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The Importance of using Discounted Cash Flow Methodology in Techno-economic Analyses of Energy and Chemical Production Plants

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ABSTRACT

This paper demonstrates the correct application of discounted cash flow methodology for evaluating and designing energy and chemical production plants. Such processes usually correspond to capital intensive long-term projects. Simple economic criteria, like the profit or production cost are insufficient for this type of decision making because they do not take into account the time value of money and underestimate the profitabilities of the evaluated plants. This paper shows that some of those criteria based on the discounted cash flows establish suitable compromises between long-term cash flow generation and profitability. As several alternative options are usually evaluated in parallel, it is shown how to rank mutually exclusive alternatives properly and how to select the best option from among them. Two large-scale case studies demonstrate that using discounted cash flow methodology can result in substantially different decisions than non-discounted criteria, however, these decisions are affected by several input parameters.

KEYWORDS

Discounted cash flow analysis, Time value of money, Net present value, Profitability, Process.

INTRODUCTION

The economic analyses of energy and chemical production plants are usually based on the evaluations and comparisons of the capital and production costs, while the increases in companies (or the public) values over the entire lifetime are often neglected. Moreover, the profitabilities of the evaluated plants, i.e. the capability for fast turnover of invested capital, are not taken into account. Consequently, the minimization of the operating costs would produce those process solutions with slow capital return [1]. OECD predicted that “Energy sector reform will require new investment – some 46×10^{12} USD before 2050 – to improve energy efficiency, increase carbon capture and storage, deploy more renewable energy, and support new technologies” [2]. It is to be expected that potential investors in these huge projects would tend to achieve suitable profitabilities for their capital as well as a sustainable long-term cash flow generation.

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Over recent years, a lot of techno-economic studies have been performed in order to evaluate the economic and energy efficiencies, as well as the environmental impacts of energy and chemical production plants. Economic feasibility models are often developed for evaluating the attractiveness of the investment in various production facilities, such as activated carbon from waste particle boards [3]. In some countries, coal is still a very important raw material, and therefore the coal-to-olefins process was compared to the oil-to-olefin process in order to establish under what conditions the coal-based processes would be economically competitive [4]. Xiang *et al.* [5] performed a techno-economic analysis of the coal-to-olefins process with and without Carbon dioxide (CO_2) capture, and the methanol-to-olefins process. They compared the capital investment and the production costs, and established the effects of the capacity, CO_2 tax and raw material prices. Techno-economic analyses of two processes for CO_2 capture and utilization, i.e. methanol synthesis and CO_2 mineralization, showed that the second option was more advantageous in terms of energy consumption and CO_2 emissions, while the first one was in economic terms [6]. Biomass-based fuel production was evaluated for the minimum fuel selling price that would make the net present value equal to zero. It was established that such a fuel is not yet competitive with oil-based equivalent products [7].

The coproduction of energy and chemicals is a very interesting option for improving economic potential and decreasing the environmental impacts. Evaluation of the electricity and Hydrogen (H_2) coproduction from coal and biomass mixtures within Integrated Gasification Combined Cycle (IGCC) plants including CO_2 Capture and Storage (CCS) revealed the calculated cost of H_2 at below 3 USD/kg, which would be acceptable [8]. Several coal gasification processes were compared, and the CO_2 tax rates were established at which CO_2 capture and utilization would become economically attractive regarding the production cost [9]. An interesting option for utilizing CO_2 was presented by Man *et al.* [10], who proposed a novel process in which CO_2 from coal gasification reacts with the methane from the coke-oven forming the syngas for olefins production. While the capital investment and CO_2 footprint of the proposed process are significantly lower than the conventional olefin process, its production cost is somewhat higher. A cash flow analysis was applied for determining a selling price of biodiesel produced from algae yielding a good value of 1.1465 USD/L (4.34 USD/gal) [11]. An municipal solid waste project was optimized by maximizing the surplus of the revenue over the cost [12]. CO_2 utilization for dimethyl carbonate production was evaluated in terms of energy consumption, CO_2 emission, global warming potential and human toxicity-carcinogenic [13]. A new application to waste glycerol was studied by producing polyesters yielding competitive production cost in comparison to the market prices [14].

Many of the above cited papers applied simplified economic figures without taking into account the inherent time value of money. This basic financial principle can be simply described as “a dollar today is worth more than a dollar tomorrow” [15]. The discounted cash-flow methodology takes into account this principle by discounting all future cash flows to the present value at a selected point in time. The most popular economic criteria based on the discounted cash flow analysis are the Net Present Value (NPV) and the Internal Rate of Return (IRR). While the former measures the long-term capability of the economic value creation, the latter represents a relative measure of the capital’s efficiency or profitability. The investors and designers would tend to achieve the best of both.

When evaluating a single process alternative, NPV and IRR provide useful information about its economic potential. However, when several options are assessed in order to finally select one of them, both criteria can lead to different conclusions. It was demonstrated that IRR is inappropriate for selecting between mutually exclusive alternatives as it does not take into account the level of investment directly but rather favors low ratio between the investment level and cash flows [16]. IRR is more appropriate for short-term projects because it does not stimulate a growth of the company over the long-term by a sustainable cash flow generation, but rather forces speculative quick payback projects. On the other hand, the NPV increases a company‘s value over the long-term at somewhat lower rate of return but provides suitable trade-offs between the profitability, operational efficiency, and environmental performance [17].

