higher conventional costs of the gas-fired power plant.

Table 2 presents the potential costs induced by climate change risks. Climate change risks considered in this assessment are a 1.5°C air temperature increase (a physical climate change risk) and the introduction of a carbon tax (transitional climate change risk). If these risks materialize at the location of the asset because the average air temperature indeed increases and because the German government decides to introduce a carbon tax for GHG emissions from electricity generation, the risks become reality, with immediate financial implications for some assets. The financial implication of a 1.5°C air temperature increase on plant operational efficiency and the resulting need for additional fuel consumption is calculated for the gas-fired power plant in Table 2. As the wind farm's operational efficiency is not affected by air temperature increases—and as it does not require any fuel for operation—this climate change risk has no implications for the wind farm even if it materializes. Other potential physical climate change impacts, such as changes in wind speed and wind patterns, are not considered in this assessment because there is a lack of knowledge and uncertainty about future changes in wind speed over the lifetime of the investment. This makes it difficult to calculate wind speed changes over the course of the 24 hours to match the demand curve. For this reason, an estimate of the impact of climate change on wind speed (and hence on the potential impact on revenues from wind power) was not included.

The introduction of a carbon tax of EUR 25/t CO_2 has cost implications over the lifetime of assets that generate electricity based on fossil fuels. Table 2 highlights the fact that the introduction of a carbon tax implies additional costs for the gas-fired power plant only because it emits GHG emissions during operation as opposed to the non-emitting onshore wind farm.

Table 2. **Potential costs induced by climate change risks over the asset lifetime – Comparison of a gas-fired power plant vs. the onshore wind farm (EUR million)**

Potential costs induced by climate change risks (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
Additional fuel consumption costs	-3.54	0.00	Physical impacts of climate change: Impact of forecast 1.5°C higher air temperatures on the efficiency of converting gas to electricity (thermal conversion is more efficient at low temperature). If thermal efficiency declines, more gas is needed to generate 1 MWh of electricity. The implication is that more gas will be needed to generate the same amount of electricity. The cost of gas will increase by EUR 3.54 Mn. Air temperature increase of 1.5°C has no implications for the onshore wind farm.
Carbon tax payments	-4.03	0.00	Regulatory changes due to climate change: Imposition of a carbon tax of EUR 25/t CO_2 for the gas-fired asset. The carbon tax is assumed to be applied to operational emissions (during electricity generation) and not lifecycle emissions of an asset. The indicated value of EUR 4.03 million captures the cumulative carbon tax payments during the operation of that asset (physical climate change impacts on additional fuel consumption not considered in this calculation). If air temperature increases caused by climate change are included, additional CO_2 emissions would be generated because of the additional amount of gas burnt to maintain the same levels of electricity generation. This would cause additional carbon tax payments and increase the total carbon tax expenditures to EUR 4.16 million.
Subtotal (2)	**-7.57**	**0.00**	Subtotal (2) sums up the potential costs induced by climate change risks. If the climate is changing as forecasted and if policy is introducing a carbon tax, the indicated costs will incur to the asset owner and will have cash flow impacts.
Subtotal (1+2)	**-73.30**	**-49.89**	Adds up all conventional costs and climate change-induced costs.

Subtotal (2) reveals that if the assessed climate change risks materialize, they will imply costs for the gas-fired power plant. The operational efficiency of the plant is negatively impacted if the air temperature increases by 1.5°C. This increase is a forecasted physical climate change impact in Germany and will lead to EUR 3.54 million higher fuel consumption costs over the lifetime of the gas-fired power plant to maintain a constant level of electricity generation. Likewise, only the gas-fired power plant emits CO_2 emissions during the operational lifetime and will hence incur cumulative costs of approximately EUR 4 million if a carbon tax is introduced and set at EUR 25 per ton of CO_2 emitted.

Assessment results of environmental, social, and economic costs and benefits (externalities) caused by each respective asset are presented in Table 3. Positive externalities are taken into account as benefits and negative externalities as costs, indicated by a minus sign. Note that externalities caused by the asset do not imply higher costs or revenues for the asset owner in the immediate term but are costs or benefits for third parties. Externalities do not have an immediate cash flow impact for the asset owner. However, they can turn into risks and change costs or revenues—such as the introduction of a carbon tax as a response to assets that cause high social costs of carbon due to their lifecycle carbon emissions.

Table 3. Externalities caused by each asset throughout the lifetime – Comparison of a gas-fired power plant vs. onshore wind farm (EUR million)

Externalities (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
Income spending from maintenance of energy capacity[4]	0.36	1.46	Employment creation due to installation and maintenance of electricity generation capacity. Electricity generation from wind generates 14.2 jobs per year, while gas capacity is projected to provide on average 2.8 jobs per year. Hired staff receive a salary and a share of that will be spent for local consumption. This fuels local economic growth.
Income spending from road construction	0.10	0.35	Employment creation due to road construction and maintenance to transport material to the site, build the plants, and operate these. The construction of access roads generates an additional four jobs per year for the wind farm and 0.6 jobs per year for a gas-fired power plant. Hired staff receive a salary and a share of that will be spent for local consumption.

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[4] If it is assumed that 100% of O&M employment is generated locally, the number of O&M jobs provided by gas and wind are 4.2 and 21.2 full-time equivalent (FTE) respectively. This implies that, if the same salary is paid for both jobs, the income created by wind would be five times larger than natural gas.

Externalities (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
Local income spending from construction (manufacturing and installation) of energy capacity[5]	0.00	2.56	Employment creation due to required manufacturing of plant equipment in proximity to the site. This applies to the wind farm as their heavy parts, such as poles, cannot be transported easily over long distances. The manufacturing of these elements generates on average 110 jobs during the first four years of the project, after which no additional capacity is installed. Hired staff receive a salary, and a share of that will be spent for local consumption. Such local manufacturing does not apply for a gas-fired power plant.
Land use	-0.03	-0.18	To value land use, an opportunity cost approach was chosen: Foregone profit for the agriculture sector and foregone tax revenues from impeded agriculture production due to the use of land for power generation capacity and established roads. The average foregone agriculture production for this area is assumed at 4 tons/hectare (ha)/year. For the wind farm, it is assumed that 5.1 ha are used for turbines and road, and no agriculture production can take place on this area. For the gas-fired power plant, the required land area is significantly smaller.
Real estate	-1.99	-0.99	Negative impact on real estate value for apartments in proximity to the gas-fired power plant and the wind farm: A reduction in real estate value of 4% is assumed for apartments in proximity to the gas-fired power plant (Davis, 2011) and 2% reduction for apartments in proximity to the wind farm (Sunak & Medlener, 2017) respectively. Therefore, the absolute reduction of the real estate value is twice as high for the gas-fired power plant as for the wind farm. Detailed assumptions are presented in Annex II.
Cost of roads	-0.23	-0.82	Capital and operational expenditures for roads necessary to construct and operate the power plants. Capital and O&M costs for green roads are used, as roads are envisaged to be permeable. The assessment does not assume the use of recycled asphalt pavement; hence full material costs apply.

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[5] If it is assumed that 100% of construction employment would be sourced locally, the average annual number of construction jobs (both manufacturing and installation) would be 17.2 for gas and 95.7 for wind. This implies that manufacturing and installing the power capacity assumed in this study requires 5.56x more jobs for wind than natural gas (10 jobs per MW for wind, 3.3 jobs per MW for gas).

Externalities (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
Biodiversity management costs (to avoid adverse impacts for bird populations)	*n/a* *(> wind) **	-5.67	Both energy generation assets are known to have adverse effects on birds and their habitats. Detailed explanations about estimated bird kills per asset follow in Section 2.3 of this chapter. Valuation approaches are explained here. **Valuation of wind farm impacts:** An agricultural compensation area is established in proximity to the wind farm to provide a new hunting ground for birds and prevent them from hunting on the wind farm territory. This strategy is meant to significantly reduce the otherwise observed bird kills caused by wind turbines and electrocution. The foregone agriculture revenues on this area are used as a valuation method. These foregone revenues occur due to only growing specific crops and not using fertilizers and pesticides on this area. We assumed a 50% agriculture yield reduction for this area, i.e., reduced productivity at 2 tons/ha/year. **Valuation of impacts from a gas-fired power plant:** We could not identify a suitable offsetting strategy in the literature to mitigate disturbance and reduce bird kills from the operation of thermal power plants. Hence, no monetary value was estimated. Due to the comparatively higher bird kills reported in studies (see Section 2.3 of this chapter), it can be assumed that an effective offsetting strategy for a gas-fired power plant would cost more than for a wind farm with the same electricity output. More research is recommended to value the negative impact of gas-fired power plants on biodiversity.

Externalities (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
Social cost of carbon	-9.92	-0.28	The social costs of carbon (SCCs) are the economic cost caused by an additional ton of carbon dioxide emission or its equivalent through the carbon cycle. This is a **top-down** assessment of the cost of carbon, which is priced at EUR 25 per ton of $CO_{2eq.}$ emissions (Nordhaus, 2017). Life-cycle emissions are considered here and not only $CO_{2eq.}$ emissions during the operational phase of an asset. Therefore, the cumulative SCC of the gas-fired asset is significantly higher than the cumulative carbon tax payments of the asset indicated in Table 2. The SCC in the case of gas are not only distinctively higher than the SCC of the onshore wind farm but also much higher than the “Health costs of air pollution” from gas. This is because $CO_{2eq.}$ emissions concentration from gas used as the fuel during the lifetime of the plant are disproportionally higher compared to the comparatively low level of air pollutants from gas with negative health implications. Moreover, the “Health costs of air pollution” represent only additional health care costs while SCC cover a variety of economic cost factors. If we consider that air temperature increase (physical climate change impact) will increase fuel consumption, the SCC of the gas-fired power plant would increase to EUR 10.13 million. Wind would remain unchanged at EUR 0.28 million.
(3a) Value of all externalities (including SCC)	**-11.71***	**- 3.58**	**Subtotal (3a) adds up all externalities, including the SCC but excluding the HCAP.**
Health costs of air pollution	-4.59	-0.72	Health costs resulting from air pollution caused by power generation: pm2.5, SO_2, and NO_x emissions. pm2.5 is a measure of air pollution (i.e., emission concentration). SO_2 and NO_x emissions are also considered because they have measurable impacts on health. We estimate the additional health care cost caused by exposure to these air pollutants. This approach is hence a **bottom-up** assessment for estimating costs. The negatively valued health costs of air pollution are much higher for the gas-fired power plant than for onshore wind. However, the valuation of air pollutants emitted by the onshore wind farm exceeds the wind farm’s SCC. If we consider physical climate change impacts, the adjusted health costs of air pollution of gas would be EUR 4.69 million. Wind would remain unchanged at EUR 0.72 million.

