SAVi Sustainable Asset Valuation

Sustainable Asset Valuation (SAVi) of the N'Diaye Wind Farm in Senegal

A focus on energy infrastructure

SUMMARY OF RESULTS

IISD International Institute for Sustainable Development

MAVA FONDATION POUR LA NATURE

BOS

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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:

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Table of Contents

List of Figures

List of Tables

Glossary

Debt service coverage ratio (DSCR): A measure of the cash flow available to pay current debt obligations. The ratio states net operating income as a multiple of debt obligations due within one year, including interest and principal.

Development planning: A range of public and private planning and decision-making processes (e.g., ranging from a national land-use plan to the annual budgetary process, and including infrastructure projects as well as sectoral policy formulation exercises) that typically involve trade-offs between competing demands for scarce resources and which have implications for the environment.

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.

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

Geographic information system (GIS): A system designed to capture, store, manipulate, analyze, manage and present all types of geographical data. Put simply, GIS is the merging of cartography, statistical analysis and computer science technology.

Green economy: An economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (United Nations Environment Programme, 2011).

Indicator: An instrument that provides an indication, generally used to describe and/or give an order of magnitude to a given condition.

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 of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Loan life coverage ratio (LLCR): A financial ratio used to estimate the ability of the borrowing company to repay an outstanding loan. It is calculated by dividing the NPV of the cash flow available for debt repayment by the amount of senior debt outstanding.

Methodology: The underlying body of knowledge for the creation of different types of simulation models. It includes theoretical foundations for the approach and often encompasses both qualitative and quantitative analyses and instruments.

Model transparency: A transparent model is one for which equations are available and easily accessible and it is possible to directly relate structure to behaviour (i.e., numerical results).

Model validation: The process of deciding whether the structure (i.e., equations) and behaviour (i.e., numerical results) are acceptable as descriptions of the underlying functioning mechanisms of the system and data.

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: Simulation that aims to identify the best solution (with regard to some criteria) from some set of available alternatives.

Policy cycle: The process of policy-making, generally including issue identification, policy formulation, policy assessment, decision making, policy implementation, and policy monitoring and evaluation.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Scenario analysis is thus 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: A model is a simplification of reality, a representation of how the system works, and an analysis of (system) structure and data. A quantitative model is built using one or more specific methodologies, with their strengths and weaknesses.

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, for example, 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.

System dynamics (SD): A methodology to create descriptive models that focus on the identification of causal relations influencing the creation and evolution of the issues being investigated. Its main pillars are feedback loops, delays and nonlinearity through the explicit representation of stocks and flows.

Vertical/horizontal disaggregation of models: Vertically disaggregated models represent a high degree of sectoral detail; horizontal models instead include several sectors and the linkages existing among them (with a lesser degree of detail for each of the sectors represented).

Abbreviations

BAU	business as usual
BOS	Bureau Operationnel du Suivi
CBA	cost–benefit analysis
CLD	causal loop diagram
CO_2e	carbon dioxide equivalent
DSCR	debt service coverage ratio
FTE	full-time equivalent
GDP	gross domestic product
HFO	heavy fuel oil
IRR	equity internal rate of return
LCOE	levelized cost of electricity
LLCR	loan life coverage ratio
mn	million
NPV	net present value
O&M	operation and management
PV	photovoltaic
SAVi	Sustainable Asset Valuation tool

1.0 Introduction

The Bureau Operationnel du Suivi (BOS), the executive agency responsible for the monitoring of the Plan Senegal Emergent, requested a SAVi assessment on the N'Diaye windfarm. The windfarm includes 48 wind turbines and 35 km of internal access roads. When fully operational, it will generate 158.7 MW of electricity into the Senegalese grid. It will be constructed in the Thiès region of Senegal, northwest of Tivaouane (Figure 1). The land on which the turbines will be build was formerly used for agriculture production. Around 49.5 ha of land for the project was acquired on a long-term lease from the Municipality of Taiba Ndiaye. The project has a lifetime of 20 years.

According to the documentation by BOS, the total cost of the project, without the cost of financing, is around CFA 185 billion (USD 330.36 million) over the 20 years. The expected capital cost for the project is CFA 124.5 billion (USD 222.4 million) spread over three years. The variable cost is expected to be CFA 7,495 per MWh (USD 13 per MWh). These estimates are based on the International Energy Agency's *World Energy Outlook 2014* for onshore wind projects based in Africa. Following industry best practices, 30 per cent of the capital cost is assumed to be financed by equity capital and the remaining 70 per cent by long-term debt.

Figure 1. Location of N'Diaye windfarm project

Source: Cabinet d'Eco-conseil et d'Etudes, 2015

2.0 Externalities, Scenarios and Risks

The SAVi assessment consists of:

- A valuation of eight externalities related to the project.
- A simulation of three scenarios: a business-as-usual (BAU) scenario, a climate-risk scenario and a scenario that includes the value of externalities and climate-related risks.
- A comparison of the levelized cost of electricity (LCOE) of the windfarm with two alternative technologies, coal- and heavy fuel oil (HFO-) fired power generation, across the different scenarios.
- A comparison of the tonnes of carbon dioxide emissions and employment creation for the wind, coal and HFO technologies.
- An assessment of the share that externalities make up in total costs (SAVi cost–benefit analysis shares).
- An assessment of the impact of externalities and climate-related risk scenarios on traditional project finance indicators.