The literature survey revealed that large-scale long-term projects for energy and chemicals production are often evaluated through the capital and production costs only. The importance of the discounted cash flow analysis is often overlooked. The intention of this paper is to fill this gap by demonstrating the proper evaluation of projects through discounted cash flow analysis, correct selection between mutually exclusive projects, and the influences of input parameters like the tax rate, discount rate, and CO_2 tax on decision-making within the economic evaluations of projects. Detailed calculations of practical examples are provided, enabling the readers to clearly follow the calculations, which is often missing in other papers.

Multi-criteria evaluations of various process options are useful for assessing their performance from several points of view [18], however, a more general tool for the final selection of an optimum alternative needs to be provided. This paper will emphasize a less known fact that suitable compromises between the long-term value generation and profitability can be established by using some specific economic criteria based on the discounted cash flows. The use of these criteria should be promoted within the scientific community. Alternative formulations of NPV are introduced like annualized net present value and value growth per unit of product, in order to enable a clearer interpretation of the net present value, which would be more convenient for process engineers.

DISCOUNTED CASH FLOW ANALYSIS

The discounted cash flow analysis is based on the concept of discounting, which introduces the time value of money, meaning that earlier cash flows are worth more to investors than the later ones. The mathematical operation of discounting is inverse to compounding [15], and can be expressed by eq. (1) which represents the present value of the cash flow anticipated at the end of year *i*:

$$V_{\mathrm{P}} = \frac{F_{\mathrm{C},i}}{(1+r_{\mathrm{d}})^{i}} \tag{1}$$

where V_{P} is the present value (EUR) of the cash flow $F_{\mathrm{C},i}$ (EUR/y) at the end of year i, r_{d} discount rate, and i the number of years from the selected origin in time. The cash flow is calculated by eq. (2):

$$F_{\mathrm{C}} = (1-r_{\mathrm{t}})\cdot(R-E)+r_{\mathrm{t}}\cdot D \tag{2}$$

where F_{C} is the cash flow (EUR/y), r_{t} the tax rate (-), R the revenues (EUR/y), E the expenditures (EUR/y) like fixed and variable production costs, and D is annual depreciation (EUR/y). The latter is calculated based on fixed capital investment, by usually applying a straight-line method.

The total capital investment is the sum of the fixed capital and the working capital. During a preliminary analysis, fixed capital is evaluated based on the purchase prices of process units which are then multiplied by special factors, the so-called Lang factors [19], in order to estimate the fixed capital investment including the installation cost, indirect cost (engineering and construction), and contractor’s fee and contingency. The typical values of the Lang factors could be assumed at around 3.1 for plants processing mostly solids, 3.6 for processing solids and fluids, and 4.7 when processing only fluids [20].

Working capital includes inventories of raw material, products, spare parts, in-process inventories, and cash and accounts receivable, and can be roughly estimated at 15% to 20% of the fixed capital investment [20], which corresponds to 13%-17% of the total capital.

The most typical discounted-cash-flow-based economic criteria for alternatives evaluation are the net present value and the internal rate of return. NPV is the sum of all discounted cash flows of the project including the positive and negative cash flows as well as the discrete and continuous cash flows throughout the entire life-cycle of the project:

$$V_{\mathrm{NP}} = -I_{\mathrm{T}} + \sum_{i=1}^{n} \frac{F_{\mathrm{C},i}}{(1+r_{\mathrm{d}})^{i}} \tag{3}$$

where V_{NP} is the net present value (EUR), I_{T} is the total capital cost (EUR), and n the project's lifetime (y). Assuming constant cash flows from the operation during the entire lifetime, the NPV can be expressed as:

$$V_{\mathrm{NP}} = -I_{\mathrm{T}} + f_{\mathrm{PA}} \cdot F_{\mathrm{C}} + \frac{I_{\mathrm{W}} + I_{\mathrm{F,salv}}}{(1+r_{\mathrm{d}})^{n}} \tag{4}$$

where I_{W} is the working capital (EUR), $I_{\mathrm{F,salv}}$ is the salvage value of the fixed capital (EUR), and f_{PA} is the present value annuity factor:

$$f_{\mathrm{PA}} = \frac{(1+r_{\mathrm{d}})^{n} - 1}{r_{\mathrm{d}} \cdot (1+r_{\mathrm{d}})^{n}} \tag{5}$$

IRR is defined as the discount rate at which the NPV becomes 0:

$$0 = -I_{\mathrm{T}} + f_{\mathrm{PA}} \cdot F_{\mathrm{C}} + \frac{I_{\mathrm{W}} + I_{\mathrm{F,salv}}}{(1+r_{\mathrm{d}})^{n}} \tag{6}$$

Eq. (5) for f_{PA} is inserted within eq. (6), resulting in the expression:

$$0 = -I_{\mathrm{T}} + \frac{(1+r_{\mathrm{IRR}})^{n} - 1}{r_{\mathrm{IRR}} \cdot (1+r_{\mathrm{IRR}})^{n}} \cdot F_{\mathrm{C}} + \frac{I_{\mathrm{W}} + I_{\mathrm{F,salv}}}{(1+r_{\mathrm{IRR}})^{n}} \tag{7}$$

The IRR of the project ($r_{\mathrm{d}} = r_{\mathrm{IRR}}$) is calculated iteratively from eq. (7).

The interpretations of NPV and IRR can be somewhat ambiguous. The NPV is an absolute measure the magnitude of which does not provide very useful information when evaluating a single project, with the exception of its positive or negative sign. The IRR is a relative measure which expresses the ratio between the cash flow and investment, and favors low investment projects.