Externalities (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
(3b) Value of all externalities (including HCAP)	**-6.37***	**- 4.02**	**Subtotal (3b) adds up all externalities, including the HCAP but excluding the SCC.**
Subtotal (1 + 2 + 3a)	**-85.00***	**-53.47**	**Adds up all conventional costs, climate change-induced costs, and externalities, including the SCC but excluding the HCAP.**
Subtotal (1 + 2 + 3b)	**-79.67***	**-53.91**	**Adds up all conventional costs, climate change-induced costs and externalities, including the "Valuation of emissions" but excluding the SCC.**

*Note: The calculated sums do not include a quantitative value for negative impacts of the gas-fired power plant on biodiversity. Explanations are provided in the respective comment column for "biodiversity management" in Table 3. Subtotals of the gas-fired power plant would further decrease if this negative externality is valued in financial terms.

Results in Table 3 above demonstrate that the negative value of externalities caused by the gas-fired power plant is more than three times higher as opposed to onshore wind (subtotal 3a), primarily caused by the high SCC over the lifetime of the gas-fired power plant. The end results look slightly different if the health costs of air pollution are included in the calculation (subtotal 3b) instead of the SCC. In that case, the gas-fired power plant still causes greater environmental, social, and economic costs (negative externalities) than onshore wind, but the discrepancy between the two assets is less significant compared to subtotal 3a.

Table 4. Revenues and net results of the integrated CBA – Comparison of a gas-fired power plant vs. the onshore wind farm (EUR million)

Net results (EUR million)	**Gas-fired power plant**	**Wind farm onshore**	**Comments**
(1) Conventional costs	-65.73	-49.89	Covers all conventional cost positions. See Table 1.
Revenues	82.13	75.05	The revenues of each asset are based on generated electricity sold over the lifetime of the asset. The electricity price development over time for wind is based on average tariff assumptions provided by B Capital Partners. A constant price of 137.73 EUR/MWh is assumed from 2033 onwards. The price of electricity generated by wind is subsidized in Germany. It is assumed that this subsidy remains in place over time. The price for electricity generated by gas is assumed to be 23.23% lower than for wind, which is reflecting the current difference in electricity prices in Germany: 89.62 EUR/MWh for wind vs. 68.80 EUR/MWh for gas (Thalman & Wehrmann, 2019). It is assumed that this difference remains constant over time. Section 3.4 of the report shows how financial performance indicators change when a higher electricity price is assumed for the gas-fired power plant. Future revenues of both assets are discounted at a rate of 4.5%.
Net results (conventional): Revenues – (1)	16.40	25.16	These net results reflect the results of a conventional CBA. The conventional costs are subtracted from project revenues. The onshore wind farm generates almost EUR 9 million higher net benefits than the gas-fired power plant.
(2) Potential costs induced by climate risks	-7.57	0.00	Cost implications for each asset if assessed climate change risks materialize.
(3a) Externalities	-11.70*	- 3.58	Including the SCC but excluding the HCAP.
(3b) Externalities	-6.37*	- 4.02	Including the HCAP but excluding the SCC.
Net results SAVi+: Revenues – (1 + 2 + 3a)	**-2.87***	**21.58**	**Net results of both assets, including the SCC excluding the HCAP.**
Net results SAVi++: Revenues – (1 + 2 + 3b)	**2.46***	**21.14**	**Net results of both assets, including the HCAP but excluding the SCC.**

*Note: The calculated sums do not include a quantitative value for negative impacts of the gas-fired power plant on biodiversity. Explanations are provided in the respective comment column for "biodiversity management" in Table 3. Net results of the gas-fired power plant would further decrease if this externality is valued in financial terms.

The results of the integrated CBA (Table 4) demonstrate that the onshore wind farm generates economic returns, irrespective of risks and externalities being integrated into the analysis or not. The net results decrease by approximately 14% (SAVi+ net results) and 16% (SAVi++ net results) if the externalities are integrated into the analysis. Therefore, the externalities of the onshore wind farm have an overall negative impact on the net results of the portfolio.

Comparing the two assets, the adverse impacts of materialized climate change risks and externalities on the net results are significantly stronger for the gas-fired power plant. The conventional net results indicate a lower value for the gas power plant than observed for the onshore wind farm but still a decent economic return of more than EUR 16 million. The SAVi net results are less convincing for the gas-fired power plant once potential costs induced by climate change as well as externalities are integrated. If the CBA includes the health costs of air pollution, the net results (SAVi ++) for gas are still positive but are 88% lower than the net results of the onshore wind farm. The renewable asset still generates more than EUR 21 million in economic returns. If the SCCs are integrated instead of the health costs (SAVi +), the net results of the gas-fired power plant even become negative while the onshore wind farm yields a similar economic return as before.

It is important to highlight that the comparatively better performance of the onshore wind farm occurs despite the longer operational period of the gas-fired power plant and the consequently higher total revenues of that plant. However, when considering the significantly longer operational phase of the gas-fired power plant, the difference in total revenues generated is not that large. This is due to the economic effect of the electricity price subsidy for the onshore wind farm. Other key reasons for the poorer performance of the gas-fired power plant are the high fuel costs, its high vulnerability to climate change impacts, and the overall higher negative value of externalities compared to the onshore wind farm. The more that risks and externalities are integrated into the CBA, the greater are the differences between the net results of both assets. These results will be even more in favour of the onshore wind farm if the negative impacts of the gas-fired power plant on biodiversity would be valued in economic terms and integrated into the CBA.

2.2 Levelized Cost of Electricity

The levelized cost of electricity generation (LCOE) is a measure of the unit cost of electricity generation. It provides a full breakdown of cost components. LCOE is a useful indicator for comparing the unit cost of different technologies over their lifetimes (IEA, 2015). It is calculated by dividing the net present costs of generation over the lifetime of capacity by the net present generation. In other words, it is calculated by dividing cumulative discounted costs (i.e., Euro) by cumulative discounted generation, typically indicated in MWh. Annex II provides a detailed formula of how the LCOE is calculated.

Similar to the integrated CBA discussed in Table 1 to Table 4, potential costs induced by climate change risks, and the value of externalities are integrated (as cost and benefit items) into the calculation of the LCOE in Table 5. The calculation of the integrated LCOE is done for both power generation assets to make the comparative analysis more comprehensive and disclose the "societal" cost of power generation by the respective asset type. Because the LCOE is a cost indicator, positive externalities (benefits) are indicated with a minus sign (they reduce the LCOE), whereas negative externalities (costs) are adding to the LCOE.

Explanations for each cost position in the below table are the same as listed in Tables 1 to 4. Please refer to the respective comment column in these tables.

Table 5. LCOE of a gas-fired power plant and onshore wind farm

Levelized cost of electricity generation by cost position (EUR/MWh)	**Gas-fired power plant**	**Share of total cost (incl. SCC)**	**Wind onshore**	**Share of total cost (incl. SCC)**
Conventional cost positions				
Capital expenditure	5.56	6.8%	32.43	47.2%
O&M expenditure	5.22	6.4%	23.11	33.6%
Cost of financing	0.71	0.9%	7.01	10.2%
Fuel costs	52.98	65.0%	0.00	0.0%
Compensation payments	0.00	0.0%	0.45	0.7%
Decommissioning costs	0.28	0.3%	1.23	1.8%
Subtotal (1): LCOE for the producer	**64.75**	**79.5%**	**64.23**	**93.4%**
Potential costs induced by climate risks				
Additional fuel consumption costs due to air temperature increases	1.21	1.5%	0.00	0.0%
Carbon tax payments	3.98	4.9%	0.00	0.0%
Total potential costs induced by climate risks	5.19	6.4%	0.00	0.0%
Subtotal (2): LCOE for the producer, incl. potential costs induced by climate risks	**69.94**	**85.8%**	**64.23**	**93.4%**

Levelized cost of electricity generation by cost position (EUR/MWh)	**Gas-fired power plant**	**Share of total cost (incl. SCC)**	**Wind onshore**	**Share of total cost (incl. SCC)**
Externalities				
Income spending from maintenance of energy capacity	-0.35	-0.4%	-1.89	-2.7%
Income spending from road construction	-0.10	-0.1%	-0.45	-0.7%
Income spending from construction of energy capacity	0.00	0.0%	-3.30	-4.8%
Land use	0.03	0.0%	0.23	0.4%
Real estate value	1.96	2.4%	1.28	1.9%
Road construction	0.20	0.2%	0.96	1.4%
Biodiversity management costs	N/A*	0.0%	7.34	12.1%
Cost of emissions: Social cost of carbon (SCC)	9.80*	12.0%	0.36	0.5%
Cost of emissions: Health costs of air pollution (HCAP)	4.53*	-	0.93	-
Total value of externalities, incl. SCC	**11.54***	**14.1%**	**4.53**	**6.6%**
Total value of externalities, incl. HCAP	**6.27 ***	**-**	**5.10**	**-**
LCOE in total, incl. potential costs induced by climate risks + value of externalities				
Subtotal (3a): LCOE for the society, incl. SCC	**81.48***	**100%**	**68.76**	**100%**
Subtotal (3b): LCOE for the society, incl. HCAP	**76.21***	**-**	**69.33**	**-**

*Note: The calculated sums do not include a quantitative value for negative impacts of the gas-fired power plant on biodiversity. Explanations are provided in the respective comment column for "biodiversity management" in Table 3. The LCOE of the gas-fired power plant would further increase if this negative externality is valued in financial terms.

The calculated LCOEs are composed of conventional costs, costs induced if climate change risks materialize, and the value of externalities. Overall, the integrated LCOEs of the onshore wind portfolio are significantly lower than the LCOEs of a gas-fired power plant. The LCOE results demonstrate that the onshore wind farm project is preferable from a societal perspective. Overall, onshore wind will provide more affordable electricity. This is the case irrespective of which subtotals of the LCOE calculation are evaluated. If considering only conventional costs (subtotal 1), onshore wind has marginally lower LCOE. If potential costs induced by climate change risks are integrated into the calculation (subtotal 2), the LCOE for the gas-fired power plant is almost 9% higher compared to onshore wind. If the value of externalities is integrated on top (subtotal 3), the discrepancy in favour of onshore wind rises further.

Several insights need to be highlighted. The conventional costs for the gas-fired power plant are dominated by the fuel costs, which amount to almost EUR 53/MWh and represent a share of 65% of the integrated LCOE produced by gas. The total conventional costs for the gas-fired power plant amount to almost 80% of the asset's integrated LCOE. The conventional costs for onshore wind, however, are characterized by high CAPEX (EUR 32.43/MWh), high OPEX (EUR 23.11/MWh) and high costs of financing. Added up, these costs are responsible for more than 90% of the integrated LCOE of onshore wind. This represents a higher share than observed for the gas-fired power plant.

