Work Package 1 – Shared modelling framework and learnings

D1.2 – Description of scientific methods

Task 1.5- Framework for socio-economic assessment

Techno-economic assessment model for bio-based technologies/products/ projects.

Lead Contractor: University of Antwerp (ANTW), Belgium.
Author(s): Dr. Maxim Tschulkow

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DELIVERABLE CONTRIBUTORS			
	Name	**Organisation**	**Job title**
Deliverable leader	Steven Van Passel	ANTW	Professor
Contributing Author(s)	Maxim Tschulkow	ANTW	Postdoctoral researcher
Reviewer(s)	Massimo Pizzol	Aalborg University	Professor
	Kira Lancz	Aalborg University	Research assistant
	Bas Davidis	BTG	Consultant
Final review and quality approval	Søren Løkke Dalia Stakenaite	Aalborg University Aalborg University	Associate Professor Project Manager

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Acronyms and abbreviations

ABBREVIATIONS	Description
CAPEX	Capital expenditure
DPBP	Discounted payback period
IRR	Internal rate of return
kWh	Kilowatt hours
LCA	Life cycle assessment
M&EB	Mass and energy balance
NPV	Net present value
OPEX	Operational expenditure
PFD	Process flow diagram
TEA	Techno-economic assessment

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Executive summary

This task consists of coordinating a consistent implementation of socio-economic assessment within the ALIGNED project. It consists of three building blocks; (i) economic evaluation (techno-economic assessment), social evaluation (social indicator model), and (iii) multi-criteria decision analysis. In this particular description, the developer focuses on the economic evaluation method the techno-economic assessment based on the work of Tschulkow et al. (2020).

It first sets the basis for identifying and analyzing the economic feasibility of technologies, products, or projects through the provided tools and tutorials that can be used by the partners and general practitioners. It will then facilitate its application to the case studies in the bio-based sector by providing specific guidelines for modelling and analyzing the economic feasibility.

1. The need for sustainability in the bio-based sectors

The 2030 Agenda for Sustainable Development expresses a dedication to realize sustainable development across economic, social, and environmental domains in a harmonized and cohesive manner (United Nations, 2015). Hence, the European Commission introduced the strategy " European Green Deal". This initiative aims to transform the European Union (EU) into a society that is both fair and prosperous, characterized by a modern, resource-efficient, and competitive economy (European Commission, 2019). In addition to governmental policies and environmental regulations, sustainability is also stimulated by customers' demand and increasing societal and environmental awareness (Leal-Millan et al., 2018). Consequently, companies are faced with the challenge of adopting new strategies, products, and technologies that prioritize sustainability.

Achieving sustainability is closely tied to the implementation of existing and novel innovative technologies and products, ideally with reduced environmental impacts and positive social and economic outcomes. In a world of population growth and increasing environmental challenges (e.g. climate change), the bioeconomy is gaining prominence as it provides an avenue to harmonize economic expansion with environmentally responsible practices, presenting the prospect of a low-carbon economy and the creation of new jobs (Eickhout, 2012). The advancement of the bioeconomy is a key element of the 2020 strategy (Fritsche and Iriarte, 2014). Consequently, the European Commission formulated the Bioeconomy Strategy in 2012 to serve as a guide for research and innovation agendas (European Commission, 2012). An updated version of this strategy was released in 2018, aligning more effectively with contemporary policy priorities (European Commission, 2018).

The development of new or enhanced industrial processes is essential for converting biomass into various energy applications and other products. However, the utilization of organic matter (i.e., biomass) for food, feed, biobased products, and bioenergy carries potential negative impacts, such as land use changes due to deforestation and unsustainable farming practices, as well as increased water use. Consequently, it is crucial to measure and monitor these sustainability-related impacts, preferably already during the developmental phase of new biobased technologies (Van Schoubroeck et al., 2018).