These indicators based on the annualized monetary figures are easier to interpret and therefore, the criteria like the equivalent annual cost or annualized NPV can also be applied. The annualized Net Present Value (NPV$_{\mathrm{an}}$) is defined as the NPV of the project divided by the present value factor, eq. (8), and represents those equivalent annual cash flows that yield the total present value equal to V_{NP}:

$$V_{\mathrm{NP,an}} = \frac{V_{\mathrm{NP}}}{f_{\mathrm{PA}}} \tag{8}$$

where $V_{\mathrm{NP,an}}$ is the annualized net present value (EUR/y). The equivalent annual total cost is then the negative of the annualized net present value. The annualized net present value has a similar interpretation to that of the annual profit, yet considers the time value of money.

The annualized net present value can be further distributed over the annual production, thus yielding a company's value growth per unit of product ($\mathrm{NPV_{prod}}$):

$$V_{\mathrm{NP,prod}} = \frac{V_{\mathrm{NP}}}{f_{\mathrm{PA}} \cdot p_{\mathrm{r}}} \tag{9}$$

where $V_{\mathrm{NP,prod}}$ is the value growth per unit of product (EUR/kg or EUR/kWh), and p_{r} is the annual production rate (kg/y or kWh/y). The NPV per unit of a product can be compared to product's selling price: the higher the ratio between the two, the higher the value growth per unit of sales turnover.

SELECTION BETWEEN MUTUALLY EXCLUSIVE ALTERNATIVES

The most common type of decision-making in engineering practice is a selection between mutually exclusive alternatives, where exactly one (or none) alternative should be selected. A typical dilemma in such cases is whether it is economically justifiable to select a more expensive alternative or, alternatively, select the one with the lower total capital cost. The profit and the total annual cost are often used in practice for this purpose, however, they are accounting figures which are not based on the discounted cash flows, and favor designs with high investment and high cash flows but low profitabilities and slow turnovers [1].

The incremental criteria based on discounted cash flows should be used for selecting between mutually exclusive alternatives. These criteria are defined by using differences in economic categories between the more and less expensive alternatives. For example, the incremental NPV is defined as:

$$\Delta V_{\mathrm{NP}} = -\Delta I_{\mathrm{T}} + f_{\mathrm{PA}} \cdot \Delta F_{\mathrm{C}} + \frac{\Delta\left(I_{\mathrm{W}} + I_{\mathrm{F,salv}}\right)}{(1+r_{\mathrm{d}})^{n}} \tag{10}$$

where ΔV_{NP} represents the incremental net present value, ΔI_{T} is the difference between the total capital costs of more and less expensive alternatives, and ΔF_{C} is the cash flow difference. The more expensive alternative should be selected if its individual NPV is positive and the incremental NPV is larger than or equal to 0.

Similarly, the incremental IRR (Δr_{IRR}) is calculated from eq. (11):

$$0 = -\Delta I_{\mathrm{T}} + \frac{(1+\Delta r_{\mathrm{IRR}})^{n} - 1}{\Delta r_{\mathrm{IRR}} \cdot (1+\Delta r_{\mathrm{IRR}})^{n}} \cdot \Delta F_{\mathrm{C}} + \frac{\Delta\left(I_{\mathrm{W}} + I_{\mathrm{F,salv}}\right)}{(1+\Delta r_{\mathrm{IRR}})^{n}} \tag{11}$$

A more expensive alternative should be selected if it's individual IRR ≥ MARR and if the incremental IRR ≥ MARR, where MARR stands for the minimum acceptable rate of return determined by the management. If more than two alternatives are evaluated, they should be ordered by increasing capital investment and evaluated regarding the incremental NPV or IRR in pairs from the least expensive alternatives onward. The winner from each pair is then compared to the next alternative in the sequence, and so on.

Note that both individual and incremental NPVs can be used for proper selection between mutually exclusive alternatives. Selection of the alternative with the highest individual NPV would produce the same result as the incremental NPV criterion larger than or equal to 0. Individual and incremental IRRs, however, could produce different results. The criterion of the highest individual IRR would select the alternative with the highest ratio of cash flow vs. capital cost. On the other hand, the condition for incremental IRR ≥ MARR would lead to the same choice as the maximum individual NPV and incremental NPV ≥ 0 [15]. The investment levels and cash flows in this case would be usually higher than that of the maximum IRR solution. Table 1 summarizes the correctness of various criteria for evaluating a single alternative as well as selecting between mutually exclusive alternatives.

Table 1. Different economic criteria for single- and mutually exclusive alternatives

Economic criteria	Evaluation of single alternative	Selection between mutually exclusive alternatives
Profit	Useful in practice (incorrect for investment decision making)	Useful in practice (incorrect for investment decision making)
Total annual cost	Useful in practice (incorrect for investment decision making)	Useful in practice (incorrect for investment decision making)
NPV	Should be ≥ 0 at selected discount rate	Select the alternative with the highest NPV
IRR	Should be ≥ MARR	Inappropriate
Annualized NPV	Should be ≥ 0 at selected discount rate	Select the alternative with the highest value
Equivalent annual cost	Should be as low as possible	Select the alternative with the lowest value
Incremental NPV	n.a.	If incremental NPV ≥ 0 select more expensive alternative
Incremental IRR	n.a.	If incremental IRR ≥ MARR select more expensive alternative

DISCOUNTED CASH FLOW ANALYSIS CASE STUDIES

This section presents two process case studies that illustrate the importance of performing thorough economic assessments based on the discounted cash flow analysis when evaluating processes for the production of energy and chemicals.