As explained in Table 2 in Section 2.1, even if the considered climate change risks materialize, these do not imply any additional costs for the onshore wind farm, whereas the gas-fired power plant is directly affected by air temperature increases and a carbon tax. The total costs induced if climate change risks materialize amount to EUR 5.19/MWh or 6.4% of the gas-fired power plant's integrated LCOE.

Finally, both assets cause a range of externalities. Positive externalities (benefits) are indicated with a minus sign because they reduce the LCOE. Negative externalities are unsigned. Detailed explanations for the different externalities are again explained in the integrated CBA captured in Table 3 above. The valued negative externalities for a gas-fired power plant are higher compared to the onshore wind farm. If the SCCs are integrated into the valuation of externalities, the negative value of externalities caused by gas is roughly EUR 7 per MWh higher than for onshore wind. If the health costs of air pollution are integrated into the assessment instead of the SCC, the valued externalities for gas are only EUR 1.17 per MWh more negative. Externalities of the gas-fired power plant represent roughly 14% of the asset's total integrated LCOE if the SCCs are included in the valuation of externalities. For onshore wind, on the other hand, the same range of externalities represent only 6.6% of the total integrated LCOE.

In total, the LCOEs, including the SCC, for the onshore wind farm portfolio amount to EUR 68.76/MWh and are therefore significantly lower than the EUR 81.48/MWh LCOE calculated for the gas-fired power plant. The discrepancy is less distinct when the health costs of air pollution are considered instead of the SCC: EUR 69.33/MWh for onshore wind as opposed to EUR 76.21/MWh for the gas-fired power plant. The LCOE results will be even more in favour of the onshore wind farm if the negative impacts of the gas-fired power plant on biodiversity would be valued in economic terms and integrated into the calculation.

2.3 Results of Physical Parameters

The following section presents results of the various biophysical parameters that serve as input factors for the valuation of environmental, social, and economic costs and benefits (externalities), and for calculating the additional costs induced by climate change risks as presented in the integrated CBA and the integrated LCOE in Sections 2.1 and 2.2. Likewise, the financial assessment in Section 3.0 of this report is based on the results of the biophysical parameters presented in the following.

Emissions

SAVi estimates various emissions that occur during the manufacturing of power capacity and during plant operation. The following table provides the physical numbers per category of emissions. These figures are the underlying indicators for the valuation of emissions presented in the CBA tables and integrated LCOE calculations above. CO_{2eq}. emissions are used to calculate the SCC. Air pollutant emissions are used to calculate the health costs of air pollution. In addition, the impacts of climate change for additional fuel consumption and according implications for costs and emissions are calculated in Table 6.

Overall, emissions are higher for the gas-fired power plant, both concerning capacity and fuel emissions (see definitions for emissions from different lifecycle phases in Table 6). Air temperature increase caused by climate change impairs the efficiency of the gas-fired power plant and leads to an increase in fuel emissions in the range of 2.2% over 40 years. Total fuel costs increase by EUR 3.54 million compared to the baseline scenario without climate impacts. No negative impacts of air temperature increases are observed for the wind farm.

Table 6. Emissions, air pollutants, and climate change impacts of the onshore wind farm and the gas-fired power plant

Indicator	Unit	Gas-fired power plant (40-year lifetime)	Wind farm (23-year lifetime)
CO_2 emissions: Emissions from fuel consumption during operation and capacity emissions are calculated. Capacity emissions refer to the manufacturing of capacity, e.g., emissions from energy use in the manufacturing process of steel used for poles and blades of wind turbines.			
Fuel emissions (fuel burned)	ton CO_2	721,849	0
	ton/MWh	0.31	0
Capacity emissions	ton CO_2	157,007	18,550
	ton/MWh	0.0674	0.0139
Air pollutant emissions: These are calculated for the entire lifetime of both energy assets. pm2.5 is a measure of air pollution, i.e., emission concentration. SO_2 and NO_x emissions are also calculated because they have measurable impacts on health.			
Emissions per MWh			
$pm_{2.5}$ emissions	kg/MWh	0.02789	0.0081
SO_2 emissions	kg/MWh	0.004	0.002
NO_x emissions	kg/MWh	0.29	0.002
Annual emissions: Allows the direct comparison of the two technology options because both wind farm and gas-fired power plant produce the same amount of electricity per year.			
$pm_{2.5}$ emissions	kg/year	1,540	390
SO_2 emissions	kg/year	210	100
NO_x emissions	kg/year	15,700	100

Indicator	Unit	Gas-fired power plant (40-year lifetime)	Wind farm (23-year lifetime)
Cumulative emissions: Cumulative emissions over the lifetime of each asset type.			
$pm_{2.5}$ emissions	kg	64,940	10,850
SO_2 emissions	kg	9,310	2,680
NO_x emissions	kg	675,280	2,680
Emissions caused by climate change impacts: Costs for additional fuel use and amount of emissions generated from the extra quantity of gas required by the gas-fired power plant under a climate change scenario. Additional fuel use serves to produce the same amount of electricity despite efficiency losses due to higher air temperatures.			
Impacts of air temperature increase on fuel use[6]	mn CF	11.81	0
Additional CO_2 emissions generated	ton CO_2	18,945	0
Additional $pm_{2.5}$ emissions generated	ton	1.73	0
Additional SO_2 emissions generated	ton	0.25	0
Additional NO_x emissions generated	ton	17.72	0

Material Intensity, Water and Land Use, Biodiversity, and Real Estate Impacts

Further parameters estimated by SAVi include each asset's consumption of water, cement, and steel. These physical parameters shed light on the sustainability of each asset in terms of its material and resource intensity.[7] Moreover, the impact of each asset on real estate values, land used for setting up physical energy plants and adverse impacts on birds were estimated. The SAVi results on each of these parameters are summarized in Table 7.

Due to different capacity lifetimes for the wind farm (23 years) and gas-fired power plant (40 years), the cumulative electricity generation differs significantly between the two assets. The cumulative value sets the baseline for calculating the various environmental and material footprints of each asset per MWh of electricity generation. Calculating a "per MWh" impact or consumption makes the two assets comparable on common grounds.

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[6] The monetary impacts of climate change on cumulative fuel costs by the end of the lifetime of the power plant is EUR 3.83 million.

[7] While these parameters could serve to calculate and value emissions of the manufacturing stage (carbon content of used materials) as well as the water footprint of each asset, these elements were not included in the scope of this assessment and are hence not reflected in the CBA.

Table 7 highlights the wind farm's higher consumption of cement in absolute and per MWh terms compared to the gas-fired power plant. The wind farm also consumes more steel per MWh but not in absolute terms. The gas-fired power plant consumes significantly more water per MWh while its absolute consumption is more than 10 times higher than that of the wind farm.

Total land use is higher for the wind farm (see detailed explanations in Table 3, resulting in a significantly higher foregone agriculture production of almost 7,800 tons compared to foregone agriculture production from the gas-fired power plant of roughly 110 tons. The negative impact on real estate value is only half as high for the wind farm compared to the gas-fired power plant.

Finally, SAVi estimated the negative impacts of both energy generation assets on birds. A figure of 1.18 bird kills per MW per year was calculated as the negative impact of operating an onshore wind farm. This figure is based on a study on large wind farms conducted in the United States (White, 2016), local documentation on bird risks in the area of the wind farm in Germany (LVA Sachsen-Anhalt, 2007), and the size of wind turbines of the onshore wind portfolio. This equals an approximate total amount of 1,247 bird kills over the lifetime of the wind farm.

For the gas-fired power plant, the number of bird kills was calculated based on a study conducted on the whole lifecycle impact from oil and gas-powered electricity generation, which indicates 5.18 birds killed per GWh (Sovacool, 2013). To calculate the value per MW and adjust it to the size of the hypothetical gas-fired power plant in our assessment, we assumed a 43.7% load factor. According estimations provide almost 302 bird kills per year and 12,061 bird kills over the entire lifecycle of the plant. However, it needs to be noted that this figure includes bird kills that occur at upstream supply chain phases of gas extraction and processing. More nuanced information that captures only the operational phase of a gas-fired power plant could not be found.[8]

As explained in Table 3, to mitigate the adverse impacts of the onshore wind farm on birds a compensation area is established in proximity to provide a new hunting ground for birds and prevent them from hunting on the wind farm territory to avoid collisions with the wind turbines and power lines. Aside from costs for managing the compensation area and applying particular agriculture practices to allow the area to become a hunting ground, this area cannot be used as productively for agriculture purposes as regular agriculture land. Foregone revenues over the lifetime of the onshore wind farm amount to EUR 5,673,458.

A similar compensation approach to mitigate adverse impacts on birds from gas-fired power plants could not be found. This is why no value is indicated in Table 7 and in the CBA.

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[8] Aside from negative impacts of gas-fired power plants on birds, further negative biodiversity impacts are expected. Air pollution from gas will also negatively affect the health of other species and ecosystems. Moreover, thermal power plants can cause thermal pollution of water courses that receive their effluents. If this water is not cooled down to temperatures of the receiving water courses, it can disturb aquatic species, food chains and entire freshwater ecosystems. However, these negative impacts were not further assessed and valued since the gas-fired power plant is the comparator in this assessment and not the core asset of interest.