2.1 Externalities

The SAVi assessment considers the monetary valuation of project-related externalities. Table 1 lists all externalities that are considered for the assessment. The monetization of these costs and benefits is primarily based on the environmental and social impact assessments of the N'Diaye onshore wind farm (Cabinet d'Eco-conseil et d'Etudes, 2015). Since most of the impacts are related to the area that will be occupied by the wind park, these costs are calculated proportionally for coal- and HFO-fired power generation based on the land occupied by the respective capacity type.

Table 1. Externalities considered in the SAVi assessment

Externalities	• Discretionary spending from labour income • Cost of land use from agriculture production • Cost of noise pollution • Cost of impacts on birds and wildlife • Cost of accidents • Cost of electrification • Social cost of carbon

Discretionary spending from labour income

Discretionary spending from labour income represents the amount of money that flows back into the economy in the form of additional consumption. Discretionary spending is assumed to be a share of the annual labour income (30 per cent). This approach estimates the beneficial socioeconomic impacts that stem from the generation of employment and indicates the expected economic and social return of an asset. In this assessment, the discretionary income taken into account is related to employment from energy generation and from the construction and maintenance of roads (based on Bassi, McDougal, & Uzsoki, 2017a, 2017b). The discretionary spending in this SAVi assessment relates to the spending of additional income that is generated through the construction and maintenance of the wind park, as well as through road maintenance.

Cost of land use from agricultural production

The cost of land-use captures the opportunity cost from using land for power generation as opposed to agriculture production. The land used for power generation capacity is multiplied by an average value added from agriculture production per hectare multiplier to obtain the annual foregone value added from land use. It also includes the loss of agricultural production.

Establishing the wind park reduces the amount of land that can be used for crop production, which reduces the total value added from agriculture production in the area. This cost is a negative externality that reflects the impact of power generation on the availability of land for agriculture production.

Cost of noise pollution

The cost of noise pollution is incurred during the construction phase of the project and is related to heavy traffic and machinery. In addition, capacity-building exercises are conducted to raise staff awareness and increase compliance to speed limits and instructions for respecting highway regulations and traffic signs.

Cost of impacts on birds and wildlife

Wind parks impact bird kills, and new infrastructure in breeding areas may have an impact on wildlife. The N'Diaye area has a sparse bird population and does not constitute breeding grounds for endangered species, so there are no major implications for wildlife in the area. This category of externalities captures the costs of bird kills by multiplying the number of birds killed by an assumed value per bird.

Cost of accidents

The cost of accidents refers to the cost of damages to built or human capital over the lifetime of the project. Accidents can occur in wind parks (broken blades, fallen towers, rotor machine catching fire, environmental pollution, road transport of the turbine, lightning strikes), and the cost of accidents represents the projected costs of accidents incurring on the wind farm over its lifetime. The costs are proportionally adjusted for coal- and HFO-fired power generation depending on the total land used for capacity.

Cost of electrification

In addition to the construction of the wind farm, neighbouring communities will be connected to the electric grid. Investments in both the connections from the wind park and the local grids of these communities are planned over the next years. A structure for dialogue will need to be set up between the authorities, the surrounding population and applicants to arrange their contributions to the costs of electrification. The electrification of neighbouring villages will likely lead to increased productivity and higher quality of life. This benefit is not monetized in this externality.

Social cost of carbon

The social cost of carbon represents the economic cost caused by an additional tonne of carbon dioxide or its equivalent. It can be regarded as the discounted value of economic welfare from an additional unit of carbon dioxide emissions (Nordhaus, 2017). The social cost of carbon is estimated at USD 31 per tonne of carbon dioxide equivalent (CO_2e) emissions generated.

2.2 Technology Comparison

BOS and the International Institute for Sustainable Development decided to compare the costs and benefits of the wind farm project to the costs and benefits of two different technologies that are currently being used to provide electricity to the population: HFO-fired power generators and coal-fired power plants.[1]

It must be noted from the outset that there is a range of issues with both of these technologies in the Senegalese context, and not all of them could be captured in the integrated cost–benefit analysis (CBA) and financial analysis of SAVi. They are, however, important to understanding the context of this SAVi analysis:

- **Coal:** The only coal power plant in Senegal to date is the Sendou power station, a project that, during its preparation and construction phase, has suffered from numerous delays, social unrest and several claims for breaches of environmental, social and human rights standards. This has made the project very costly and it is unlikely that Senegal will pursue another coal project anytime soon (Business & Human Rights Resource Centre, n.d.; Review of Business and Technology, 2017; The Center for Media and Democracy, 2019). Furthermore, coal is being shipped by sea and transported over land to the coal plant. The financial costs along with pollution and emissions caused by the transportation infrastructure needed (ports and roads) are making the coal power plant even more expensive. These costs are not taken into account in the comparator of the technology in the SAVi analysis.
- **HFO:** HFO is heavily subsidized in Senegal (Saïd Ba, 2018). The investment cost of HFO power generation is based on this subsidized cost.