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2. Techno-economic assessment

Techno-economic assessment (TEA) is a commonly used method to assess the economic feasibility of (new/emerging) technologies through their design, identifying the hot spots, and helping the decision-makers to make strategic investment choices (Kuppens et al., 2015). It integrates technological insights into economic assessments, identifies economic challenges at lower Technology Readiness Levels, and evaluates economic feasibility at higher TRL. TEA consists of four steps (Tschulkow et al., 2020):

1. **Market study**: this step identifies market-related parameters that could potentially influence the project's commercialization prospects.

2. **Process flow diagram (PFD) and mass and energy balance (MEB)**: These provide a schematic overview of the primary process units, inputs, and outputs. It is the technological backbone of the method.

3. **Economic assessment**: This involves assessing the economic feasibility of the project/technology or product based on technical and economic variables.

4. **Sensitivity analysis**: This evaluates the most influential and critical variables affecting the economic performance of the technology.

2.1 Economic indicators

Economic indicators give the user insights about the cost structure and the potential economic feasibility of established, new, emerging technology, projects, or products. Two types of indicators are used in the TEA, intermediate and finite indicators:

2.1.1. Intermediate indicators

The intermediate indicators are (Peters et al., 2006):

- **Capital expenditure (CAPEX)**: CAPEX, also called initial investments, is the amount of money that is necessary to be invested before the technology can operate.
- **Operational expenditure (OPEX)**: OPEX represents the costs that are needed for the annual operation and maintenance of the facilities, processes, and units to keep the production running.
- **Revenues**: Revenues show the financial inflows coming from the sale of the produced products.

2.1.2. Finite indicators

The finite indicators are:

- **Net present value (NPV)** indicates the discounted profitability of a project over a pre-defined lifespan, as illustrated in Equation 1. The NPV weights the amount of investment in year 0 (today) to the future discounted cash flows (revenues – costs) originating from the initial investment over a lifespan (e.g. 20 years) of the project that is discounted back to a present value.

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} - CAPEX \qquad (1)$$

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- **Internal rate of return (IRR)**: IRR is the discounted NPV that equals zero. To be profitable the IRR must be higher than the discount rate which represents the return rate that can be generated in other alternative investments, calculated as in Equation (2). The IRR does not give any insights into the absolute profit value. Hence, it is advised to use IRR in combination with NPV.

$$0 = \sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} - CAPEX \qquad (2)$$

- **Discounted payback period (DPBP)**: It is a point in time at which the initial investment is fully covered by the incoming net cash flows. It considers the discounted value of money over time.
- **Levelized cost of product**: it is calculated by considering the sum of all costs (OPEX and CAPEX) divided by the amount produced products over the lifespan of the entire project. To calculate the annual CAPEX, Equation 3 must be applied:

$$Annualized\ CAPEX\ installation = \frac{CAPEX\ installation}{\frac{1-(1+i)^{-t}}{i}} \qquad (3)$$

2.2 Relation between TEA and LCA

TEA is a method to evaluate the economic feasibility (see economic indicators) of projects, technologies, or products whereas the Life Cycle Assessment (LCA) focuses on the environmental impacts. There are similarities between the two and the two tools can be used together complementing each other.

Gate-to-Gate approach:

The primary focus of a TEA is the assessment of the midstream (technology) of a value chain which is equivalent to the Gate-to-Gate approach in LCA's.

Cradle-to-Gate approach:

The upstream stage includes stages such as plantation, exploitation, transportation, shredding, and drying until it is ready to enter the process stage (midstream, biorefinery). The cost of the upstream is usually reflected in the price of the feedstock. Including the upstream and midstream is equivalent to the Cradle-to-Gate approach of an LCA.

Cradle to-Grave approach:

Downstream stages, such as the utilization, distribution, and disposal stage of the product are usually not included in a TEA. Technically it is possible to include all life stages of the product, making it a life cycle costing method. Including all life cycle stages, upstream, midstream, and downstream, is equivalent to the Cradle-to-Grave approach.