Table 7. Material use, resource use, and externalities of the onshore wind farm compared to a gas-fired power plant

Indicator	Unit	Gas-fired power plant	Wind farm
Cumulative generation	MWh	2,328,535	1,338,910
Cement use			
per MWh	Ton/MWh	0.0007	0.00243
Annual cement use	Ton/year	38	125
Cumulative cement use	Ton	1,639	3,260
Steel use			
per MWh	ton/MWh	0.00158	0.002223
Annual steel use	ton/year	86	114
Cumulative Steel use	ton	3,679	2,976
Water use			
per MWh	m^3/MWh	0.03180	0.00545
Annual water use	m^3/year	1,852	317
Cumulative water use	m^3	74,094	7,297
Land use for power generation capacity, including road network and compensation area			
Direct land use for capacity	ha	0.70	5.10
Total land use (direct + compensation area)	ha	0.70	164.36
Foregone agriculture production from direct land use (based on an assumed yield of 4 ton /hectare)	ton	109.5	466.1
Total foregone production	ton	109.5	7,793.9
Visual pollution (impact on real estate)			
Impact on real estate valuation	EUR	2,000,000	1,000,000
Biodiversity			
Birds killed[9]	birds/MW	10.51	1.81
Birds killed annually	birds/year	301.53	51.95
Cumulative bird kills	birds	12,061.11	1,246.73
Opportunity cost from using land for biodiversity management	EUR	n/a	5,673,458

3.0 SAVi Results of the Financial Analysis

This chapter presents the SAVi results of the financial analysis conducted for the onshore wind portfolio and the hypothetical gas-fired power plant. This financial analysis assesses the financial impact of potential costs induced by climate change risks as well as the financial impact of the monetary value of environmental, social, and economic costs and benefits (externalities) if they are internalized (climate change risks and all considered externalities are presented in detail in Section 2 of this report). The analysis provides a holistic picture of the two energy generation technologies by highlighting how their key financial indicators would change if the identified risks and externalities are integrated as costs or benefits. Indeed, this demonstrates to investors how the financial performance of infrastructure projects changes if climate change risks would materialize and externalities would need to be internalized in the coming years. Regulators and governments are starting to realize the importance of accounting for diverse risks of infrastructure as well as for negative and positive externalities that these projects imply for the environment and our economies. The introduction of a carbon tax is one example of how an externality—the SCC caused by projects' GHG emissions—is becoming a regulatory risk that infrastructure projects are expected to internalize in the near future.

The scope of this financial analysis deviates from Section 2 of the SAVi assessment in one dimension. The financial analysis of the onshore wind portfolio is conducted from the investor's perspective. Hence, it captures the asset's performance from the point of acquisition onwards and not the entire asset life cycle. The financial analysis for the gas-fired power plant comparator, however, covers the entire asset lifecycle and hence uses the full cost of technology.

3.1 Internalization Methodology and Data Inputs

The potential costs induced by climate change risks and the monetary value of externalities can be integrated into the financial model either in the profit and loss (P&L) statement as a change in operating costs or in the cash flow (CF) statement as a change in cash flow. The pros and cons of both alternatives are outlined in Annex 1. For the purposes of this assessment we used the CF statement approach. The two assets are first assessed separately and then compared at the end of this section. For both, we have first integrated the valued externalities into the CF statement. Secondly, we have integrated the assessed costs induced by climate change risks into the CF statement. These risks apply only to the gas-fired power plant. As of today, neither the externalities, nor the risks have an operational impact on the cash flows.[10]

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[10] One might argue that the assessed climate change risks are very likely to materialize in the near future as physical impacts (effective 1.5°C air temperature rise will increase fuel consumption of the gas-fired asset) and regulatory change (carbon tax payments for the gas-fired asset) and hence will be directly internalized. The materialized risks will have cash flow impacts. Compared to that, a range of assessed negative externalities are more unlikely to turn into material project risks with cash flow impacts. This is why risks and externalities are assessed separately in this chapter.

Risks and externalities can be integrated as time-series or levelized values into the financial analysis. In order to demonstrate the differences between the two, we have calculated the results for the onshore wind portfolio using both approaches. The levelized values were used to compare financial performance results with the gas-fired power plant.

Time-series

The time-series approach allows the internalization of risks and externalities at the point in time when they actually materialize as costs or benefits. The assessment period can range from the whole life cycle of the project to only parts of the operation phase, in case of a change of ownership, for example. The particularity of this approach is that for brownfield investments, any risks or externalities that may have occurred during the initial construction phase are automatically excluded from the analysis. For example, “Income spending from manufacturing” represents the income that construction workers received and spent during manufacturing and installation of the energy capacity. It is an economic benefit (positive externality) that occurs during the construction phase. For a brownfield investment, the time-series approach would disregard this externality. This approach was applied to the onshore wind portfolio as highlighted by the blue-outlined externality in Table 8.

Table 8. Example of integrating externalities as time-series

SAVi Financial Impact Assessment

Period start			01-Jan-13	01-Jan-14
Period end		31-Dec-12	31-Dec-13	31-Dec-14
Externalities – Time Series				
Business as usual	EUR '000	-	-	-
Income spending from energy capacity	EUR '000	(1,818.03)	(89.62)	(89.62)
Income spending from road construction	EUR '000	(312.40)	(20.79)	(16.47)
Income spending from manufacturing	EUR '000	-	-	-
Land use	EUR '000	273.61	13.49	13.49
Social cost of carbon (SAVi)	EUR '000	458.04	22.04	22.04
Valuation of emissions (SAVi+)	EUR '000	1,159.81	53.44	53.44
Real estate	EUR '000	-	-	-
Cost of roads	EUR '000	462.82	53.96	34.13
Biodiversity management	EUR '000	9,753.30	424.06	424.06
SAVi All	**EUR '000**	**9,977.15**	**456.57**	**441.06**

Levelized Value

Calculating levelized values for the financial analysis is in line with the approach of how the LCOE is calculated in Section 2 of this report. This is done by dividing the total amount of undiscounted monetized externalities (or potential costs induced by climate change risks) during the construction, operation, and decommissioning of the project by the total energy generation over its life cycle. In order to integrate the levelized value of externalities and climate risks (LVOE) into the financial model, LVOE values are then multiplied by the energy generation for each year assessed. This approach takes all externalities and risks into account that have occurred across the project's life cycle. This means that the risks and externalities are allocated to each year of energy generation irrespective of when they occur. For example, this can be seen in Table 9 for the externality "income spending from manufacturing." The levelized value of this externality amounts to EUR -1.76 per MWh, while the accumulated value is slightly above EUR 2 million. This is allocated to the different years of the asset's lifetime according to MWh of energy generated.

Table 9. Example of integrating externalities as LVOE

SAVi Financial Impact Assessment			
Period start		01-Jan-13	01-Jan-14
Period end	31-Dec-12	31-Dec-13	31-Dec-14

Externalities – LVOE		**LVOE**
Business as usual	EUR/MWh	-
Income spending from energy capacity	EUR/MWh	(2.07)
Income spending from road construction	EUR/MWh	(0.39)
Income spending from manufacturing	EUR/MWh	(1.76)
Land use	EUR/MWh	0.23
Social cost of carbon (SAVi)	EUR/MWh	0.37
Valuation of emissions (SAVi+)	EUR/MWh	0.96
Real estate	EUR/MWh	0.75
Cost of roads	EUR/MWh	0.76
Biodiversity management	EUR/MWh	7.52
SAVi All	**EUR/MWh**	**6.37**

SAVi Financial Impact Assessment

Generation	MWh p.a.	1,152,562.95	56,330.00	50,206.00
Business as usual	EUR '000	-	-	-
Income spending from energy capacity	EUR '000	(2,385.81)	(116.60)	(103.93)
Income spending from road construction	EUR '000	(449.50)	(21.97)	(19.58)
Income spending from manufacturing	EUR '000	(2,028.51)	(99.14)	(88.36)
Land use	EUR '000	265.09	12.96	11.55
Social cost of carbon (SAVi)	EUR '000	426.45	20.84	18.58
Valuation of emissions (SAVi+)	EUR '000	1,106.46	54.08	48.20
Real estate	EUR '000	864.42	42.25	37.65
Cost of roads	EUR '000	875.95	42.81	38.16
Biodiversity management	EUR '000	8,667.27	423.60	377.55
SAVi All	**EUR '000**	**7,341.83**	**358.82**	**319.81**

3.2 Financial Performance Indicators

The internal rate of return (IRR) is arguably the most important financial performance indicator that investors use to evaluate infrastructure projects. IRR is the discount rate that makes the net present value (NPV) of all cash flows equal to zero. Changes in the IRR demonstrate the significance and potential financial impact of the risks and externalities when they are integrated into the financial model.

For our assessment, we have used both the project and equity IRRs. The latter shows the expected rate of return for equity investors, including the financing cash flows. It is calculated using the net cash flow for each year adjusted with the relevant risks and externalities. The net cash flow represents what shareholders receive after all the costs and debt have been paid.

On the other hand, the project IRR is the expected rate of return for the whole project, including both equity and debt capital, thus excluding financing cash flows. It is calculated by readjusting the earnings before interest taxes (EBIT|) by non-cash items and the SAVi risks and externalities. Then the income tax is recalculated to get the final project cash flow that is used for the Project IRR calculations.

3.3 Assumptions for the Comparative Financial Analysis

Onshore Wind Portfolio

The SAVi financial assessment of the onshore wind portfolio is based on both the profit/loss and cash flow statements. The financial model starts in 2013, when the current owner acquired the assets, and finishes in 2035, at the end of the projects' lifetime. In other words, the financial data used for the assessment does not cover the entire life of the asset, only the time period when the current owner made this brownfield investment. The SAVi risks and externalities were integrated into the cash flow statement as none of them have a tangible impact on the cash flows at the time of writing. Financial data between 2013 and 2018 are actuals. Data between 2019 and 2035 are based on forecasts.

Construction time	Not relevant as it is a brownfield project
Operation time	21 years – since time of purchase
Construction cost	EUR 43.174 million
Electricity generation	58,213 MWh p.a. under normal operating conditions; actual generation varies each year
Price of electricity	EUR 89.62/MWh on average, varies each year
Operation cost	EUR 28.92/MWh on average
Capital split	70% debt, 30% equity
Discount rate	Unlevered: 5% Levered: 7%
Debt tenor	13 years
Location	Onshore wind farm located in Germany
Risks and externalities	Same as discussed in Section 2.1 of the report. Only the "Costs of Roads" have not been accounted for as they have already been included in the CAPEX and OPEX of the project. We have used the LVOE approach when calculating the IRR.

Gas-Fired Power Plant Comparator

By comparing the onshore wind portfolio to other energy generation technologies, the financial impact of risks and externalities discussed earlier can be put into better perspective. For this purpose, a hypothetical gas power plant was chosen as a suitable comparator. A financial model was set up to calculate the power plant's financial performance and the impact of the relevant risks and externalities. As it is a hypothetical project, a series of assumptions were made while ensuring that the results remain comparable.

The main assumptions are the following:

Construction time	3 years
Operation time	40 years
Construction cost	EUR 6.08 million
Electricity generation	58,213 MWh p.a.
Price of electricity	EUR 68.80/MWh = average energy price level in Germany in 2019 based on Thalman & Wehrmann (2019)
Operation cost	EUR 5.35/MWh
Capital split	70% debt, 30% equity
Discount rate	Project: 5% Equity: 7%
Debt tenor	13 years
Location	Identical to that of the onshore wind farm in Germany
Risks and externalities	As measured by SAVi in the earlier sections. The LVOE approach was used for calculating the IRR.