Case study 1. Coal to olefins vs. Oil to olefins

The first example is taken from Xiang *et al.* [3], who made a comparison of two processes: Coal To Olefins (CTO) with a capacity of 0.7 Mt/y, and Oil To Olefins (OTO) with a capacity of 1.5 Mt/y. In a CTO process, coal is gasified, following by methanol synthesis, and olefin synthesis. An OTO process involves naphtha cracking, quenching of cracking gas, separating gasoline and fuel oil, gas washing and drying, and final separation of olefins. The CO_2 emission of OTO process is significantly lower than the CTO process, however, many countries have large reserves of coal but scarce resources of oil. It is therefore expected that coal would be the important raw material for the production of energy and chemicals during the following decades.

It could be derived from the original literature [3] that the CTO process has considerably lower production cost due to the low coal price, however, the investment in this process is significantly higher than the OTO process. Table 2 presents the main economic figures obtained from the cited reference. The exchange ratio 0.1212667 EUR/CNY was used to convert the yuan to EUR.

Table 2. Data for economic evaluation derived from literature [3] (case study 1)

Economic figure	CTO (0.7 Mt/y)	OTO (1.5 Mt/y)
Capacity [Mt/y]	0.7	1.5
Total capital investment [EUR/(t/y)]	3,055.92	1,033.92
Total capital investment [M EUR]	2,139.14	1,550.88
Working capital [M EUR]	307.24	222.75
Fixed capital [M EUR]	1,831.91	1,328.13
Production cost incl. depreciation [EUR/t]	786.54	1,133.84
Annual production cost incl. depreciation [M EUR/y]	550.58	1,700.77

Discounted cash flow analysis. Based on the information in Table 2, a thorough economic assessment based on the discounted cash flow analysis is performed assuming an average price of the olefins 1,250 EUR/t. This study reveals:

- The revenue from selling the olefins amounts to 875 M EUR/y for the CTO process, and 1,875 M EUR/y for the OTO process (Table 3);
- The depreciation is calculated based on the fixed capital cost assuming 4% salvage value and 20 years depreciation period, as follows for the CTO process:

$$D = \frac{1{,}831.91 \cdot (1-0.04)}{20} = 87.93\ \frac{\text{M€}}{\text{y}} \tag{12}$$

Table 3. Calculated economic figures for CTO and OTO processes

Economic figure	CTO (0.7 Mt/y)	OTO (1.5 Mt/y)
Revenue [M EUR/y]	875.00	1,875.00
Depreciation [M EUR/y]	87.93	63.75
Cash flow [M EUR/y]	347.47	203.14
NPV [M EUR]	875.64	219.56
NPV_{an} [M EUR/y]	102.85	25.79
NPV_{prod} [EUR/t]	146.92	17.19
IRR [%]	15.49	11.95

Similarly, the depreciation of OTO process is obtained at 63.75 M EUR/y.

- The cash flow is calculated assuming a 20% profit tax rate (corporate income tax rate) for the CTO process:

$$F_{\text{C}} = (1-0.2)\cdot(875-(550.58-87.93))+0.2\cdot 87.93 = 347.47\ \text{M€/y} \tag{13}$$

In a similar way, the cash flow of the OTO process is estimated to be 203.14 M EUR/y, as shown in Table 3.

- Assuming a 20 years lifetime and 10% discount rate, the present value annuity factor is 8.5136. The NPV of the CTO process is calculated as:

$$V_{\text{NP}} = -2{,}139.14 + 8.5136 \cdot 347.47 + \frac{307.24 + 1{,}831.91 \cdot 0.04}{1.1^{20}} = 875.64\ \text{M€} \tag{14}$$

In a similar way, the NPV of the OTO process is calculated at 219.56 M EUR.

- The IRR of the CTO process is calculated to be 15.49%, and of the OTO process 11.95%, while the incremental IRR of the difference (CTO-OTO) is 24.27%.

Based on the results in Table 3, it could be concluded that the CTO process at 1.38-times higher total capital cost and half of production capacity compared to the OTO process generates about 1.7-times higher cash flow which results in 4 times higher net present value. Both IRRs are higher than 10%, however, the incremental IRR of the CTO minus the OTO process is considerably higher than 10%, i.e. 24.27%, indicating that the selection of a more expensive CTO process would be economically favorable over the OTO process, not only with regard to the NPV criterion but also regarding the IRR criterion.

The ratio between NPV_{prod} and the selling price of olefins (1,250 EUR/t) is 0.1175 for CTO process and 0.0137 for OTO process, which also confirms the higher value growth in the case of CTO process. The break-even price of olefin which gives NPV equal to zero is 1,066 EUR/t for the CTO process, and 1,228.5 EUR/t for the OTO process, which indicates less sensitivity of the CTO process to reduction of product's price.

The influence of capacity variations. The influence of variations in production capacities on both processes is studied based on the data in the original paper [3]. Figure 1 shows that the NPV of the CTO process would be positive at all capacities within the studied range from 0.3 Mt/y to 2 Mt/y, while the NPV of the OTO process would become positive only above the production rates of 1.1 Mt/y.

The curves in Figure 1 are obtained at a 10% discount rate. At higher discount rates, however, break-even capacities would occur at higher capacities, for example, at 0.58 Mt/y for the CTO process when using 14% discount rate, while the NPV of the OTO process would remain negative over the entire range of the studied capacities from 0.3 Mt/y to 2 Mt/y.