2.3 Climate Change-Related Risks

Physical risk: Change in temperature

While the efficiency of renewable energy is dependent on natural resources such as wind, solar radiation and water flows, the efficiency of thermal power generation sources depends on outside temperature and the availability of water for cooling purposes (U.S. Department of Energy, 2015). If the average outside temperature increases, thermal generation becomes less efficient, which means that more fuel is needed to generate the same amount of electricity. Everything else being equal, this will increase the total cost of power generation compared to the scenario without climate impacts.

Transitional risk: Change in policies

Transitional risks include parameters that are uncertain in the policy environment. In the case of fossil fuels, the introduction of a carbon tax would significantly impact the costs of electricity generation, while the costs of renewable power generation would not be affected.

2.4 Scenarios

Table 2 provides an overview of the scenarios simulated for the SAVi N'Diaye assessment. The presentation of results is described along the lines of these scenarios, and differences will be highlighted.

[1] For reasons of simplification, these three technology options are termed wind, coal and HFO in the subsequent sections.

Table 2. Scenarios simulated for the N'Diaye SAVi energy assessment

Scenario	Assumptions	Parameter	Wind	HFO	Coal
Scenario 0: Baseline	• Conventional assessment (investment, O&M and fuel costs, financing costs)	Capital cost	USD 1.45 mn	USD 1.07 mn	USD 1.3 mn
		O&M	USD 36,920 (2018)	USD 20,000 (2018)	USD 42,670 (2018)
			USD 32,870 (2035)	USD 20,000 (2035)	USD 5,190 (2035)
		Fuel cost	—	USD 1.02 / L	USD 68 / tonne
		Load factor	28.8%	42%	60%
Scenario 1: Climate risk	• Conventional assessment • The impact of a temperature increase by 1.5°C • Transitional risks (Carbon tax)	Climate impacts on load factor	—	-0.75%	-0.75%
		Carbon tax per MWh	USD 5.5 / tonnes CO_2 (2016) USD 7.7 / tonnes CO_2 (2020) USD 17.6 / tonnes CO_2 (2030) USD 27.5 / tonnes CO_2 (2035)		
Scenario 2: Climate risk and externalities	• Conventional assessment • The impact of a temperature increase by 1.5°C • Transitional risks (carbon tax) • Valuation of externalities		Under this scenario, the values of the externalities (as listed in Table 1) are added to Scenario 1.		

Note: mn = million; O&M = operation and maintenance; L = litre

3.0 Results

3.1 Integrated CBA

Key messages:

- The conventional CBA assessment yields favourable results for coal and wind. HFO scores unfavourably due to high fuel costs.
- Accounting for climate impacts, transitional risks and externalities in the assessment illustrates that the negative externalities related to HFO and coal are two to three times higher than those for wind.
- Everything considered, the wind park is projected to be the most favourable option for the N'Diaye area, as it minimizes environmental impacts while maximizing socioeconomic benefits.
- Wind energy maximizes employment and increases local spending, while minimizing land use, water use, emissions and road disruptions.

3.2 Description of Results

Table 3 presents the LCOE for each power generation technology and for each scenario. The assessment considers a lifetime of 20 years for onshore wind and 40 years for coal and HFO generation respectively. The results indicate that, in Scenario 0, the baseline traditional assessment, coal power generation is cheaper than wind with CFA 33,452 (USD 57) per MWh compared to CFA 43,337 (USD 74) per MWh. While HFO is widely used in Senegal, it is not a financially attractive option to generate a large amount of electricity. The cost of HFO fuel-generated electricity amounts to CFA 145,659 (USD 249) per MWh. When climate risk and externalities are taken into account (Scenarios 1 and 2), we see that the cost of wind decreases to CFA 43,266 (USD 74) per MWh due to the positive externalities related to the technology. The cost of coal power generation increases to CFA 52,998 (USD 91) per MWh due to the negative externalities such as the social cost of carbon. A full breakdown of the cost of the climate risk and the externalities is provided in Table 4.

Table 3. LCOE by technology and scenario (CFA/MWh)

LCOE by scenario	Wind	HFO	Coal
Scenario 0: Baseline	43,337	145,659	33,452
Scenario 1: Climate risk	43,337	151,481	40,798
Scenario 2: Climate risk and externalities	43,266	155,898	52,998

In Table 4, the cost of financing is the lowest for coal at CFA 1,652 (USD 2.80) per MWh, followed by CFA 1,966 (USD 3.40) per MWh for HFO, and finally CFA 7,510 (USD 12.90) per MWh for the wind energy project. The cost of financing for the wind park is that high because of the high capital cost of the project. In terms of externalities, Table 4 shows that the social cost of carbon for HFO and coal is much more significant than for wind power. In terms of positive externalities, we note that the discretionary spending from additional employment created through the energy project is higher for wind than for HFO and coal. The values of these positive and negative externalities, as well as the cost of climate risks, demonstrate that the wind project provides more benefits and ultimately has a lower LCOE compared to other energy technologies.