3.4 Results of the Financial Analysis

The financial assessment of the onshore wind portfolio and the gas-fired power plant demonstrates how the project and equity internal rate of return (IRR) change when the potential costs induced by climate change risks and environmental, social, and economic costs and benefits (externalities) measured by SAVi are integrated into the financial model.

1. ONSHORE WIND PORTFOLIO

The project has the following IRR without including any of the risks or externalities.

- Project IRR of 4.93%
- Equity IRR of 6.70%

Table 10 presents the changes in IRR when internalizing externalities as levelized values. The results demonstrate that a renewable energy project, such as a wind farm, can also cause externalities that would have an overall negative impact on financial performance when internalized. Two different methodologies were used to calculate the valuation of emissions: the social cost of carbon (SCC) and the health cost of air pollution (HCAP). Therefore, two final sums for the impact of externalities on the equity and project IRR are calculated to demonstrate the variation in results based on the methodology applied for valuing emissions (see rows 9 and 10 in Table 10). In case the SCC is integrated, the equity IRR drops by 1.46% while the project IRR decreases by 0.84%. The IRRs decrease slightly more when the HCAP is internalized instead of the SCC. The costs of biodiversity management have the largest negative impact, and the additional income spending from energy capacity has the largest positive contribution to the IRR.

Table 10. The impact of externalities on IRRs using the LVOE approach for the onshore wind portfolio

#	Onshore wind farm – LVOE	Equity IRR	Change compared to BAU	Project IRR	Change compared to BAU
0	No externalities = Baseline	6.70%	-	4.93%	-
1	Additional income spending from energy capacity	7.34%	0.64%	5.29%	0.36%
2	Income spending from road construction	6.82%	0.12%	5.00%	0.07%
3	Income spending from manufacturing	7.25%	0.55%	5.24%	0.31%
4	Land use	6.63%	(0.07%)	4.89%	(0.04%)
5	SCC	6.58%	(0.12%)	4.86%	(0.07%)
6	HCAP	6.40%	(0.30%)	4.76%	(0.17%)
7	Real estate	6.46%	(0.23%)	4.79%	(0.13%)
8	Biodiversity management	4.32%	(2.38%)	3.55%	(1.38%)
9	**All the above except HCAP**	**5.23%**	**(1.46%)**	**4.09%**	**(0.84%)**
10	**All the above except SCC**	**5.05%**	**(1.65%)**	**3.98%**	**(0.95%)**

When following the time-series approach, the overall adverse impacts of externalities on the IRRs are larger (see Table 11) than when applying the levelized values approach. This difference is due to some of the positive externalities (benefits), such as income spending from manufacturing, being more relevant in early project phases and hence not being taken into account when using time-series data.

Table 11. The impact of externalities on IRRs using the time-series approach for the onshore wind portfolio

#	Onshore wind farm – time-series	Equity IRR	Change compared to BAU	Project IRR	Change compared to BAU
0	No externalities = Baseline	6.70%	-	4.93%	-
1	Additional income spending from energy capacity	7.19%	0.49%	5.21%	0.28%
2	Income spending from road construction	6.78%	0.08%	4.97%	0.05%
3	Income spending from manufacturing	6.70%	-	4.93%	-
4	Land use	6.62%	(0.07%)	4.88%	(0.04%)

#	Onshore wind farm – time-series	Equity IRR	Change compared to BAU	Project IRR	Change compared to BAU
5	SCC	6.58%	(0.12%)	4.86%	(0.07%)
6	HCAP	6.39%	(0.31%)	4.75%	(0.18%)
7	Real estate	6.70%	-	4.93%	-
8	Biodiversity management	4.13%	(2.57%)	3.43%	(1.50%)
9	**All the above except HCAP**	**4.53%**	**(2.17%)**	**3.66%**	**(1.27%)**
10	**All the above except SCC**	**4.33%**	**(2.37%)**	**3.55%**	**(1.38%)**

The assessed climate change risks (air temperature increase, and introduction of a carbon tax) do not imply costs for and hence do not affect the performance of the onshore wind portfolio. This is explained in detail in Section 2 of the report. Consequently, these risk factors do not need to be considered for the financial performance assessment of this asset.

2. GAS-FIRED POWER PLANT COMPARATOR

The project has the following IRR without including any of the risks or externalities.

- Project IRR of 3.27%
- Equity IRR of 3.57%

Table 12 demonstrates that the environmental, social and economic costs and benefits (externalities) caused by the gas-fired power plant would have a significant financial impact if internalized. Irrespective of whether the SCC or the HCAP is internalized, both negative values are large enough to make the asset financially unviable.

Table 12. The impact of externalities on IRRs of the gas-fired power plant using the LVOE approach

#	Gas-fired power plant, 68.80 EUR/MWh	Equity IRR	Change compared to BAU	Project IRR	Change compared to BAU
0	No externalities = Baseline	3.57%	-	3.27%	-
1	Additional income spending from energy capacity	3.57%	-	3.27%	-
2	Income spending from road construction	3.71%	0.13%	3.36%	0.09%
3	Income spending from manufacturing	4.12%	0.54%	3.62%	0.35%
4	Land use	3.52%	(0.05%)	3.24%	(0.03%)
5	SCC	Negative	> (3.57%)	0.00%	(3.27%)
6	HCAP	0.00%	(3.57%)	Negative	> (3.27%)
7	Real estate	2.09%	(1.48%)	2.27%	(1.00%)
8	Cost of roads	3.34%	(0.23%)	3.12%	(0.15%)
9	Biodiversity management	3.57%	-	3.27%	-
10	**All the above except HCAP**	**Negative**	**> (3.57%)**	**Negative**	**> (3.27%)**
11	**All the above except SCC**	**Negative**	**> (3.57%)**	**Negative**	**> (3.27%)**

Table 13 demonstrates which electricity price is required to ensure that the gas-fired power plant remains a profitable project when all valued externalities are internalized. The gas-fired power plant would only break even when the selling price of electricity increases from EUR 68.80/MWh to EUR 79/MWh. In other words, EUR 79/MWh is the lowest price that would make the IRR under all scenarios positive.

If the same electricity price is assumed for the gas-fired power plant as for wind power (EUR 89.62/MWh), the gas-fired power plant would outperform wind even if all valued externalities are internalized. If all externalities are internalized (including the health cost of air pollution but excluding the SCC), the gas-fired power plant would yield a project IRR of 9.89% while the project IRR for onshore wind amounts to only 3.98% (line 10 in Table 10). Finally, the same project IRR is realized by both assets if an electricity price of EUR 89.62/MWh is assumed for wind and EUR 81.30/MWh for the gas-fired power plant. These results underline the significant regulatory exposure of gas-fired electricity generation.

Table 13. **The impact of externalities on IRRs of the gas-fired power plant; increased electricity price of EUR 79 / MWh**

#	Gas-fired power plant, EUR 79/MWh	Equity IRR	Change compared to BAU	Project IRR	Change compared to BAU
0	No externalities = Baseline	17.57%	-	10.60%	-
1	Additional income spending from energy capacity	17.57%	-	10.60%	-
2	Income spending from road construction	17.67%	0.10%	10.65%	0.05%
3	Income spending from manufacturing	18.00%	0.43%	10.80%	0.20%
4	Land use	17.53%	(0.04%)	10.58%	(0.02%)
5	SCC	2.47%	(15.10%)	2.33%	(8.27%)
6	HCAP	10.83%	(6.74%)	7.28%	(3.32%)
7	Real estate	16.44%	(1.13%)	10.06%	(0.54%)
8	Cost of roads	17.39%	(0.18%)	10.51%	(0.09%)
9	Biodiversity management	17.57%	-	10.60%	-
10	**All the above except HCAP**	**1.32%**	**(16.25%)**	**1.53%**	**(9.07%)**
11	**All the above except SCC**	**9.92%**	**(7.65%)**	**6.80%**	**(3.80%)**

Climate change risks have a significant financial impact in the case of the hypothetical gas-fired power plant if they materialize. For this assessment, the cost implication of a 1.5°C air temperature increase was analyzed (physical climate change risk) as well as the additional costs implied by the introduction of a carbon tax (transitional climate change risk). The results are displayed in Table 14. If a carbon tax of EUR 25/ t CO_2 is introduced for the operational emissions of the gas-fired asset, the asset becomes financially unviable. In case the physical climate change risk materializes, the IRR drops to around 1%. This would be below the expected rate of return that investors require for an investment with a similar risk profile.

As noted before, the onshore wind portfolio is not affected by the assessed climate change risks, and hence they do not have any impact on financial performance.

Table 14. The impact of materialized climate risks on IRRs of the hypothetical gas power plant

#	Gas-fired power plant, 68.80 EUR/MWh	Equity IRR	Change compared to BAU	Project IRR	Change compared to BAU
0	No climate risk = Baseline	3.57%	-	3.27%	-
C1	Carbon tax	Negative	> (3.57%)	Negative	> (3.27%)
C2	Air temperature increase	0.63%	(2.94%)	1.24%	(2.03%)

3. COMPARISON OF RESULTS: ONSHORE WIND PORTFOLIO AND THE GAS-FIRED POWER PLANT

The impacts of the SCC, HCAP, or the carbon tax are each large enough to make the gas-fired power plant financially unviable. On the other hand, even with all valued externalities included, the onshore wind portfolio still generates a decent project IRR: 4.09% when the SCC is included and 3.98% in the case of integrating the HCAP, as shown in Table 15.

Table 15. Financial impact of externalities on the project IRRs of onshore wind portfolio vs. gas-fired power plant

#	Externality	Wind project IRR	Gas project IRR	IRR Difference (Wind – Gas)
0	No externalities = Baseline	4.93%	3.27%	1.66%
1	Additional income spending from energy capacity	5.29%	3.27%	2.02%
2	Income spending from road construction	5.00%	3.36%	1.64%
3	Income spending from manufacturing	5.24%	3.62%	1.61%
4	Land use	4.89%	3.24%	1.65%
5	SCC	4.86%	0.00%	4.86%
6	HCAP	4.76%	Negative	> 4.76%
7	Real estate	4.79%	2.27%	2.52%
8	Cost of roads[11]	4.93%	3.12%	1.81%
9	Biodiversity management	3.55%	3.27%	0.28%
10	**All the above except HCAP**	**4.09%**	**Negative**	**> 4.09%**
11	**All the above except SCC**	**3.98%**	**Negative**	**> 3.98%**

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[11] The cost of roads for the onshore wind portfolio are already included in the CAPEX and OPEX of the wind portfolio's financial model. These costs are hence already reflected in the baseline project IRR indicated in line 0.

