ASSESSING THE LONG-TERM IMPACT OF PI MEASURES IN INDUSTRIAL PROCESS SYSTEMS

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ENERGY MARKET SCENARIOS

Process integration (PI) is an important approach for identifying opportunities to achieve substantially increased energy efficiency and reduced GHG emissions for industrial processes. Profitability and net GHG emissions reduction potential of related investments must be assessed by quantifying their impact within a future energy market context. Future energy market conditions are, however, subject to significant uncertainty. One way to handle decision-making subject to such uncertainty is to evaluate candidate PI investments using different scenarios that include future fuel prices, energy carrier prices, as well as indicative values of GHG emissions associated with important energy flows related to industrial plant operations. By assessing profitability for different cornerstones of energy market conditions, robust PI investment options can hopefully be identified, i.e. investment decisions that perform acceptably for a variety of different energy market scenarios.

Scenario consistency is very important, i.e. different energy market parameters must be clearly related to each other within a scenario (e.g. via key energy conversion technology characteristics and substitution principles). For constructing consistent scenarios, a calculation tool incorporating these inter-parameter relationships is essential. For this purpose, the Energy Price and Carbon Balance Scenarios tool (ENPAC) was developed by researchers at Chalmers for assessing the long term impact of PI measures, as described in Refs [1,2]. The ENPAC tool calculates energy prices for large-volume users based on possible future world market fossil fuel prices and relevant policy instruments (e.g. costs associated with emitting GHGs, incentives for increased use of renewable energy sources in the electric power market or increased use of climate-neutral fuels in the transportation market), and key characteristics of energy conversion technologies in the district heating and electric power sectors. Figure 1 summarizes the use of energy market tools for evaluation of energy efficiency investments in industry.

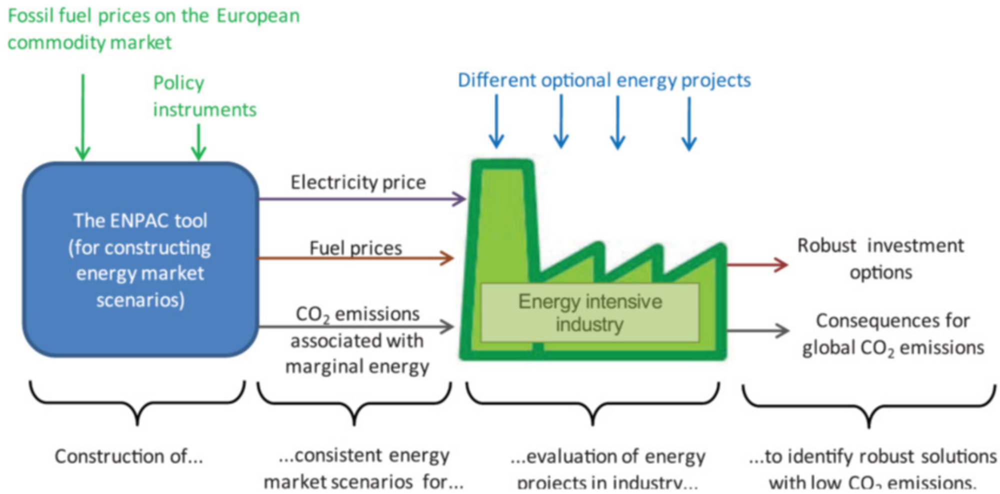

Figure 1: Overview of the purpose of energy market scenarios for evaluation of energy efficiency investments in energy intensive industry where the ENPAC tool is used to construct the scenarios.

Required user inputs to the ENPAC tool include fossil fuel prices and charge for emitting GHG (other policy instruments can be included on an optional basis). Based on these inputs, the electric power generation technology with the lowest levelized cost of electricity in the base-load market can be identified (build margin). This in turn determines the electricity wholesale price together with GHG emissions associated with marginal use of electricity. In a similar manner, the wood fuel market price is calculated based on the willingness to pay (WTP) for a specified marginal wood fuel user category. The

GHG emission consequences of marginal use of biomass can thus also be determined, assuming that biomass is a limited resource. Finally, WTP for industrial excess heat in the district heating market is determined based on the identified price setting technology in a representative heat market. With this procedure, consistent future energy market prices can be determined. Moreover, GHG emissions related to changes of energy flows to/from an industrial can also be determined.