Table 4. Breakdown of LCOE by category and technology (CFA/MWh)

LCOE breakdown by cost position	Wind	HFO	Coal
Project-related costs			
Capital investment	23,461	11,746	9,990
Project preparation			
Cost of soil compacting	1.9	2.8	1.9
Cost of vegetation removal	1.9	2.8	1.9
Costs of damage to roads	0.3	0.4	0.3
Operating phase			
Damages to roads	0.2	0.3	0.2
Preparatory activities	1.2	1.7	1.2
Cost of O&M	7,495	609	5,362
Fuel cost	0	126,580	11,692
Cost of financing	7,510	1,966	1,652
Project-related taxation	4,865	4,750	4,750
Subtotal (1)	**43,337**	**145,659**	**33,452**
Climate change-related risks			
Climate impacts	0	3,308	306
Carbon tax	0	2,514	7,040
Subtotal (2)	**0**	**5,822**	**7,346**
Externalities			
Planning and construction phase			
Discretionary spending from labour income (wind park)*	(365.2)	(110.3)	(82.8)
Costs of land use from agriculture production	42.7	65.5	45.9
Costs of noise pollution	0.4	0.5	0.4
Operating phase			

LCOE breakdown by cost position	Wind	HFO	Coal
Costs of impacts on birds and wildlife	1.3	0.7	0.5
Cost of accidents	1.7	0	0
Cost of electrification	0.9	1.3	0.9
Social cost of carbon	363	4,459	12,355
Discretionary spending from labour income (road maintenance)*	(115)	(169.4)	(119)
Subtotal (3) project externalities	**(70)**	**4,247.3**	**12,200.9**
Total LCOE, including externalities and climate risks	**43,266**	**155,728**	**52,998**

**Positive externalities are indicated as negative value, as they reduce the LCOE by generating social or environmental benefits.*

The SAVi CBA shares, presented in Table 5, indicate the share that externalities contribute to the total costs reported for each SAVi+ assessment (Scenario 3). These shares indicate the percentage that externalities hold in total costs if externalities are considered in addition to capital, O&M and fuel costs. For coal and HFO, externalities constitute 23 per cent and 2.7 per cent of total cost, respectively. For the wind farm, positive externalities such as tax revenues, income and value added from employment over the lifetime of the project outweigh the negative ones and contribute to reducing the LCOE of the project. In the case of the N'Diaye wind park project, the value of positive externalities leads to a "net reduction" in the costs of electricity generation.

Table 5. CBA shares by technology

CBA shares (SAVi)	Wind	HFO	Coal
Capital, O&M and fuel	100.2%	97.3%	77.0%
Externalities	(0.2%)	2.7%	23.0%

In terms of direct employment from power generation, the SAVi assessment indicates that onshore wind is projected to generate at least 66 full-time equivalent (FTE) jobs per year, which is much higher than the employment generated by both coal (11 jobs) and HFO generation (15 jobs). Establishing the N'Diaye wind park could contribute to avoiding between 2.1 million and 6 million tonnes of CO_2e emissions, respectively, that would be emitted between 2019 and 2042 if implementing HFO or coal power instead. This is equivalent to a cumulative discounted avoided social cost of carbon of approximately CFA 23.7 million (USD 40,600) and CFA 65.6 million (USD 112,400). Table 6 provides an overview of annualized employment, cumulative CO_2e emissions from the use of fossil fuels and cumulative life-cycle CO_2e emissions.

Table 6. Employment creation and CO_2e emissions

Category	Wind	HFO	Coal
Employment (FTE/year)	66	15	11
Emissions – fuel (mn tonnes)	0.0	2.1	6.0
Emissions – life cycle (mn tonnes)	0.1	2.2	6.1

3.3 Financial Analysis

The financial analysis demonstrates the financial impact of the externalities and climate risks for the onshore wind, HFO and coal energy projects. The outputs of the analysis are divided into two groups: profitability indicators (Table 8) and credit ratios (Table 9). While the internal rate of return (IRR) and net present value (NPV) demonstrate the financial attractiveness of the project, the debt service coverage ratio (DSCR) and loan life coverage ratio (LLCR) are mostly used by lenders to assess the project's ability to service its debt.

The financial analysis includes three scenarios, similar to the integrated CBA:

- The baseline scenario includes only the project-related costs, such as capital and operating expenditures.
- Scenario 1 extends the baseline scenario by also including the impact of climate-related risks, both physical and transitional.
- Scenario 2 builds on Scenario 1 by also incorporating the different environmental, social and economic externalities measured by SAVi.

Table 7. Scenarios simulated for the N'Diaye SAVi energy assessment

Scenario	Assumptions
Scenario 0: Baseline	• Conventional assessment (investment, O&M and fuel costs)
Scenario 1: Climate risk	• Conventional assessment • The impact of a temperature increase by 1.5°C • Transitional risks (carbon tax)
Scenario 2: Climate risk and externalities	• Conventional assessment • The impact of a temperature increase by 1.5°C • Transitional risks (carbon tax) • Valuation of externalities

3.3.1 KEY FINDINGS

- Wind performs on par with coal when externalities and climate risks are taken into account. It is important to note that the economic assessment carried out with SAVi focuses on the cost of power generation at the plant level. As a result, it does not include the cost of infrastructure and provisioning of coal and HFO (while it does consider the cost of road construction and connection to the grid for wind power).