Climate change risks have a significant financial impact in the case of the hypothetical gas-fired power plant if they materialize. This is demonstrated by the results in Table 16. On the other hand, the financial performance of the wind project is not vulnerable to assessed climate change risks.[12]

Table 16. Financial impact of materialized climate risks on the project IRRs of onshore wind portfolio vs. gas-fired power plant

#	Climate risks	Wind project IRR	Gas project IRR	IRR Difference (Wind – Gas)
0	No climate risks = Baseline	4.93%	3.27%	1.66%
1	Carbon tax	4.93%	Negative	> 4.93%
2	Air temperature increase	4.93%	1.24%	3.69%

This financial assessment reveals that potential costs induced by climate change risks and environmental, social, and economic costs and benefits (externalities) could have an impact on the financial performance of energy generation assets if they are internalized. If the valued externalities are indeed internalized into the CF statement of the onshore wind portfolio, they will have a negative impact on the IRRs, as indicated in line 10 and 11 in Table 15. At the same time, the internalization would not endanger the financial viability of the project.

On the other hand, the financial performance of the hypothetical gas-fired power plant is more vulnerable to the potential cost implications of climate change risks and the internalization of valued externalities. Depending on the electricity price and resulting revenues, the internalization of risks and externalities into the CF statement could lead to difficulties servicing debt obligations and covering operating costs.

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[12] Other potential physical climate change impacts, such as changes of wind speed and wind patterns, are not considered in this assessment because there is lack of location-specific and reliable data on future changes in wind speed over the lifetime of the assets.

REMOVING MARKET DISTORTION TO EVALUATE ONSHORE WIND AND GAS ON EQUAL GROUNDS

Electricity generation from the onshore wind portfolio is currently subsidized. This is reflected in the models by the use of two different market prices for the electricity sold: EUR 89.62/MWh for onshore wind and EUR 68.80/MWh for the gas-fired power plant. What would be the result of the analysis if we considered the same market price for wind and gas?

We can answer this question using two sets of results presented in this report:

- First, in the LCOE section of the report, we estimate that the power generation cost is lower for onshore wind when compared to the gas-fired power plant (see Table 5 in Section 2.2). This is the case both for a conventional assessment (Subtotal 1), when potential costs induced by climate risks are included (Subtotal 2) and when all externalities are considered (Subtotal 3). Therefore, even when no subsidy is provided, the onshore wind portfolio will still perform better than the gas-fired power plant on a cost basis (even if by a very small margin when using a conventional approach, i.e., Subtotal 1).
- Second, in the financial analysis section, we estimate that the breakeven price for electricity generated by a gas-fired power plant is EUR 79/MWh for realizing positive financial return in all scenarios. We also estimate that, when using the same price as for wind power (EUR 89.62/MWh), the gas-fired power plant would outperform wind. When all externalities are considered, the gas-fired power plant yields a project IRR of 9.89% and onshore wind only 3.98% (line 10 in Table 10). Finally, the same project IRR is realized by both assets if an electricity price of EUR 89.62/MWh is assumed for wind and EUR 81.30/MWh for the gas-fired power plant.

The results above highlight that using different approaches leads to possibly different results: for the hypothetical gas-fired power plant we used the cost of technology to estimate LCOE and IRR; for wind, we used the cost of technology to estimate the LCOE, but for estimating the IRRs, we used the P&L and CF statements provided by the client. For the latter, we go beyond the cost of technology and use the full cost of making the wind asset operational. This, together with the use of different modelling approaches, leads to the emergence of different patterns when comparing the LCOE and the IRR of the two technologies under different scenarios. This highlights the need for the simultaneous use of different modelling approaches, especially when one of the approaches considers the full lifecycle of the asset while the other is applied during operation.

In our case, we note that the P&L and CF statements used for the financial analysis does not provide all the inputs required for the system dynamics assessment, which is also what is needed for calculating the LCOE. This is also due to the fact that B Capital Partners purchased the asset a few years after its construction, and its valuation includes not only the technology (e.g., wind turbines) but also all installation costs (e.g., connection to the local grid) and other costs required to make the wind asset operational. Therefore, the original capital expenditure was calculated by taking the value of the plants and equipment at the time of B Capital Partners acquiring the asset and adjusting this number with the depreciation and amortization for each year since construction. With this calculation, the CAPEX per MW increases by about

50%, to EUR 1.5 million/MW relative to using the cost of technology. When using this new assumption, the LCOE for wind increases by EUR 18.78/MWh. This implies a new LCOE value of EUR 75.55/MWh for Subtotal 1 (against EUR 64.75/MWh for the gas-fired power plant) and for Subtotal 2 (against EUR 69.94/MWh for the gas-fired power plant) and EUR 78.33/MWh for Subtotal 3 (compared to EUR 76.21/MWh for the gas-fired power plant).

These results are provided to allow for a more complete, although imperfect, comparison of the results. As mentioned above, the LCOE calculations use the technology costs for both the gas-fired power plant and onshore wind. On the other hand, the financial analysis uses technology data for the hypothetical gas-fired power plant and the actual capital expenditures for the onshore wind portfolio.

4.0 Conclusion

SAVi was used to conduct a comparative sustainability assessment of the onshore wind portfolio and a hypothetical gas-fired power plant. Assessment results were sought to provide insights and evidence of how an asset valuation changes if diverse sustainability parameters are integrated into the assessment. SAVi was customized to these two assets to simulate and value how results of the three SAVi assessment components (CBA, LCOE, Financial Analysis) change when potential costs induced by climate change risks as well as environmental, social, and economic costs and benefits (externalities) are integrated into the assessment. The SAVi assessment components generated a variety of outputs that allow for the comparison of both assets comprehensively: an integrated cost-benefit analysis (CBA), the integrated levelized costs of electricity (LCOE), as well as financial performance results in the form of project IRR and equity IRR. The key insights of the SAVi assessment are as follows:

A conventional CBA yields positive economic returns for both assets. EUR 16.4 million for the gas-fired power plant and EUR 25.16 million for the onshore wind farm. Likewise, the financial analysis demonstrates that both assets generate solid IRRs in the baseline. The onshore wind farm yields a project IRR of 4.93% and an equity IRR of 6.70%. The gas-fired power plant yields a slightly lower project IRR of 3.27% and a much lower equity IRR of 3.57%. Consequently, the baseline results confirm that both projects are financially viable, while the onshore wind farm is the more attractive investment alternative. When considering only the conventional cost positions for calculating the LCOE, both assets are almost on par and need to account for approximately EUR 64/MWh.

The integration of both the potential costs induced by climate change risks as well as the valued economic, environmental, and social costs and benefits (externalities) provides new insights for this comparative assessment. First and foremost, the performance of the onshore wind portfolio remains relatively constant compared to the baseline, while the performance of the gas-fired power plant slumps significantly across all SAVi results. Therefore, the onshore wind portfolio is the more resilient asset, given what was analyzed. One could, however, also conclude that the internalization of valued externalities has an adverse impact on the performance of both assets across the board of all calculated SAVi results. Potential costs induced by climate change risks, on the other hand, imply negative performance effects only for the gas-fired power plant.

The LCOEs of the two assets diverge the more potential costs induced by climate change risks and valued externalities are integrated into the calculation. The total integrated LCOE for the gas-fired power plant ranges between EUR 76.21/MWh and EUR 81.48/MWh, depending on which methodology for valuing emissions is chosen. The total integrated LCOE for the onshore wind farm amounts to approximately EUR 69/MWh, irrespective of the methodology for valuing emissions. Therefore, internalizing risks and externalities increases the LCOE of the onshore wind farm only slightly by approximately 7% compared to the baseline (≈ EUR 64/MWh) while the LCOE of the gas-fired power plant increases more significantly between 15% and more than 20%.

The integrated CBA still reveals a positive net result of EUR 2.46 million for the gas-fired power plant if potential costs induced by climate change risks and valued externalities, including the health cost of air pollution, are integrated into the calculation. But if emissions of the gas-fired power plant are valued as an SCC and integrated into the CBA, total costs outweigh the benefits, and the project yields a negative net result of EUR -2.87 million. In both instances, the performance is much poorer than in the baseline. The net results for the onshore wind farm remain at approximately EUR 21 million—irrespective of how emissions are valued—and hence are roughly 20% lower compared to the results of a conventional CBA.

The financial analysis shows a similar picture when comparing the two assets. The project IRR of the onshore wind farm decreases from 4.93% to approximately 4% if the value of all measured environmental, social and economic costs and benefits (externalities) is internalized. Likewise, the equity IRR decreases from 6.70% to 5.23% and 5.05% respectively, depending on the methodology for valuing emissions of the asset. Despite these detrimental effects of externalities, the asset remains financially attractive. The financial performance of the gas-fired power plant, on the other hand, is more adversely affected if potential costs induced by climate change risks and valued externalities are internalized. If certain externalities, such as the SCC or the HCAP are internalized, the IRRs of the asset would shrink to zero or become even negative. However, one needs to note that internalizing the assessed externalities into the CF statement is rather hypothetical. In the near future, these externalities don't imply costs for the project and hence don't have cash flow impacts for the gas-fired power plant. The situation is different when considering climate change risks. Physical impacts such as air temperature increases and regulatory changes with cost implications such as a carbon tax are likely to become a reality soon. Integrating the additional costs of a carbon tax (transitional climate risk) into the CF statement would impair the cash flows of the gas-fired power plant and yield a negative equity IRR and a negative project IRR. Costs induced by increasing air temperature (physical climate risk) have less severe implications for that asset but would still lower the equity IRR to 0.63% and the project IRR to 1.24%. Therefore, if the assessed climate change risks materialize, the gas-fired power plant would not be financially viable anymore.

The latter insight of this SAVi assessment could be particularly worrying for investors in fossil fuel-based energy generation assets. The investment rationale changes if the cost implications of climate change risks are integrated into the asset valuation. And indeed, the likelihood of a naturally and/or regulatory enforced internalization of costs induced by climate change is arguably much higher than some of the externalities valued in this assessment. The possibility of a carbon tax is already on the agenda in several countries, while air temperature increase is an unfortunate reality of climate change. The magnitude of both risks can have adverse impacts on the financial performance of a fossil fuel-based asset and make it financially unviable, as demonstrated by this assessment. Onshore wind projects such as the onshore wind portfolio, on the other hand, are proven to be largely resilient to such risks. Although the internalization of environmental, social, and economic costs and benefits (externalities) caused by this asset reduces the positive net results, the extent is much lower compared to the gas-fired power plant comparator. Altogether, the onshore wind portfolio is the more resilient and more profitable investment choice as well as the more beneficial (less costly) energy generation asset from a societal point of view.