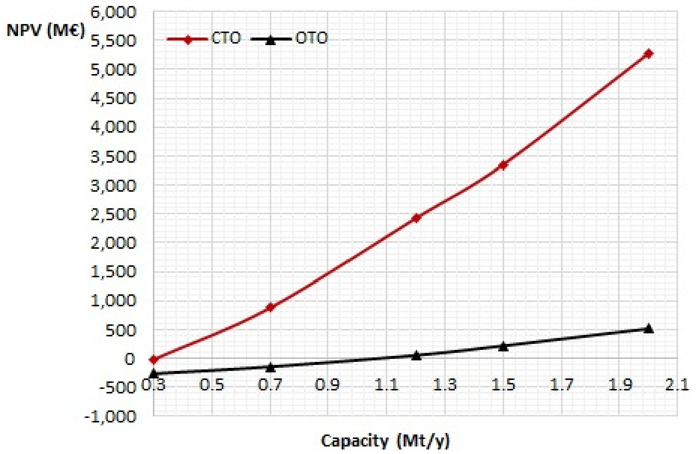

Figure 1. NPV of CTO and OTO processes at different capacities (no CO_2 tax)

The influence of CO_2 tax. The NPV analysis is repeated by including CO_2 tax into the operating cost. Xiang *et al.* [3] reported that the CTO process emits 4.05 Mt CO_2 per year, and the OTP process 1.55 Mt/y. Assuming a CO_2 tax rate of 20 EUR/t, the annual CO_2 tax amounts to 81 M EUR/y for the CTO process with a capacity of 0.7 M EUR/y, and 31 M EUR/y for the OTO process with a capacity of 1.5 MT/y. These taxes also reduce the final cash flows yielding lower NPVs, i.e. 323.5 M EUR for the CTO and 9.5 M EUR for the OTO process. The NPV of the CTO process would remain positive at CO_2 taxes up to 32 EUR/t, while the NPV of the OTO process, despite the lower CO_2 emission, only up to 21 EUR/t (Figure 2).

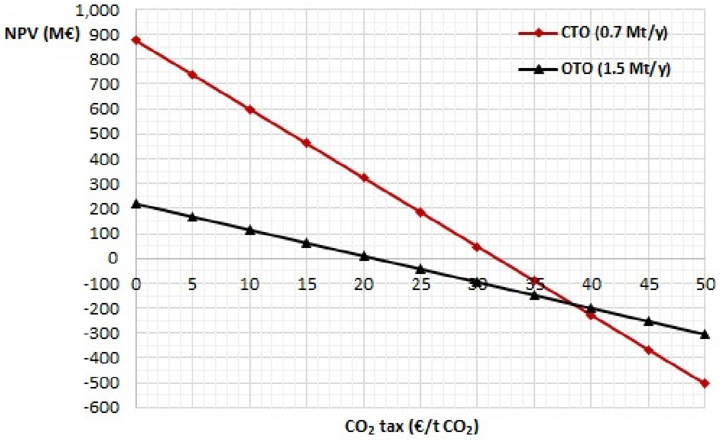

Figure 2. NPV of CTO and OTO processes at different CO_2 tax rates

The inclusion of CO_2 tax also affects the relation between the NPV and the production capacity. Figure 3 presents the situation at a CO_2 tax rate of 20 EUR/t. The NPV of the CTO process would become positive at an annual production rate of 0.5 Mt/y, while the OTO process would be at 1.5 M EUR/y. It could be concluded, that the production of olefins from coal would be economically more viable than from oil because of lower production cost as a result of lower raw material price.

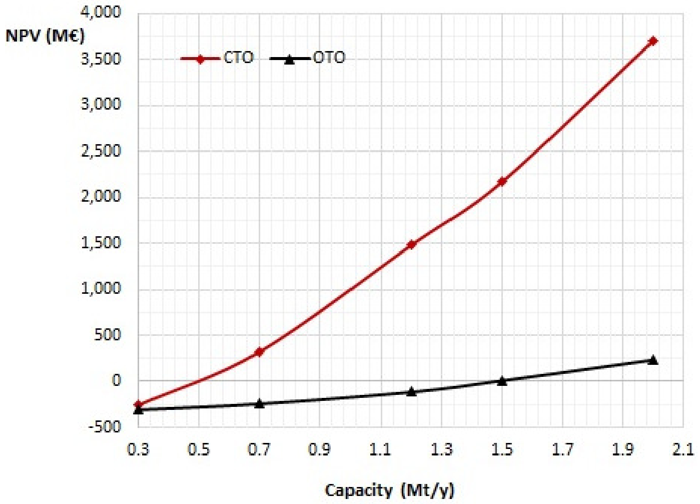

Figure 3. NPV of CTO and OTO processes at different capacities (20 EUR/t CO_2 tax)

Case study 2. Gas assisted coal to olefins

A coal-based production of olefins with feed-in coke-oven gas is taken as a next demonstration case [10]. This case study presents an integrated systems in which CO_2 capture technologies are combined with the production of chemicals, thus representing a very promising option for CO_2 footprint reduction.

In this process coal is gasified in order to produce crude syngas from which sulphur and CO_2 are removed by Acid Gas Removal Technology (AGR). The separated CO_2 is sent to a Dry Methane Reforming unit (DMR) where it reacts with the methane which was separated from the coke-oven gas, thus producing syngas. This process also includes a Steam Methane Reforming unit (SMR) in which methane reacts with steam producing a syngas with a high ratio of H/C. By mixing the syngas streams from the AGR, DMR and SMR units, an appropriate inlet stream could be obtained for methanol synthesis with a required H/C ratio of around 2.1. The lifecycle CO_2 emission of such a process was estimated to be around 85% lower compared to the conventional coal-based olefin production. The capacity of olefins production is 600,000 t/y on both processes.