- The financial impact of environmental, social and economic externalities is significant.
- The HFO option significantly underperforms compared to the other two energy generation technologies and is not considered to be financially viable.

Table 8. Profitability indicators

	Wind		HFO		Coal	
	IRR (%)	**NPV (USD mn)**	**IRR (%)**	**NPV (USD mn)**	**IRR (%)**	**NPV (USD mn)**
Scenario 0: Baseline	12.17%	156.95	Negative	(943.67)	23.53%	305.54
Scenario 1: Climate risk	12.17%	156.95	Negative	(1,010.30)	19.59%	236.86
Scenario 2: Climate risk and externalities	12.19%	157.38	Negative	(1,060.14)	13.27%	129.64

Table 9. Credit ratios

	Wind		HFO		Coal	
	Min. DSCR (x)	**Min. LLCR (x)**	**Min. DSCR (x)**	**Min. LLCR (x)**	**Min. DSCR (x)**	**Min. LLCR (x)**
Scenario 0: Baseline	1.73x	2.00x	(6.98x)	(6.97x)	3.20x	3.58x
Scenario 1: Climate risk	1.73x	2.00x	(7.55x)	(7.54x)	2.66x	2.96x
Scenario 2: Climate risk and externalities	1.73x	2.00x	(7.97x)	(7.96x)	1.83x	1.97x

Wind performs on par with coal when climate risks and externalities are considered.

Under the traditional financial assessment (Scenario 0), coal has a higher expected IRR (23.53 per cent) than the onshore wind project (12.17 per cent). This is mainly due to the capital expenditure of the renewable alternative being more than double the capital expenditure of coal.

The NPV tells a similar story: coal is leading with a significant margin (USD 305.54 million) compared to the onshore wind project (USD 156.95 million). Finally, credit ratios being comfortably above 1.00x means that neither of the two projects is expected to have cash flow problems to repay the loan with interest.

When the potential effects of climate change are factored in (Scenario 1), the financial performance of coal worsens materially. This is due to the additional costs of the carbon tax as well as to sub-optimal energy generation under higher temperatures.

When the environmental, social and economic externalities as well as the risks of climate change are included in the model (Scenario 2), onshore wind performs on par with the coal power plant. Based on NPV alone, the renewable option (USD 157.38 million) even outperforms the fossil fuel alternative (USD 129.64 million). **These insights underline the significance of externalities when being integrated into the financial assessment of infrastructure projects. These results also demonstrate that the coal option is not cheaper under a more holistic analysis.**

One needs to note that, while it appears important to consider externalities in the financial assessment in order to make sustainable investment decisions, they do not directly affect the cash flows of the project under assessment. Consequently, financial indicators calculated under Scenario 2 represent a societal view on the performance of project alternatives. IISD looks forward to the dialogue with BOS on how to enhance this part of the financial assessment.

The HFO option underperforms compared to the other two energy generation technologies.

The financial performance of the HFO option is very weak across all of the scenarios modelled. This is the result of the high cost and inefficiency of burning HFO to generate electricity. The NPV over the 40-year project lifetime is eminently negative and amounts to approximately USD -1 billion across scenarios, with all other financial indicators telling a similar story. These numbers are especially striking when considering that HFO is still often used for energy generation in Africa.

4.0 How SAVi for the N'diaye Windfarm Was Built

4.1 Systems Thinking and System Dynamics

The SAVi analysis focused on the assessment of opportunities and externalities related to the onshore wind project N'Diaye, in Senegal. The underlying dynamics of the energy sector, including driving forces and key indicators, are summarized in the causal loop diagram (CLD) displayed in Figure 1. The CLD includes the main indicators analyzed during this SAVi assessment, their interconnections with other relevant variables in the sector, such as energy demand and price, and the feedback loops they form. The CLD was developed and customized to the local context in collaboration with stakeholders working with the BOS, who also provided the necessary information for the assessment. The CLD is the starting point for the development of the mathematical stock and flow model. The model results are presented in Section 3.

BOX 1. READING A CAUSAL LOOP DIAGRAM

CLDs 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 10):

- 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.

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

Table 10. **Causal relations and polarity**

Circular causal relations between variables form causal, or feedback, loops. These can be positive or negative. A negative feedback loop tends toward a goal or equilibrium, balancing the forces in the system (Forrester, 1961). A positive feedback loop can be found when an intervention triggers other changes that amplify the effect of that initial intervention, thus reinforcing it (Forrester, 1961). CLDs also capture delays and non-linearity.

The creation of a CLD has several purposes: first, it combines the team's ideas, knowledge and opinions; second, it highlights the boundaries of the analysis; third, it allows all stakeholders to achieve basic-to-advanced knowledge of the analyzed issues and their systemic properties. Having a shared understanding is crucial for solving problems that influence several sectors or areas of influence, which are common in complex systems. Since the creation of a CLD touches upon and relies on cross-dimensional knowledge, it supports developing a shared understanding of the factors that generate the problem and those that could lead to a solution among all the parties involved in the decision-making process and implementation, and to effectively implement successful public–

private partnerships. As such, the solution should not be imposed on the system, but should emerge from it. In other words, interventions should be designed to make the system start working in the favour of decision makers and relevant stakeholders to solve the problem, rather than generate it.