Market study:

In the LCA approach, the goal and scope stage defines what question should be answered by the LCA. It also defines the functional unit and the system boundaries of the chosen product. This

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stage also included the study of the products, the technology behind the process, and all necessary information that is required to understand the activities within the system boundaries.

The market study of the TEA has a similar purpose. Based on the research question, the user defines what indicator needs to be studied. To assess the economic feasibility, the technology and the entire value chain (LCA: life cycle stages) must be studied to understand the technological process, what inputs (outputs) are going in (out), and what their associated cost and prices are.

Technological backbone

The technological backbone of the TEA, consisting of the process flow diagram and the mass and energy balance, is equivalent to the foreground life cycle inventory of the LCA. This means that the data can be shared between both methods which saves time and financial resources. Hence, the technological backbone can be seen as the interlinkage between the TEA and LCA, aligning and harmonizing both methods.

Within the LCA, activities (or materials) of the foreground system and their associated amounts are linked to the environmental indicator values of the background system to define the absolute value of the particular activity. For the TEA, a similar process is applied. The activities of the technological backbone are linked to prices on the market defining the absolute cost (value) of the particular input (output) material. To find this information it is advised to consult the literature, databases such as STATA or Eurostat, websites that sell the products on industrial scales (e.g. Alibaba), or companies producing the same or similar products.

3. Guideline to use the 'Techno-economic assessment for ALIGNED'

To conduct a techno-economic assessment (TEA), the University of Antwerp (ANTW) provides an Excel-based tool 'Techno-economic assessment for ALIGNED'. The tool is available in the T1.5 repository. The Excel file consists of the following worksheets:

- ReadMe
- PFD and M&EB
- Operational costs
- Revenues
- Investment cost
- Economic assessment
- Sensitivity analysis

This guide provides an explanatory tutorial of how to conduct a TEA. To do so, the study of Tschulkow et al. (2020) is used as an example.

Before using the TEA, the user is advised to pay attention to the legend which indicates which values need to be (i) inserted, (ii) calculated automatically, or (iii) represent the results:

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LEGEND (color indication)
Value to be inserted by the user
Value calculated authomatically
Results

Figure 1: Color-based legend.

3.1. ReadMe

This sheet provides a general overview of all worksheets and their purposes within the Excel file 'Techno-economic assessment for ALIGNED'. Moreover, it describes the utilization of the different sources within the datasheets.

3.2 PFD and M&EB

The worksheet 'PFD and M&EB' has two areas. At the upper part of the worksheet, the user can insert the process flow diagram for illustration purposes, see Figure 2:

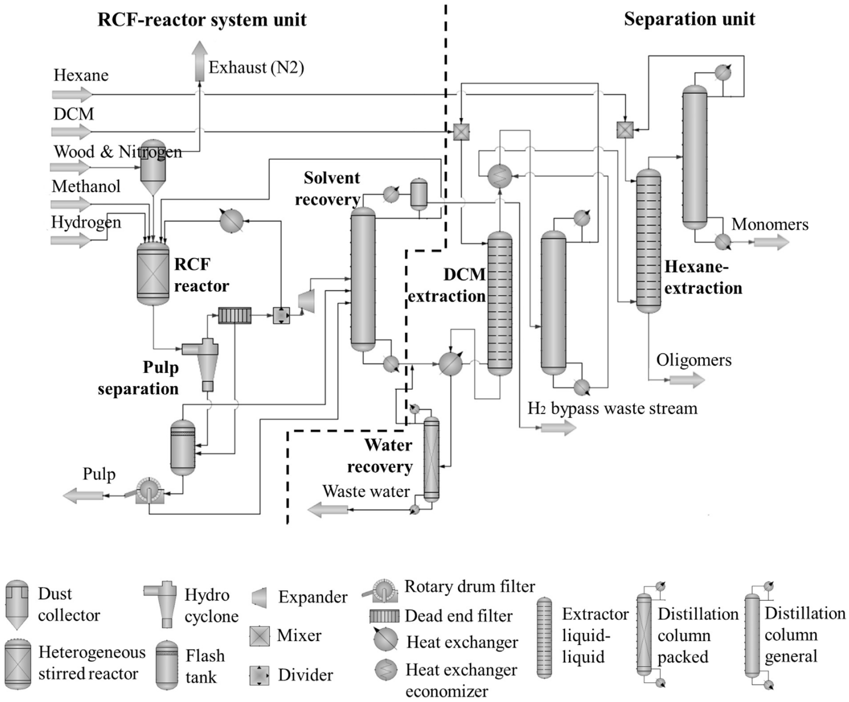

Figure 2: Process flow diagram (Tschulkow et al., 2020).

In the lower part '**mass and energy balance**', the user can insert the material inputs and outputs of the project, technology, or process.

- **Column B** lists three life cycle stages, upstream (processing stage), midstream (Biorefinery), and downstream (distribution, use, post-treatment, and disposal).
- **Column C** defines inputs (outputs) that are coming in (out).
- **Column D** defines units in which the inputs/outputs are calculated (e.g. kg/h, kWh, etc.).

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- **Columns E-F**, represent the processing activities (upstream) before entering the biomass processing stage (potential biorefinery).
- **Columns G - P** represent the potential units of the biorefinery (midstream).
- Columns **Q - X** represent all stages of the downstream (distribution, use, post-treatment, and disposal).
- **Column Y** calculates the balance for each activity through the entire life cycle. These values are connected to costs and prices in the worksheets '**Operational costs**' and '**Revenues**', respectively.

Action required: Inputs and outputs are required to be inserted between Columns E and X. In Column Y, the balance will be calculated automatically.

3.3 Operational cost

The worksheet 'Operational cost' consists of three parts, material cost, operating cost, and the rest.

For the **material cost**, inputs from the worksheet 'PDF and M&EB" are linked to costs, calculating the annual cost of the production.

- **Column B** lists three life cycle stages, upstream (processing stage), midstream (Biorefinery), and downstream (distribution, use, post-treatment, and disposal).
- **Column C** defines inputs (material) that are necessary for the production process.
- **Column D** defines units in which the inputs are calculated (e.g. kg/h, kWh, etc.).
- **Column E** defines the quantity of materials that are processed per hour.
- **In column F**, the production is scaled to an annual production, calculating the annual quantity.
- **Column G** defines the units after scaling up. The units are converted from kg to tons.
- **Column I** represents the cost per unit (€/ton).
- **In column J**, the annual cost per material is calculated and summed up (€/year) in total material cost.

Action required: Connect the inputs (materials) and quantities from the "PFD and M&EB" worksheet to Column C and Column E in the "Operational cost" worksheet. Then, insert the prices of the materials in the green boxes. Finally, the annual cost will be calculated automatically in Column J, as depicted in Table 1.

Table 1: Material costs

Material costs										
Stage	Inputs	Units	Quantity/hour	Quantity /year	Units	Conversion	Cost per unit (€/unit)		Cost/year (€/y)	
Midstream	Lignocellulose biomass	kg/h	17857.5	142860000	tons	150000	€	171.03	€	25,654,017.86
	Methonal	kg/h	1091.776523	8734212.186	tons	8734.212186	€	393.00	€	3,432,545.39
	Hydrogen	kg/h	181.1461915	1449169.532	tons	1449.169532	€	2,100.00	€	3,043,256.02

For the **operating cost**, costs are included that are not connected to the materials that are used in production. Other actions (e.g. maintenance) and resources (e.g. labour) are calculated. Some of these costs are expressed in percentage of another part of costs.

- **Column L** the other types of expenses.
- **Column M** expresses the cost in % of another cost.
- **Column N** defines the activity that the other cost is expressed of.