In the economic analysis, the authors of the original paper [10] determined the total capital cost and the production cost of the proposed coke-oven gas assisted coal to olefins (GaCTO) process, and compared these figures to the conventional CTO process. Table 4 presents the main economic figures obtained from the cited reference. The exchange ratio 0.121226 EUR/CNY is used, salvage value of fixed capital is assumed to be 0.

Table 4. Data for economic evaluation derived from literature [10] (case study 2)

Economic figure	CTO	GaCTO
Total capital investment [M EUR]	2,133.58	1,503.20
Working capital [M EUR]	306.44	215.90
Fixed capital [M EUR]	1,827.14	1,287.30
Depreciation [M EUR/y]	91.36	64.37
Production cost incl. depreciation [EUR/t]	763.72	866.77
Annual production cost incl. depreciation [M EUR/y]	458.23	520.06

From the results in Table 4, the authors concluded that the proposed GaCTO process has lower total capital cost but higher production costs, however, if the CO_2 tax were to be introduced at a rate of around 18 EUR/t (150 CNY/t) this novel process would be superior over the traditional process regarding the costs.

Discounted cash flow analysis. The results from the discounted cash flow analysis are presented in Table 5 assuming 20 years lifetime and 10% discount rate. The internal rate of return of the CTO process amounts to 14.32%, and of the GaCTO process to 15.76%, while the incremental IRR of the difference (CTO-GaCTO) is 10.76%.

Table 5. Calculated economic figures for the CTO and GaCTO processes

Economic figure	CTO	GaCTO
Cash flow [M EUR/y]	324.78	248.32
NPV [M EUR]	676.98	642.96
NPV_{an} [M EUR/y]	79.51	75.52
NPV_{prod} [EUR/t]	132.52	125.87
IRR [%]	14.32	15.76

It could be concluded that at 20% profit tax rate and 10% discount rate, the NPVs of both processes would be highly positive, however, the NPV of the CTO process is higher than the GaCTO. In contrast, the IRR of the conventional CTO process is lower than the GaCTO process. This implies that the NPV and IRR criteria would result in a different ranking of the alternative options.

Anyway, considering that individual IRR is an inappropriate measure for selection between mutually exclusive alternatives, the process with the higher NPV should be selected, that is the more expensive CTO process which still has a satisfactory profitability, i.e. IRR (14.32%) higher than MARR (10%). This is in compliance with the value of the incremental IRR = 10.76% which is also higher than 10%, indicating that selection of the more expensive process CTO is economically justified.

The influence of discount rate. As was shown in the previous section, the CTO process would be preferable at 10% discount rate. If stricter discount rates were requested because of higher risk, for example, the GaCTO process would be economically superior over the conventional one at discount rates above 11% (Figure 4). However, the NPVs of the CTO and GaCTO processes would become negative above 14% and 16%, respectively. This indicates how sensitive the outcomes of the decision-making process would be to input parameters used during the economic evaluations.

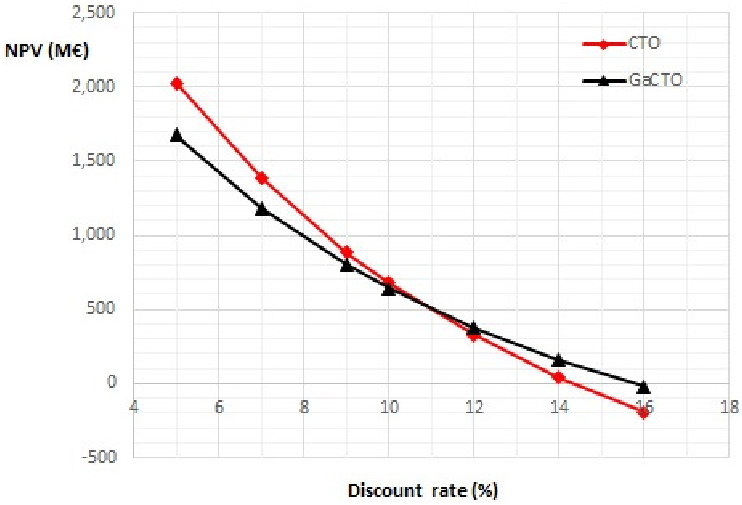

Figure 4. The effect of the discount rate on the NPV

The influence of the profit tax rate. The effect of the corporate tax rate is shown in Figure 5 at a constant discount rate 10%. It follows that at tax rates below 27% the conventional CTO process would be preferable, however, in those countries with higher tax rates the new GaCTO process would be better.

If lower discount rates were used, the CTO would be preferable even at higher tax rates. For example, by using 8% discount rate, the CTO process would have higher NPV than the GaCTO up to tax rates of 43%. On the other hand, at 14% discount rate, the GaCTO would be better at any tax rate.