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Annex 1. SAVi Customization for the Onshore Wind Portfolio

IISD used the SAVi energy model for the analysis of the onshore wind portfolio and the alternative gas-fired power plant. The assessment monetizes climate change risks as well as environmental, social and economic costs and benefits (externalities) and provides information about their impact on the financial performance of the onshore wind farm portfolio and a gas-fired power plant.

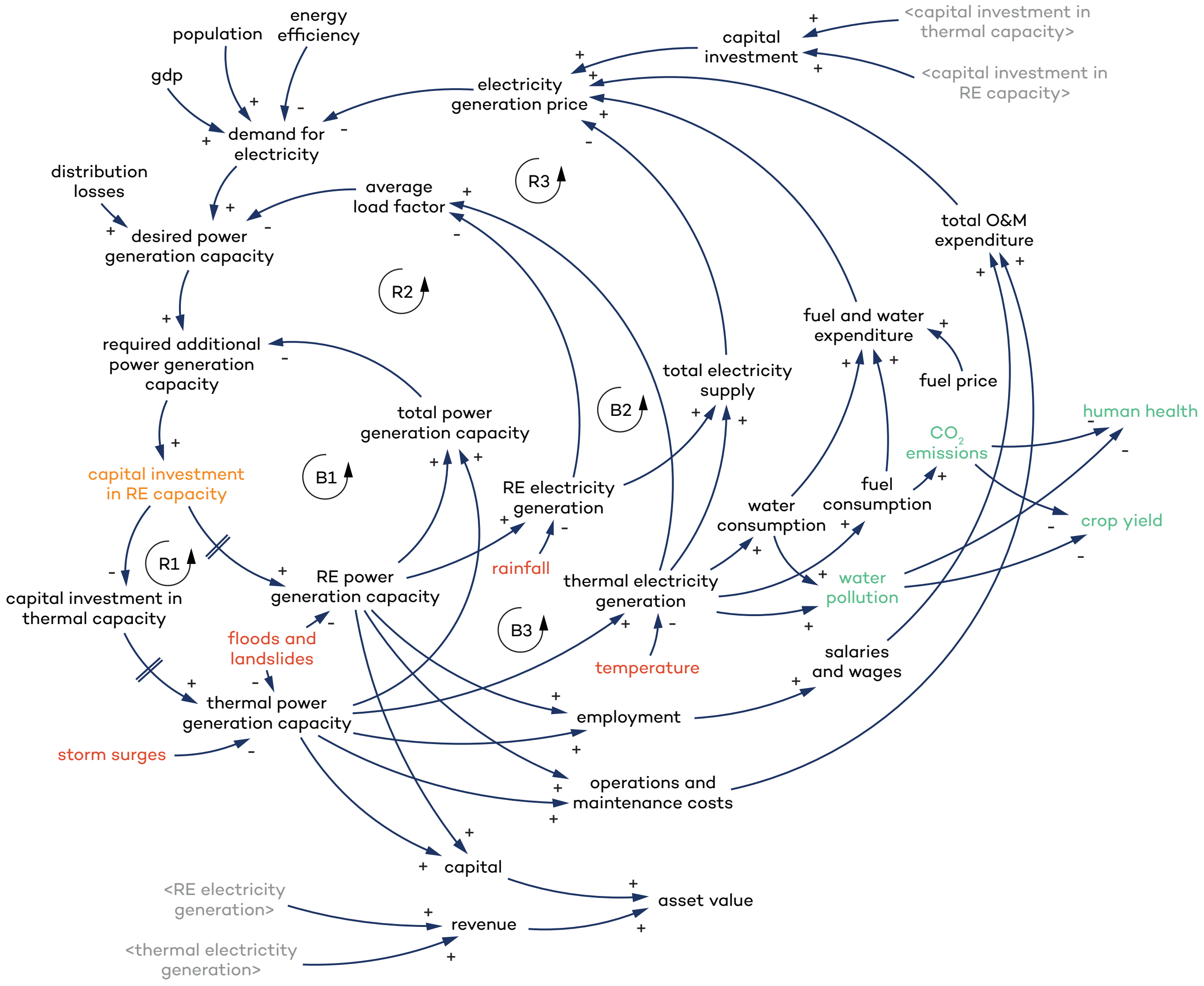
1. Systems Thinking and System Dynamics

Model Overview

Figure 1 in Section 1 is the customized causal loop diagram (CLD), which presents the dynamics that underlie the analysis of the SAVi energy model used for this comparative assessment. This builds on the CLD of the generic SAVi energy model, as displayed in Figure A1. Most dynamics of the generic CLD are relevant for this study, aside from the macroeconomic drivers of change (e.g., population and GDP affecting electricity demand). There are four major feedback loops that drive the dynamics of the energy sector, loops (R1), (R2) and (B1), (B2). The character (R) represents a reinforcing loop and the character (B) represents a balancing loop. What these different feedback loops imply and how a CLD can be read is explained below Figure A1.

- Loops (R1) and (B1) represent the adjustment of power generation capacity. The current amount of capacity, renewable and non-renewable, is compared to the required amount of capacity to provide the desired electricity supply. The gap between current and desired capacity determines the required investments in the respective technology types. **For this specific SAVi application, the gap is represented only by the capacity (MW) of the projects (wind farm and gas-fired power plant).**
- The desired capacity level depends on the average effectiveness, also called average load factor, of the current energy technology mix. A gas-fired power plant is usually characterized by higher load factors. This increases the average load factor, which is captured by loop (R2). Renewable energy technologies are comparatively less efficient due to their dependency on, for example, sunlight and wind speed, captured by loop (B2). Consequently, a transition toward renewables likely requires the installation of higher capacity than an energy system primarily based on thermal technologies. **For this specific SAVi application, the difference in load factor is taken into account, and the corresponding capacity is calculated.**
- The price of electricity is the third major driver affecting the demand for power generation capacity (via demand for electricity). On the other hand, the impact of price on demand (and hence sales) is not considered when a single asset is analyzed. The underlying assumption is that all electricity generated is sold.

Figure A1. **Causal Loop Diagram SAVi energy model**



Designing and Reading a Causal Loop Diagram

The capturing of feedback allows to see the asset as part of socioeconomic and environmental subsystems and allows for inferring direct and indirect impacts. A CLD is the starting point for the development of the mathematical stock and flow model. Designing a CLD for a project helps to combine and integrate a team's knowledge, ideas and concepts. Moreover, an interactive CLD design and verification process with key stakeholders of a project ensures that these stakeholders have a common understanding of the analysis being undertaken, both in terms of its overarching scope and its underlying factors. This will then enable these stakeholders to later appreciate and make use of analysis results (TEEB, 2018; Pittock et. al., 2016). In this regard, CLDs highlight the root causes of a problem, as well as the variables of a system that could, with the appropriate technical or policy interventions, be targeted to develop solutions. (UNECA, 2018)

To design solution-oriented and effective interventions, CLDs need to capture causal relations of a system correctly. Therefore, CLDs establish causal links between variables by linking them with arrows and attributing a sign to the arrow (either + or −) that indicates whether a change in one variable generates a positive or negative change in the other (see Table A1).

As noted by Bassi et. al.:

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction" (Bassi et al., 2016).

Table A1. Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Moreover, these causal interactions can form what is known as a positive or negative "feedback loop" (Forrester, 1961). In other words, an intervention made in that system can support the tendency towards an equilibrium within the overarching system, in which case this negative feedback loop is called a balancing loop. Alternatively, an intervention can reinforce the intervention's impact and hence create a positive feedback loop, which is called a reinforcing loop (Bassi, 2009; Forrester, 1961). What makes CLDs especially useful for decision-makers and other stakeholders is this feedback component, showing how the different elements within a system interact with each other and either exacerbate or ameliorate a given situation (TEEB, 2018). These mapped relationships may not necessarily indicate linear behaviour, and potential impacts may occur delayed, which is why a CLD that captures the extent and complexity of this system is important. The interaction of "feedback loops" may also be where the source of a given policy problem lies, and therefore where decision-makers will need to direct their efforts for finding a solution—along with being aware of how this solution will affect the rest of the system (WWF, 2014).

Expenditure, Avoided Cost, and Added Benefits

SAVi calculates expenditure, avoided costs, and added benefits.

EXPENDITURE

From a private sector perspective, expenditures refer to the monetary costs of project implementation, such as investment, operation and maintenance (O&M) costs, and extrabudgetary expenditure.

AVOIDED COSTS

The estimation of avoided costs considers the results of the successful implementation of an investment or policy. In the case of power generation, the use of wind allows the reduction of fuel costs and, in some cases, fuel import (also improving the national balance of payments).

ADDED BENEFITS

This category captures additional benefits generated by planned investments or policy implementation that would not accrue in a business-as-usual scenario. For wind, when compared to natural gas, we forecast higher employment creation.

2. Methodology of the Financial Analysis

Risks and externalities can be integrated into the financial model either in the profit and loss (P&L) statement as a change in operating costs or in the cash flow (CF) statement as a change in cash flows. For this SAVi assessment, it was decided to follow the latter approach, as outlined in Part III of the report. Key considerations and advantages of both approaches are outlined in the following.

Profit and Loss Statement

An important difference between the two approaches is how risks and externalities affect the taxes payable. Risks and externalities included in the P&L statement change the operating costs of the project and therefore result in a change in the taxable income. For this reason, risks and externalities (that are likely to become project risks) that have an actual cash flow impact and have a legal base to be considered in the income statement should be integrated this way. On the other hand, if one needs to assess the financial impact of internalizing these risks and externalities, integrating them in the P&L statement can be justified. In this case, the underlying assumption is that the full cost (or benefit) of the risk or externality would be internalized. This could occur in the form of physical risks that materialize, and/or additional taxes, penalties and fees enforced by regulators as well as tax credits and offsets awarded by regulators in case of a positive impact.

Cash Flow Statement

Integrating risks and externalities in the CF statement avoids changes in the taxable income by adjusting the net cash flow or earnings before interest taxes, depreciation, and amortization (EBITDA). This approach can be used when risks did not yet materialize, externalities do not have a direct impact on the P&L or when externalities are unlikely to be fully internalized during the life of the asset. For the purposes of this assessment, we have followed this approach as the externalities measured are not expected to have an operational cash impact at this stage.

Annex 2. Assumptions and Data

1. Financial and Technical Data of the Energy Assets

Conventional Costs of Onshore Wind Portfolio

The portfolio consists of 14 wind turbines of 2.05 MW per turbine. The following table summarizes key assumptions for both turbine types used by onshore wind power plants in the onshore wind portfolio: 5 REpower MM82 turbines and 9 Enercon E-70 turbines. Capital costs for the Enercon E-70 are EUR 1.93 million (Open Energy Monitor, 2016) and for the REpower MM82 EUR 1.85 million (Shata, Abdelaty, & Hanitsch, 2008) per turbine, respectively.