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- **In column O**, the annual cost of other expenses are calculated and summed up (€/year) in total operating costs.

Besides the sum up of the total material and operating cost in 'Other costs' additional costs are added such as:

- cost of selling expressed in the percentage of revenue sales,
- and sales, administrative, and R&D cost are expressed in the percentage of revenues as well.
- and royalties, accruals, provisions, depreciation, amortization, and interest expenses.

3.4. Revenues

The worksheet 'Revenues' defines the revenue flows that are generated by selling the end product. Outputs from 'PDF and M&EB" are linked to their prices calculating the annual revenues generated from the production.

- **Column B** defines the end products that generate the revenue flows.
- **Column C** defines the units in which the outputs are calculated.
- **Column D** defines quantity of materials that are produced per hour.
- **Column E** defines the outputs that are scaled-up to an annual production, calculating the annual quantity of products.
- **Column F** defines the units in which the outputs are calculated after scaling up to annual production.
- **Column G** defines quantity of materials in tons that are produced per year.
- **Column H** defines the price per unit (€/tons).
- **Column I** defines the revenues per year (€/tons) of each individual revenue flows leading to the total revenue.
- **Column L** defines the operating hours per year.

Action required: Connect the outputs (end products) and quantities from the "PFD and M&EB" worksheet to Column B and Column D in the "Revenues" worksheet. Then, insert the prices of the end products in the green boxes. Finally, the annual revenues will be calculated automatically in Column I, as depicted in Table 2:

Table 2: Revenues

Revenues							
End products	Units	Quantity/hour	Qunatity (kg)/year	Unit	Qunatity (tons) /year	Price per unit	Revenue/year
Pulp	kg /h	9182.3265	73458612	tons	73458.612	€ 404.00	€ 29,677,279.25
Oligomers	kg /h	1145.081713	9160653.707	tons	9160.653707	€ 1,750.00	€ 16,031,143.99
Monomers	kg /h	1910.755897	15286047.18	tons	15286.04718	€ 1,750.00	€ 26,750,582.56

3.5. Investment cost

The worksheet 'Investment cost' defines the initial investments that are required to establish the necessary plant, including the units, processes, and other facilities, before starting production.

For the total equipment cost several columns are defined:

- **Column B** lists three life cycle stages, upstream (processing stage), midstream (Biorefinery), and downstream (distribution, use, post-treatment, and disposal).
- **Column C** defines the equipment that is required for the plant.
- **Column D** defines the size of the units.

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- **Column E** defines the number of units that are required. Sometimes certain facilities need to be scaled up.
- **Column F** defines the costs per unit.
- **Column G** defines the total costs consisting of the price multiplied by the number of units. The sum of all costs leads to the total equipment cost.

To calculate the total investment cost, the delivered equipment cost method of Peters et al. (2006) and the pre-defined ratio factors for different direct and indirect costs that are additionally required to set up the plant/ production process. Note, the factor can be adjusted according to the structure of the technology.

- **Column I** defines different cost types.
- **Column J** defines cost components to calculate the total investment costs.
- **Column K** defines the ratio factors of the cost components that need to be added up.
- **Column E** defines the finite cost for all cost components. which are summed up in the total investment cost.

Action required: Insert the required equipment cost to calculate the total equipment cost (Table 3). For the delivered equipment cost method, adjust the percentages according to the user's project (Table 4)

Table 3: Equipment cost.

Midstream	Reactor (RCF)	€ 13,828,307.06
	Separation	€ 1,011,827.35

Table 4: Delivered equipment cost method.