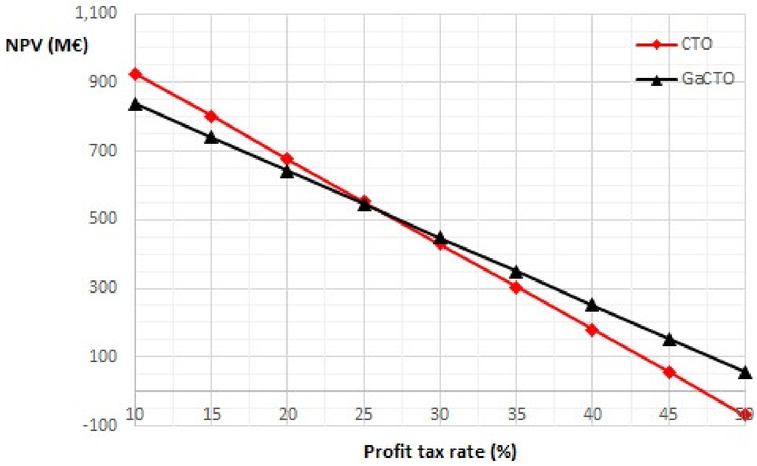

Figure 5. The effect of the profit tax rate on the NPV

The influence of CO_2 tax rate. The authors in their paper [10] also studied the influences of CO_2 tax, and found out that at values below 18 EUR/t CO_2 (150 CNY/t) the conventional CTO process would be preferable regarding the production cost, while above that value the GaCTO process. In this paper the analysis is performed using the NPV criterion at 10% discount rate and 20% tax rate which reveals that the GaCTO process would already become preferable at a CO_2 tax of around 2 EUR/t (Figure 6). However, if the discount rate were to approach zero, the break-even CO_2 tax rate would approach 18 EUR/t. At the very high profit tax rates, e.g. 40%, the new process GaCTO would be preferred over the CTO process at all CO_2 tax values.

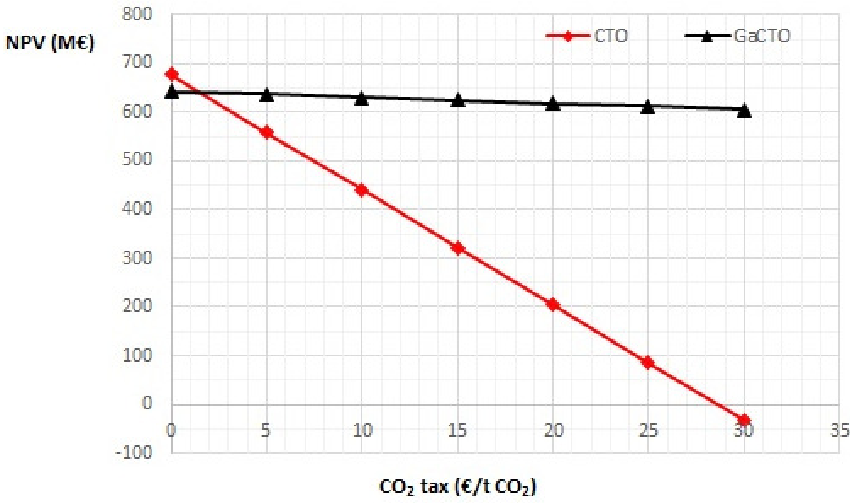

Figure 6. The effect of the CO_2 tax on the NPV

It also follows from Figure 6, that the NPV of the GaCTO process is much less sensitive to the CO_2 tax rate, and remains positive even at high values because of significantly lower CO_2 emission. In contrast, the NPV of the CTO process decreases rapidly, and becomes negative above the CO_2 tax of 28.5 EUR/t CO_2.

CONCLUSIONS

This paper highlighted the importance of using discounted cash flow methodology during the economic evaluations of capital-intensive long-term projects for energy and chemical production. Many important and useful information for decision making can be extracted from those economic analyses based on the discounted cash flows.

It was shown that evaluating capital and production cost provides insufficient information for long-term decision making. Those economic criteria based on the discounted cash flow methodology, like the NPV criterion, assure proper selection between mutually exclusive projects, and provide compromise process solutions with stable long-term value generation at suitable profitability. The processes for energy and chemical production, potentially also including CO_2 capture technologies, present capital intensive long-term projects, where the investors cannot expect short payback times and quick turn-overs. Investors of "patient" capital should be willing to accept lower returns and longer payback periods, yet still at suitable profitability. These types of process designs can be produced when using proper economic decision criteria based on the discounted cash flow methodology. Although some additional input parameters would be required that can be a subject of a specific level of uncertainty and variability, e. g. discount and tax rates, these criteria should be used systematically for evaluating energy and chemical production plants.

NOMENCLATURE

D	depreciation	[EUR/y]
E	expenditures	[EUR/y]

F_C	cash flow	[EUR/y]
f_{PA}	present value annuity factor	[y]
i	index of years	[-]
I_F	fixed capital investment	[EUR]
$I_{F,salv}$	salvage value of fixed capital investment	[EUR]
I_T	total capital investment	[EUR]
I_W	working capital investment	[EUR]
n	project lifetime	[y]
p_r	production rate	[kg/y]
R	revenue	[EUR/y]
r_d	discount rate	[-]
r_t	corporate tax rate	[-]
V_{NP}	net present value	[EUR]
$V_{NP,an}$	annualized net present value	[EUR/y]
$V_{NP,prod}$	net present value per unit of product	[EUR/kg]
V_P	present value	[EUR]

Greek letters

Δ	difference, incremental

Abbreviations

CNY	Chinese Yuan
CTO	Coal-To-Olefins
GaCTO	Coke-Oven Gas Assisted Coal-To-Olefins Process
IRR	Internal Rate of Return
MARR	Minimum Attractive Rate of Return
NPV	Net Present Value
OTO	Oil-To-Olefins