Table A2. Capital expenditure (CAPEX) and O&M expenditure (OPEX) assumptions onshore wind portfolio

Indicator	Unit of measure	Enercon E-70	REpower MM82
CAPEX per turbine	EUR / Turbine	1,930,000	1,850,000
CAPEX per MW	EUR / MW	941,460	902,440
OPEX per turbine	EUR / Turbine/ Year	113,500	74,000
OPEX per MW	EUR / MW / Year	55,366	26,100

Deployment Schedule for Onshore Wind Project and Gas-Fired Power Plant

Table A3 provides an overview of the deployment schedule for wind and gas capacity. Capacity is phased out 23 years (wind) and 40 years (gas) after deployment.

Table A3. Capacity deployment of the onshore wind portfolio and gas-fired power plant

Capacity type	Unit	2006	2007	2009
Wind capacity	MW	6.15	8.20	14.35
Gas capacity	MW	3.26	4.34	7.60

Employment

The assessment considers direct job creation in the manufacturing, construction, and operations of the power plant. Employment for gas extraction and transport to the power plant is not included.

Real Estate Value Impacts

The following assumptions were made to estimate the impact on real estate valuation:

a) We considered the total population in the area, arriving at a total of 10,000 people being potentially affected.

b) We assumed a household size of four people per household.

c) Dividing (a) by (b) gives us the number of dwellings (i.e., house or apartment), in this case 2,500.

d) Based on research on dwelling prices in the area, we assume an average price of EUR 200,000 per dwelling (Trovit, 2019).

e) We assume that 10% of dwellings would/could be near the power plant and estimate the value of the real estate in the proximity of the power plant.

f) We found in the literature that the impact of proximity to the gas power plant is in the range of a reduction of real estate value of 4%–7% (Davis, 2011), while the impact of wind power ranges between 1%–5% with coefficients of -0.01 to -0.025 (Sunak & Medlener, 2017). For the proximity of gas and wind power, a reduction in real estate value of 4% and 2% is assumed, respectively.

We multiply (e) by (f), and we obtain the real estate impact (EUR 2 million for gas, EUR 1 million for wind).

Energy Asset Revenues: Electricity price assumptions (provided by B Capital Partners)

The electricity prices displayed in Table A4 apply for electricity generated by the onshore wind farm as well as by the gas-fired power plant. From 2033 onwards, the electricity price indicted for year 2033 is assumed.

Table A4. Electricity price over time for the onshore wind portfolio

Year	Average Tariff
2013	96.58
2014	94.48
2015	93.98
2016	90.79
2017–2021	90.13
2022	91.43
2023	92.37
2024	93.56
2025	96.32
2026	99.45
2027	102.39
2028	106.80
2029	112.34
2030	116.04
2031	125.15
2032	131.86
2033	137.73

2. Assumptions and Externalities for the CBA and LCOE Calculations

Calculation: Levelized Cost of Electricity Generation (LCOE)

The LCOE is calculated as follows:

$$LCOE = \frac{\sum [(CAPEX_t + OPEX_t + Fuel_t) \times (1+r)^{-t}]}{\sum MWh \times (1+r)^{-t}}$$

Where the different parameters indicate:

LCOE = the levelized costs of generating one MWh over the lifetime of the asset

MWh = the amount of electricity generated by the asset in Mega-Watt-hours

$(1+r)^{-t}$ = the discount factor for year t to discount capital and O&M costs and generation

r = the discount rate applied for the discounting of costs and generation

$CAPEX_t$ = the capital cost in year t

$OPEX_t$ = the operation and maintenance costs in year t

$Fuel_t$ = the fuel costs in year t

The LCOE calculation considers project-related costs as well as externalities. Table A5 provides an overview of the assumptions used in the model for the economic valuation.

Table A5. Overview of assumptions for the onshore wind portfolio

Parameter	Unit	Value	Source
Foregone agriculture value added			
Direct land use onshore wind	ha/MW	0.176	(LVA Sachsen-Anhalt, 2007; REpower Systems, 2011)
Total land use onshore wind	ha/MW	1.035	
Average value creation by agriculture	EUR/ha/Year	2,662	(World Bank, 2018)
Foregone tax revenues from agriculture			
Tax rate	%	29.7	(Trading Economics, 2019)
Discretionary spending from additional employment			
Onshore wind capacity	MW	28.7	B CAPITAL PARTNERS
Construction employment	person / MW	10	(Greenpeace International, 2009; Wei, Patadia, & Kammen, 2009)
Average O&M employment	Person/MW/year	0.22	
Annual salary energy workers	EUR/year	42,000	(Gehalt.de, 2019)
Employment per km of road	person/km	7.778	(CIBD, 2005)

Parameter	Unit	Value	Source
Annual salary road workers	EUR/year	31,820	(PayScale, 2019)
Share of income discretionary	%	30	Assumption
Cost of road construction			
Capital cost per kilometre of roads[13]	EUR/km	118,956[14]	(Terhell, Cai, Chiu, & Murphy, 2015; Sade, N.D.)
O&M cost per km of road	EUR/km/year	1,010	Based on (Terhell, Cai, Chiu, & Murphy, 2015)
Length of road	km	5.3	Based on (LVA Sachsen-Anhalt, 2007)
Ha of road per turbine	ha	0.227	
Width of road	metres	3	Assumption[15]
Real estate impacts			
Assumed number of properties	properties	2,500	Assumption based on local population
Share of properties affected	%	10	Assumption based on location of the wind parks
Average value per property	EUR/property	200,000	(Trovit, 2019)
Reduction in real estate value from the proximity of gas power plants	%	4	(Davis, 2011)
Reduction in real estate value from the proximity of wind turbines	%	2	(Sunak & Medlener, 2017)
Biodiversity impacts			
Bird deaths per MW	bird kills/MW/year	4.12	(White, 2016)

In addition to the monetary valuation of externalities, biophysical indicators such as cement and steel consumption are computed by the SAVi energy model. The parameters used for the calculation of biophysical indicators are summarized in Table A6.

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[13] Capital and O&M for green roads are used, as roads are envisaged to be permeable. The assessment does not assume the use of recycled asphalt pavement, hence full material costs apply.

[14] Cost per m^2 of road (USD 33.04/m^2) based on Sade is supplemented with the additional cost of permeable pavement, which is assumed to be 20% higher than for conventional roads, based on Terhell et al. (2015).

[15] Assumption is based on minimum road width required for transporting wind turbines.

Table A6. Assumptions used for the biophysical assessment of the onshore wind portfolio

Parameter	Unit	Value Wind	Value Gas	Source
Resources and Land				
Cement use	ton/MWh	0.008401	0.000704	In-depth review SAVi energy (2017)
Steel use	ton/MWh	0.002223	0.00158	
Water use	ltr/MWh	5.45	31.82	(Kaza & Curtis, 2014; Ministry of New and Renewable Energy (MNRE), 2018)
Land use	ha/MW	0.176	0.045	(National Renewable Energy Laboratory (NREL), 2009; National Renewable Energy Laboratory (NREL), 2013; United States Nuclear Regulatory Commission (U.S.NRC), 2016; LVA Sachsen-Anhalt, 2007)
Compensation area (bird protection)	ha	159.3	-	(LVA Sachsen-Anhalt, 2007)
Emissions				
Lifecycle CO_2 emissions	ton/Mwh	0.01402	0.38	(Turconi & Boldrin, 2013)
pm2.5 emissions	ton/MWh	8.1e-006	2.789e-005	(International Energy Agency (IEA), 2016; Frischknecht, 2017; Chipindula, Botlaguduru, Du, Kommalapati, & Huque, 2018)
SO_2 emissions	ton/MWh	2e-006	4e-006	
NO_x emissions	ton/MWh	2e-006	0.00029	
Valuation of emissions				
Social cost of carbon	USD/MWh	31.00		(Nordhaus, 2017)

Health costs of air pollution		2020	2030	2050	Source
pm2.5	USD/ton	120,000	140,000	160,000	(EPA, 2013)
SO_2	USD/ton	33,000	39,000	51,000	(EPA, 2013)
NO_x	USD/ton	4,900	5,600	7,000	(EPA, 2013)

Foregone Value Added From Agriculture (Opportunity Cost)

Foregone agriculture production determines the amount of production that does not happen due to the use of agriculture production area for wind turbines. The direct area used for turbines is 5.07 hectares (LVA Sachsen-Anhalt, 2007; REpower Systems, 2011), or 0.176 hectare per MW. The assumed value creation per hectare of agriculture land is EUR 2,662 per year (World Bank, 2018).

Foregone Tax Revenues From Agriculture Production

The foregone tax revenues from impeded agriculture production are calculated based on the foregone value added and the average tax rate in Germany, which is assumed to be 29.7% (Trading Economics, 2019). Foregone tax payments are calculated by multiplying the annual foregone value added by the tax rate.

Discretionary Spending From Power Generation and Road Employment

Discretionary spending from power generation and road construction is the salary earned by workers that is spent and flows back into the economy in the form of discretionary consumption (assumed to be 30% of the annual labour income). The annual labour income per employee in power generation is EUR 42,000 per year (Gehalt.de, 2019).

Cost of Road Construction

The cost of road construction depends on the kilometres of road that need to be constructed for the project and the cost per kilometre. LVA Sachsen-Anhalt indicates that the land use for the roads required to establish the seven turbines totals around 1.588 ha, which is equivalent to 0.227 ha per turbine or 0.092 ha per MW. We estimate the total length of 5.3 Km, and use the unit cost of EUR 118,956/Km.

Real Estate Impacts

The SAVi assessment assumes that the establishment of power generation capacity has a negative impact on the valuation of real estate in the near proximity (<2 km) of the power plant. The value of properties in proximity to a gas-fired power plant is assumed to decline by 4% (Davis, 2011) while the value of properties in proximity to a wind farm is assumed to decline by 2% (Sunak & Medlener, 2017). It was estimated that approximately 2,500 residences are in the surrounding area of energy-generating plants, and that 10% of these properties are affected. The average property value is assumed at EUR 200,000 per building (Trovit, 2019).

Biodiversity Impacts of Onshore Wind Farms

Bird kills are negative impacts of power generation on biodiversity. The number of birds killed by wind turbines is estimated based on a study on the U.S. energy system, the mean bird deaths per MW of wind power generation capacity equals 4.12 birds killed per year (White, 2016). The number of MW for onshore wind is multiplied by the mean number of birds killed per MW to obtain project-related annual bird kills.

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