Delivered equipment cost method				
Cost types	**Cost components**	**% Equipment cost**		**Cost**
	Total equipment cost		€	15,903,406.67
	Delivery allowance	**10%**	**€**	**1,590,340.67**
	Total delivered equipment cost	**100%**	**€**	**17,493,747.33**
Direct costs	Installation	39%	€	6,822,561.46
	Piping (installed)	31%	€	5,423,061.67
	Instrumentation & controll (inst)	26%	€	4,548,374.31
	Auxiliaries	10%	€	1,749,374.73
	Builings & structure (incl. services)	29%	€	5,073,186.73
	Outside Lines	12%	€	2,099,249.68
	Service facilities	55%	€	9,621,561.03

3.6 Results

The worksheet 'results' sums up the cash flow statement (Figure 3), which includes all cost, revenues, and other relevant parameters to generate the cash flows that define the chosen economic indicators.

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Sales revenue (=)
Cash operating cost **(-)**
Royalties **(-)**
Accruals **(-)**
Provisions **(-)**
EBITDA(Earning before net Income, taxes, interest expense, d
Depreciation **(-)**
Amortization **(-)**
EBIT (Earnings before interest and taxes) (=)
Interest expenses **(-)**
EBT (Earnings before taxes) (=)
Tax **(-)**
Tax credits **(+)**
Net income (=)
Deprication **(+)**
Amortization **(+)**
Accruals **(+)**
Provisions **(+)**
Interest expenses **(-/+)**
Non-operational payment/income **(-/+)**
Cash Flow from operation (before investment) (=)
Investment, Exploration (if not tax deductable) **(-)**
Net investment in working capital **(-)**
Start-up expenses **(-)**
Cash flow available to creditors/shareholders (=)
Proceeds from new debt issues **(+)**
Loan repayment **(-)**
Interest expenses (-)
Annual net cash flow available to shareholders (CF to Equity)
Discounted cash flow
Cummulative cash flow

Figure 3: Cash flow statement.

Action required: After inserting the tax rate and discount rate, the economic indicators are calculated automatically. as depicted in Figure 4.

The chosen economic indicators are displayed at the end of the cash flow statement:

Net present value (NPV for 20 years)	**€**	**(25,612,676.99)**
Discounted pay back time	**€**	**20.00**
Internal rate of return (IRR)		**9.9495%**

Figure 4: Finite economic indicators.

3.7 Sensitivity analysis

The worksheet 'Sensitivity analysis' has the purpose of identifying variables whose variation can influence the results the most.

<u>One-at-time sensitivity analysis</u>

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The first sensitivity analysis is a One-At-a-Time (OAT) sensitivity analysis. To perform a sensitivity analysis, variables are changed to a specific degree (e.g. +/- 10%), see Figure 5:

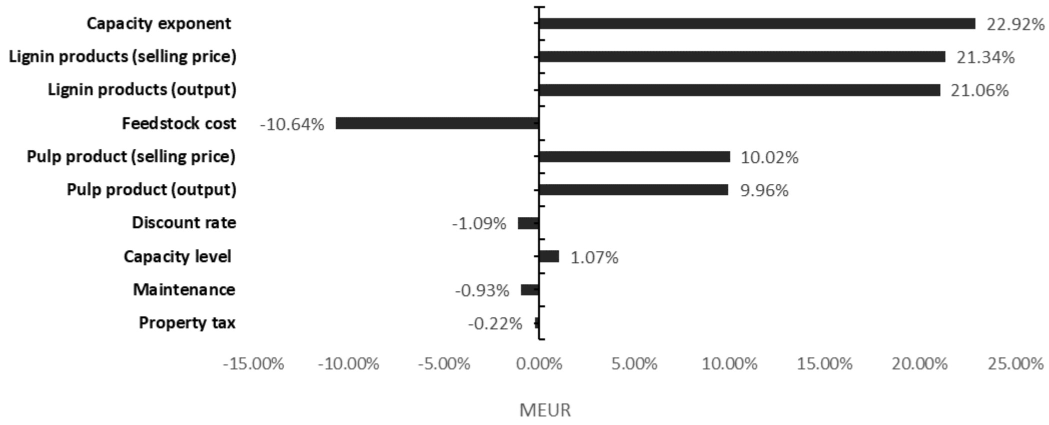

Figure 5: Tornado diagram: Most sensitive variables and their contributions to variance in NPV.