In this context, the role of feedbacks is crucial. It is often the very system we have created that generates the problem, due to external interference or to a faulty design. These limitations emerge as the system grows in size and complexity. In other words, the causes of a problem are often found within the feedback structures of the system. The indicators are not sufficient to identify these causes and explain the events that led to the creation of the problem. We are too often prone to analyzing the current state of the system, or to extending our investigation to a linear chain of causes and effects, which does not link back to itself, thus limiting our understanding of open loops and linear thinking.

4.2 Model Overview

In the context of ensuring energy generation security for Senegal, BOS approached IISD to carry out an assessment on the feasibility of different power generation options. We have applied the SAVi energy model to inform decision makers about the potential risks and externalities of each technology. The SAVi energy model projects asset-related performance that considers different risks and externalities over its lifetime. The assessment monetizes risks and externalities and provides information about social and environmental impacts on top of the conventional economic assessment.

In addition to the planned onshore wind park, steam coal and HFO were included in the assessment as suitable technologies given the local context. In order to fully account for the impacts of the considered technologies, the socioeconomic and environmental impacts of each option need to be assessed. The SAVi assessment considers both asset-related externalities and the adequacy of the planned investment in the face of increasing uncertainty induced by climate change impacts and population development trajectories.

Figure 2 presents a CLD of the dynamics that underlie the analysis of the energy sector. It presents the key variables that drive the construction of power generation capacity over time, such as population, economic demand for electricity and the determinants of the efficiency of power generation technology. There are six major feedback loops that drive the dynamics of the energy sector: loops R1 through R3 and B1 through B3.

- 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.
- The desired capacity level depends on the average effectiveness (average load factor) of the current technology mix. While thermal capacity, usually with higher load factors, increases the average load factor, which is captured by loop R2, renewable technologies are less efficient due to their dependency on, for example, sunlight and wind speed, captured by loop B2. This indicates that a transition toward renewables probably yields higher capacity requirements than the use of thermal technologies.
- The price of electricity is the third major driver impacting the demand for power generation capacity, via the demand for electricity. Assuming that input costs of generation remain constant, higher generation reduces the price of electricity, which increases demand and vice versa. Reinforcing loop R3 captures the increase in electricity generation price that occurs if the share of renewable generation in the power generation portfolio is increased. Balancing loop B3 captures the counteracting impacts that low-cost fossil fuel generation have on the

cost of power generation and hence the electricity generation price.