EX-ANTE EVALUATION OF BIOREFINERY OPTIONS FOR A TMP PULP MILL USING ENERGY MARKET SCENARIOS

The approach outlined above has been used successfully in some recent large R&D projects in collaboration with Swedish industry, see for examples Refs [3-8]. Hereafter we present highlights from recent PI studies at Chalmers [9] that illustrate the importance of time-depending factors for GHG mitigation assessments of possible biorefinery concepts based on thermal gasification of wood biomass integrated with a thermo-mechanical pulp (TMP) mill co-located with a sawmill, as shown in Figure 2. Three possible options for utilizing the gas produced via biomass gasification were evaluated: (i) combustion in a gas turbine for electricity generation; (ii) production of methanol; (iii) production of Fischer-Tropsch (FT) liquids. The integrated biorefinery plants were assumed to be sized such that the excess heat they release corresponds exactly to the external heating demand of the host TMP mill. The different alternative biorefineries were evaluated with respect to impact on the overall mill mass and energy balances and GHG emissions.

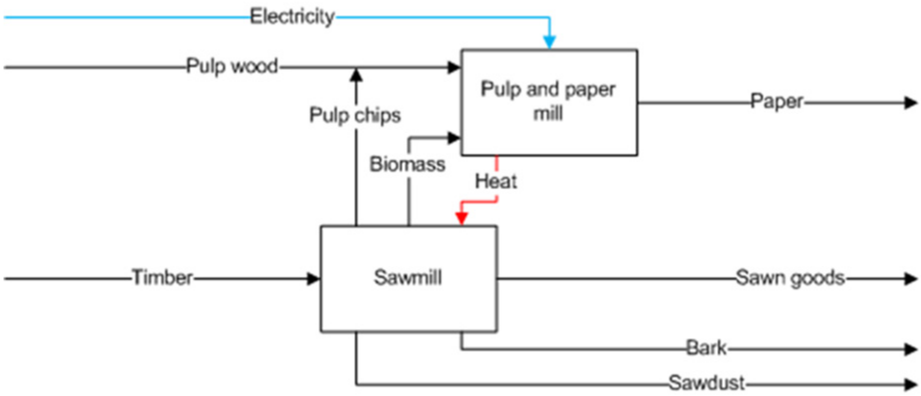

Figure 2. *Energy and material flows of the combined TMP mill and sawmill. The biomass residues (bark, sawdust, cutter shavings) delivered from the sawmill to the TMP mill match the fuel demand of the steam boiler.*

Detailed PI studies were conducted for the integrated biorefineries and biomass input, power balance as well as product output were calculated for the three cases. Table 1 shows the relative change in biomass usage and electricity/biofuel production for the mill integrated with the biorefinery compared to the pulp mill base case.

	CHP	Gas turbine	Methanol	FT liquids
Biomass [MW_{LHV}]				
Demand	98.6	220	635	285
Available on site[a]	98.6	98.6	98.6	98.6
Surplus/deficit[b]	0	−121.4	−536.4	−186.4
Electricity [MW]				
TMP/sawmill	−194	−194	−194	−194
Energy mill	17.8	83	−14.4	−18.6
Surplus/deficit[c]	−176.2	−111	−208.4	−212.6
Compared to base case[d]	–	−65.2	32.2	36.4
Biofuel [MW_{LHV}]	–	–	322	148

[a] [Available on site – demand].
[b] [Surplus/deficit (base case) – surplus/deficit (energy mill)].
[c] [TMP/sawmill + energy mill].
[d] [Surplus/deficit (base case) – surplus/deficit (energy mill)].

Table 1. *Summary of results for integrated cases including the sawmill.*

Three different energy market scenarios (generated using the ENPAC tool) were considered, with substantially different base-load build margin grid power generation technologies so as to highlight how this parameter has a major influence on the GHG mitigation potential for the three integrated biorefinery concepts. The build margin power plant technologies and associated CO_2 emissions in the three scenarios were (i) coal-fired steam cycle (680 kg_{CO2}/MWh_{el}), (ii) natural gas fired combined cycle (NGCC) (329 kg_{CO2}/MWh_{el}), and (iii) coal-fired steam cycle with CCS (similar to wind or solar power from a GHG emissions perspective) (129 kg_{CO2}/MWh_{el}). Figure 3 shows the specific CO_2 emissions reduction (accounting for the changes in power grid emissions) for the three evaluated cases, related to the necessary extra biomass input compared to base case operation.