Action required: In case the user has specific insights about the sensitivity of variables, the user can adapt the ranges accordingly (.e.g. +10% and -20%).

Bi-variable sensitivity analysis

The second sensitivity analysis is a Bi-variable sensitivity analysis. It considers changes in two variables simultaneously that are plotted against each other. Figure 6 shows how the internal rate of return (IRR) changes when taxes and prices vary. in this case, the threshold of being profitable lies above a 10 % discount rate (see explanation and difference about IRR).

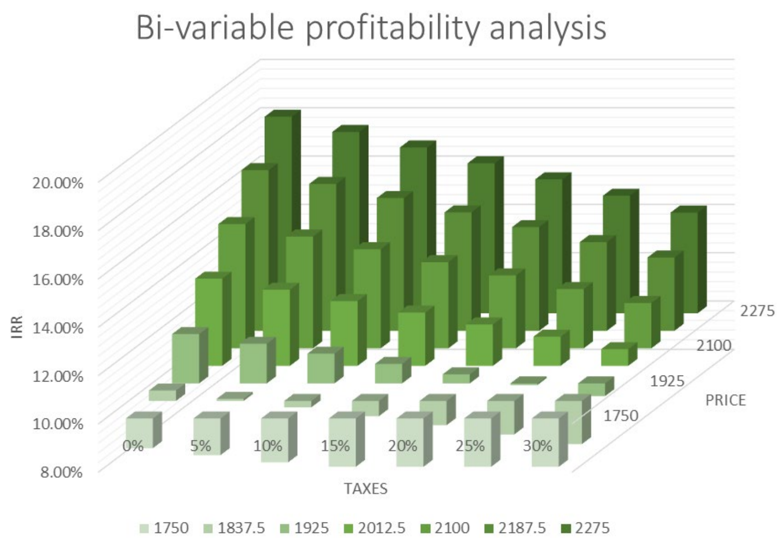

Figure 6: Bi-variable sensitivity analysis.

Action required: The user can choose different variables to be plotted against each other. also, the economic indicator can be chosen according to the ‘ needs.

Cost and revenue plot

A cost revenue plot is developed to show the user in which relation costs are to the revenues. By looking at Figure 7, the user has a quick overview of the main cost, revenues, NPV and, IRR simultaneously.

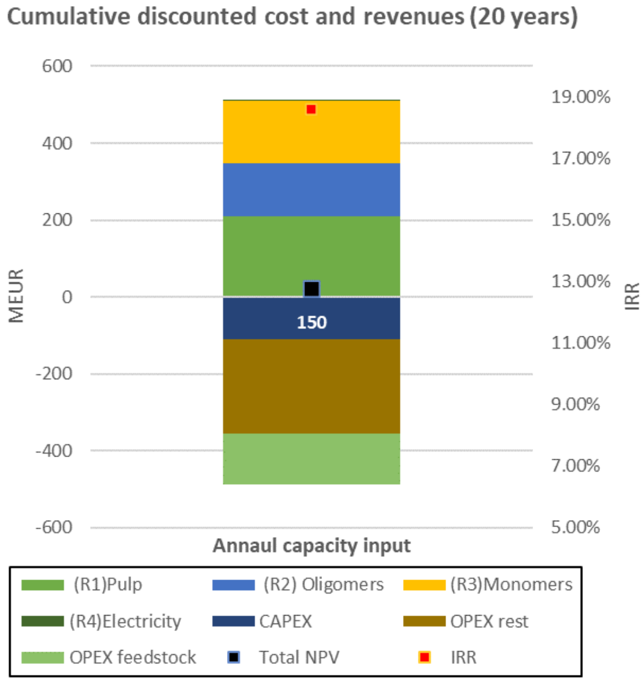

Figure 7: Cost and revenue comparison.

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