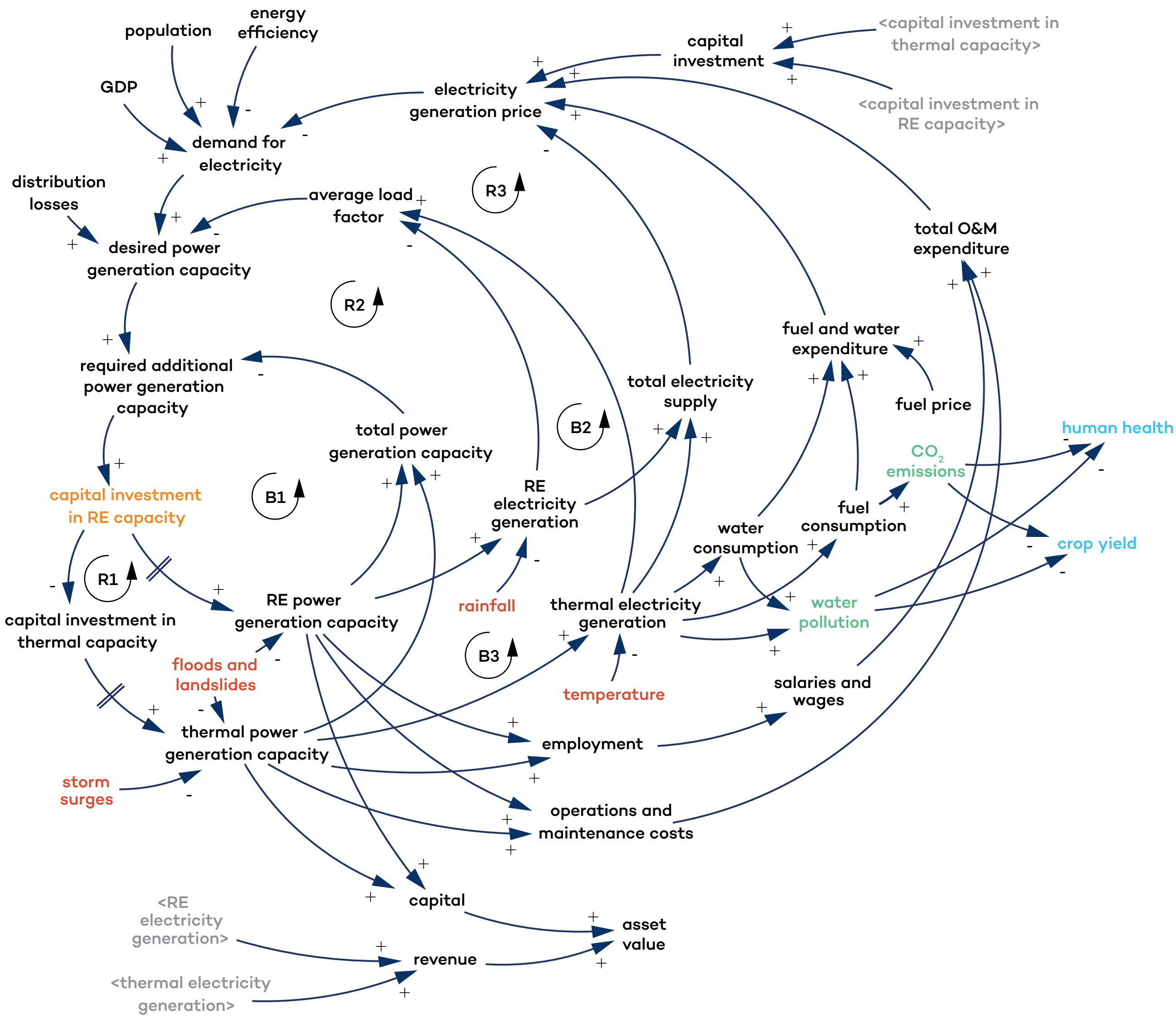

Figure 2. CLD for an energy assessment

Note: RE = renewable energy

4.3 Method

The LCOE serves as the key indicator for each of the technologies. The LCOE is a useful indicator for comparing the unit cost of different technologies over their lifetime (International Energy Agency, 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., USD) by cumulative discounted generation, typically indicated in MWh.

To fully account for the impact of power generation capacity, it is necessary to regard capacity as part of the system rather than in isolation. A system dynamics model assesses and monetizes asset-related externalities and risks, such as climate impacts on generation efficiency, transitional risks (e.g., carbon tax) and health impacts from particle and other emissions. This information is used to complement the traditional LCOE assessment and to determine the "real social, economic and environmental costs" of power generation technologies. In addition to the conventional LCOE, including cost parameters such as capital investment, O&M and fuel costs, an integrated LCOE is presented that considers the monetized externalities and risks related to each technology. This approach allows a full account of asset-related impacts and provides a holistic picture of capacity-related advantages and disadvantages.

The LCOE of power generation options depends on a variety of factors, such as upfront capital intensity, O&M costs, total generation and the lifetime of the asset. The traditional LCOE is calculated by using the following equation:

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

where the different parameters indicate

LCOE = the levelized costs of generating one MWh of electricity over the lifetime of the asset
MWh = the amount of electricity generated by the asset in megawatt-hours
$(1+r)^{-t}$ = the discount factor for year t to discount capital and O&M costs and generation equally
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

To convey a more holistic assessment, the SAVi assessment includes transitional risks (e.g., carbon tax), climate risks and various externalities in the calculation in addition to the conventional assessment. The additional parameters considered in this analysis are presented in Section 3. These parameters have been identified in collaboration with local stakeholders and project owners, and belong to one of the three different categories: expenditure, avoided costs and added benefits.

4.4 Indicators Concerning Expenditure, Avoided Cost and Added Benefits

We have assessed three main categories of implementing coal, HFO and wind capacity: expenditure, avoided costs and added benefits, whereby expenditure includes both capital investment and O&M expenditure over the lifetime of the asset. The assessment integrates both social and environmental avoided costs and added benefits in addition to the more traditional economic ones. The example of energy-efficient buildings, which reduce energy use, energy costs and emissions, illustrates this approach.

4.4.1 EXPENDITURE

From a private sector perspective, expenditures refer to the monetary costs of project implementation, such as investment, O&M costs and extrabudgetary expenditure. For utility operators, complying with emission standards might entail, for example, purchasing efficient mitigation technologies. Contractors will consider the costs for selected mitigation technologies, certification fees for new power generation capacity and auditing for existing ones. From a public sector point of view, expenditures refer to the allocation and/or reallocation of financial resources with the aim of reaching a stated policy target—for example, providing subsidies for investments in efficient power generation technologies to stimulate the construction of renewable capacity or capacity that delivers the best value for money according to the determined indicators.

4.4.2 AVOIDED COSTS

The estimation of potential avoided costs considers the results of the successful implementation of an investment or policy. In the case of power generation, avoided costs refer to direct savings derived from the operation of power plants, such as, for example, reduced fuel costs, avoided investments in mitigation technology or O&M expenditure, and water costs.

4.4.3 ADDED BENEFITS

Among the added benefits are the monetary value of economic, social and environmental outcomes obtained from investment or policy implementation. Added benefits are assessed by comparing the investment scenario against the baseline scenario, focusing on short-, medium- and long-term impacts across sectors and actors. In the case of power generation capacity, added benefits include job creation, a reduction in health impacts from emissions, opportunity costs of land use and the social cost of carbon. This category captures additional benefits generated by planned investments that would not accrue in a BAU scenario.