REFERENCES

1. Kasaš, M., Kravanja, Z. and Novak Pintarič, Z., The Effect of Economic Objective Function on Economic, Operational and Environmental Performance of Optimal Chemical Processes, *Chemical Engineering Transactions*, Vol. 21, pp 1435-1440, 2010.
2. OECD, Environment: Transforming the Energy Sector to deliver Greener Growth, www.oecd.org/newsroom/environmenttransformingtheenergysectortodelivergreenergrowth.htm, 2011, [Accessed: 24-June-2016]
3. Vanreppelen, K., Schreurs, S., Kuppens, T., Thewys, T., Carleer, R. and Yperman, T., Activated Carbon by Co-pyrolysis and Steam Activation from Particle Board and Melamine Formaldehyde Resin: Production, Adsorption Properties and Techno Economic Evaluation, *Journal of Sustainable Development of Energy, Water and Environment Systems*, Vol. 1, No. 1, pp 41-57, 2013, http://dx.doi.org/10.13044/j.sdewes.2013.01.0004
4. Xiang, D., Qian, Y., Man, Y. and Yang, S., Techno-economic Analysis of the Coal-to-olefins Process in Comparison with the Oil-to-olefins Process, *Applied Energy*, Vol. 113, pp 639-647, 2014, http://dx.doi.org/10.1016/j.apenergy.2013.08.013
5. Xiang, D., Yang, S., Liu, X., Mai, Z. and Qian, Y., Techno-economic Performance of the Coal-to-olefins Process with CCS, *Chemical Engineering Journal*, Vol. 240, pp 45-54, 2014, http://dx.doi.org/10.1016/j.cej.2013.11.051
6. Perez-Fortes, M., Bocin-Dumitriu, A. and Tzimas, E., Techno-Economic Assessment of Carbon Utilisation Potential in Europe, *Chemical Engineering Transactions*, Vol. 39, pp 1453-1458, 2014.

7. Zhu, Y., Biddy, M. J., Jones, S. B., Elliott, D. C. and Schmidt, A. J., Techno-economic Analysis of Liquid Fuel Production from Woody Biomass via Hydrothermal Liquefaction (HTL) and Upgrading, *Applied Energy*, Vol. 129, pp 384-394, 2014, http://dx.doi.org/10.1016/j.apenergy.2014.03.053
8. Chen, Q., Rao, A. and Samuelsen, S., H2 Coproduction in IGCC with CCS via Coal and Biomass Mixture using Advanced Technologies, *Applied Energy*, Vol. 118, pp 258-270, 2014, http://dx.doi.org/10.1016/j.apenergy.2013.12.051
9. Man, Y., Yang, S., Xiang, D., Li, X. and Qian, Y., Environmental Impact and Techno-economic Analysis of the Coal Gasification Process with/without CO_2 Capture, *Journal of Cleaner Production*, Vol. 71, pp 59-66, 2014, http://dx.doi.org/10.1016/j.jclepro.2013.12.086
10. Man, Y., Yang, S., Zhang, J. and Qian, Y., Conceptual Design of Coke-oven Gas Assisted Coal to Olefins Process for High Energy Efficiency and Low CO_2 Emission, *Applied Energy*, Vol. 133, pp 197-205, 2014, http://dx.doi.org/10.1016/j.apenergy.2014.07.105
11. Silva, C., Soliman, E., Cameron, G., Fabiano, L. A., Seider, W. D., Dunlop, E. H. and Coaldrake, A. K., Commercial-Scale Biodiesel Production from Algae, *Industrial & Engineering Chemistry Research*, Vol. 53, No. 13, pp 5311-5324, 2014, http://dx.doi.org/10.1021/ie403273b
12. Ng, W. P. Q., Varbanov, P. S., Klemes, J. J., Hegyhati, M., Bertok, B., Heckl, I. and Lam, H. L., Waste to Energy for Small Cities: Economics versus Carbon Footprint, *Chemical Engineering Transactions*, Vol. 35, pp 889-894, 2013.
13. Kongpanna, P., Pavarajarn, V., Gani, R. and Assabumrungrat, S., Techno-economic Evaluation of different CO_2-based Processes for Dimethyl Carbonate Production, *Chemical Engineering Research & Design*, Vol. 93, pp 496-510, 2015, http://dx.doi.org/10.1016/j.cherd.2014.07.013
14. Bueno, L., Toro, C. and Martin, M., Techno-economic Evaluation of the Production of Polyesters from Glycerol and Adipic Acid, *Chemical Engineering Research & Design*, Vol. 93, pp 432-440, 2015, http://dx.doi.org/10.1016/j.cherd.2014.05.010
15. Brealey, R. A., Myers, S. C. and Marcus, A. J., *Fundamentals of Corporate Finance*, McGraw-Hill/Irwin, New York, NY, USA, 2009.
16. Novak Pintarič, Z. and Kravanja, Z., The Importance of Proper Economic Criteria and Process Modeling for Single- and Multi-objective Optimizations, *Computers & Chemical Engineering*, Vol. 83, pp 35-47, 2015, http://dx.doi.org/10.1016/j.compchemeng.2015.02.008
17. Kasaš, M., Novak Pintarič, Z. and Kravanja, Z., Achieving Profitably, Operationally, and Environmentally Compromise Flow-sheet Designs by a Single-criterion Optimization, *AICHE Journal*, Vol. 58, No. 7, pp 2131-2141, 2012, http://dx.doi.org/10.1002/aic.12747
18. Koziol, J. and Mendecka, B., Evaluation of Economic, Energy-environmental and Sociological Effects of Substituting Non-renewable Energy with Renewable Energy Sources, *Journal of Sustainable Development of Energy, Water and Environment Systems*, Vol. 3, No. 4, pp 333-343, 2015, http://dx.doi.org/10.13044/j.sdewes.2015.03.0025
19. Brown, T., *Engineering Economics and Economic Design for Process Engineers*, CRC Press, Boca Raton, FL, USA, 2006, http://dx.doi.org/10.1201/b15877
20. Turton, R., Bailie, R. C., Whiting, W. B., Shaeiwitz, J. A. and Bhattacharyya, D., *Analysis, Synthesis, and Design of Chemical Processes*, Pearson Education, Upper Saddle River, NJ, USA, 2013.

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