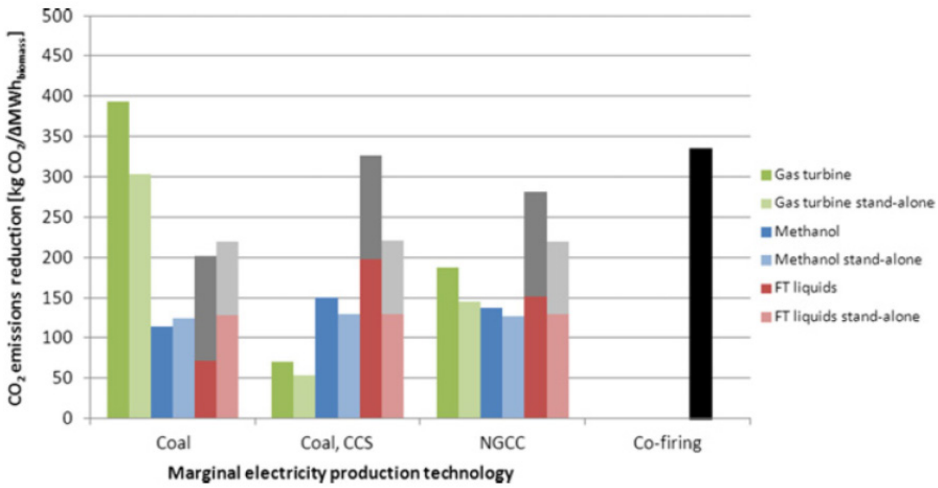

Figure 3 *Specific CO_2 emissions reduction of integrated and stand-alone energy mills for three different marginal electricity production technologies. The grey bar, on top of a red bar, indicates the reduction potential if CO_2 streams in the FT processes are captured and stored. The specific CO_2 emissions reduction potential of co-firing biomass in a coal power plant is shown for comparison.*

The biorefinery concept with the highest CO_2 emissions reduction potential is dependent on the marginal electricity production technology. The large electricity surplus achieved by the gas turbine cogeneration plant leads to a high CO_2 emissions reduction potential if the marginal base-load grid emissions are high (coal or NGCC power plants without CCS). Conversely, the transportation fuel cases (methanol and FT liquids) have substantial electricity deficits, compared with the mill base case, and are thus favoured by scenarios with carbon-lean electricity generation technology (e.g. coal with CCS).

The amount of available biomass on site was assumed to be fixed, whereas the amount of external biomass feedstock depends on the size of the biorefinery. The specific reduction is calculated as the amount of energy product (electricity or transportation fuel) produced per unit of external biomass input. Even though this implies that large quantities of biomass feedstock must be transported in some cases, the related CO_2 emissions are nevertheless very small compared to the overall emissions over the whole value chain.

For comparison, the specific emissions reduction from co-firing biomass in a coal power plant are shown to the right (in black) in Figure 3. The figure shows clearly that the gas turbine case is the only option that can achieve greater CO_2 emissions reduction than co-firing of biomass in a coal power plant. Both of the biofuel cases always have a significantly lower CO_2 emissions reduction potential than co-firing with coal.

CONCLUSION

The example discussed in this paper shows that the GHG emissions mitigation potential for a biorefinery concept can change considerably over time, if the possible variation of important input parameters are considered. The grid base load build margin power generation technology was selected to illustrate this. Other important parameters will also affect both the GHG emission reduction potential and the economic performance of biorefinery concepts and other process decarbonisation measures. By combining PI methods with *ex-ante* assessment of process decarbonisation measures, considerably improved knowledge on how changes of time-dependent parameters will affect the performance of such measures can be achieved. This approach is crucial for strategic decision-making in the process industry and for risk mitigation when making implementation decisions.

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