4.5 Model Overview: Project finance

The main purposes of a project finance model are: (i) to identify the optimal capital structure, (ii) to assess the financial viability of the project and (iii) to calculate the expected return on investment under different operational and risk scenarios.

1. Project sponsors use financial models to determine what should be the optimal debt-equity split used in the financing of the project. This largely depends on the project's revenue and cost profile: the timing and size of incoming cash flows during operations and the associated costs in each period. Most infrastructure projects follow a so-called "J-curve": having high upfront costs and relatively small but steady revenue streams. The "J" represents a certain number of years before the project breaks even and generates a return on investment.
2. Project finance models can also calculate whether the cash flows generated by the project will be sufficient to service the debt and generate an attractive risk-adjusted return for both equity and debt investors. This assessment includes the calculation of key profitability and credit indicators, such as the IRR, NPV, DSCR and LLCR. The definition of these indicators can be found in the glossary.
3. Project finance models are also well placed to stress test projects and assess how the expected return changes under certain operational and risk scenarios. This is calculated by a so-called "scenario table," which modifies key project assumptions and shows how key financial indicators react to these changes. Scenarios could be simple operational events, such as an increase in the price of feedstock, disruption in operation, or more complex climate events, such as heat waves, sea-level rise or carbon tax.

The project finance model used in SAVi is built in Microsoft Excel and follows Corality SMART best practices in order to improve readability and auditability of the model by a third party. The outputs of the system dynamics model in SAVi are used as inputs in the project finance model and vice versa. The system dynamics model quantifies and monetizes the relevant environmental, social and economic externalities associated with the project. It also helps to identify the scenarios used in the scenario table. Depending on the purpose of the assessment and the target audience, some of the externalities are included as costs or benefits in the scenario table. Outputs of the system dynamics model can also change some of the key assumptions of the project finance model.

The main outputs of the project finance model are the financial indicators mentioned earlier. During the customization of the model, the list of indicators can be changed or extended as needed. Project-specific data, such as cost of financing, can also be extracted from the project finance model and fed back into the system dynamics model.

5.0 Conclusions

The conventional CBA assessment yields favourable results for coal-fired power generation and the wind farm project. HFO-fired power generation scores unfavourably due to high fuel costs. The CBA reveals that, when climate risks and externalities are taken into account, the picture changes. The LCOE of coal-fired power generation is 23 per cent higher than the LCOE of the onshore wind farm project and the LCOE of HFO-fired power generation is more than 3.5 times higher. The calculated externalities, notably the social cost of carbon, have an even larger impact on the LCOE of coal-fired and HFO-fired power generation than the climate risks. Electricity generated by wind power becomes comparatively more affordable.

Consequently, the wind farm is projected to be the most favourable option for the N’Diaye area, as it minimizes environmental impacts while maximizing socioeconomic benefits. Wind energy creates significantly more employment than the alternative technologies and increases local spending while minimizing land use, water use, emissions and road disruptions.

The comparison of financial performance indicators demonstrates that the wind farm performs on par with coal-fired power generation when externalities and climate risks are taken into account. In this scenario, the NPV of the wind farm project is even comparatively higher. The HFO option performs financially very weakly compared to the other technologies and is considered to be financially not viable. This is the result of the high cost and inefficiency of burning HFO to generate power.

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Annex I. Costs and Revenues by Asset (CFA million)

Category	Wind onshore	HFO	Coal
Capital and O&M cost	41,897	21,498	18,283
Planning and construction phase			
Cost of soil compacting	9.6	14.6	10.2
Cost of vegetation removal	9.6	14.6	10.2
Costs of damage to roads	1.4	2.2	1.5
Operating phase			
Damages to roads	0.9	1.4	1.0
Preparatory activities	5.9	9.1	6.4
Fuel costs	0.0	690,314.5	63,763
Cost of financing	55,415.9	14,504.8	12,191
Project-related taxation	24,736.9	25,214.2	25,214.2
CC impacts on fuel costs	0.0	0.0	-77.5
Carbon tax	0.0	13,905.8	38,936
Subtotal (1)	**122,077**	**765,479**	**158,339**
Income spending	(1,857)	(586)	(439)
Externalities			
Planning and construction phase			
Agriculture value added	179.8	288.6	202.0
Tax revenues from agriculture	36.0	57.7	40.4
Costs of noise pollution	1.9	2.9	2.0
Operating phase			
Yield impacts	0.9	1.4	1.0
Bird impacts	4.1	0.0	0.0
Wildlife impacts	2.3	3.6	2.5

Category	Wind onshore	HFO	Coal
Accidents	8.8	0.0	0.0
Cost of electrification	4.4	6.8	4.8
Discretionary spending from road maintenance	(586)	(899)	(629)
Land use	180	289	202
Social Cost of Carbon	1,846.5	23,670.0	65,580.7
Value of externalities	(179)	22,835	64,967
Subtotal (1 + 2)	**121,898**	**788,313**	**223,306**
Revenues	**323,803**	**323,803**	**323,803**
Costs and Benefits	**201,904**	**(464,511)**	**100,497**

SAVi Sustainable Asset Valuation

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