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Application of Decision Support Tool (DST) based on Analytical Hierarchy Process for Screening of Carbon Capture Technologies

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Abstract

Achieving net-zero emissions will depend significantly on carbon capture, utilization, and storage (CCUS). In today's technology, there are many carbon capture methods, which can be classified as post-combustion, pre-combustion, or oxy-combustion. Although there are huge numbers of publications on various carbon capture methods, comprehensive databases or sources that evaluate carbon capture technologies on a comparable basis are lacking. Furthermore, the choice of the right capture technology can be influenced by factors such as the maturity of the technology, CO_2 concentration in the flue gas, the presence of impurities, the operating pressure, etc. Therefore, a technology selection process can be a challenging and time-consuming task to determine the optimal technology for a given configuration. In order to provide an easy-to-use data overview and assist with the selection process, a decision support tool (DST) based on the analytical hierarchy process (AHP) with a double-weighted matrix [15] is used to evaluate well-suited capture technologies considering engineering, economics and environmental criteria as well as user preference. There are numerous key performance indicators (KPIs) under each criterion such as technology readiness level (TRL), achievable capture rate, CO_2 capture cost per ton of CO_2, etc. where user can indicate preferences among the criteria. The most suitable CO_2 capture technologies are screened and a ranking is then evaluated to provide the most promising options for the available carbon capture technologies in line with the user requirements. In this work, a preliminary result mainly comparing chemical and physical absorption system under post-combustion methods are presented where the tool's relevance is demonstrated through case studies.

Keywords: Decision Support Tool (DST); Carbon Capture, Utilization and Storage (CCUS); Analytical Hierarchy Process (AHP)

1. Introduction

Global warming and climate change are driving an ever-increasing need to reduce greenhouse gas emissions from industry [7]. A major driver is CO_2 emissions, making carbon capture utilization, and storage (CCUS) a crucial strategy for reducing such emissions. The International Energy Agency (IEA) estimates that carbon capture and sequestration (CCS) technology will reduce greenhouse gas emissions by around 20% by the year 2050 [23]. However, it is worth to note that the current global CCUS deployment status shows that the worldwide annual CO_2 capture is less than 1% of the desired scale proposed a decade ago [6] which shows faster actions are required. Fortunately, the global status of CCS report 2020 states that proposals for at least 60 commercial CCUS projects have recently been announced [4]

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and this indicates that there is great momentum in carbon capture technology deployments. While there are many technologies to treat CO_2-containing streams, choosing the right one is largely determined by the concentration of CO_2 in the stream, pollutants, and pressure conditions and therefore, it is not a trivial task to select specific technology options and the selection process involves multi-criteria analyses and trade-offs.

In this study, the goal of this paper is to present a decision support tool (DST) that can assist with a comprehensive evaluation of CO_2 capture technologies in terms of three criteria; engineering, economics, and environment. There are selected key performance indicators (KPIs) under each criterion which play important roles and both criteria and KPIs are weighted using the analytical hierarchy process (AHP). A database associated with each KPI is built based on literature data and own modelling results, and used to score each technology accordingly. Lastly, CO_2 capture technology options are evaluated and ranked to recommend suitable options based on a decision maker's preferences.

2. CO_2 capture technologies and current status

There are a number of options for CO_2 capture, including post-combustion, pre-combustion, oxy-fuel combustion and Direct Air Capture systems [13]. The separation and capture of CO_2 from flue gas generated by the burning of fossil fuels in the air is referred to as post-combustion capture. Flue gas streams under post-combustion typically have low CO_2 concentrations (3% to 33% vol.) and low CO_2 partial pressures (0.03 bar to 5 bar) with high flow rates [22]. In order to extract CO_2 from the flue gas during the CO_2 capture process, a chemical solvent, solid sorbent, membrane, etc. can be used. In the case of pre-combustion, CO_2 is captured prior to fuel combustion where the fuel is consumed with oxygen or air to produce syngas containing CO_2 and H_2 via gasification or reforming process at high pressure [14]. Then, CO_2 can be separated via numerous capture processes for either storage or utilization. Oxy-fuel combustion involves burning fuel at extremely high temperatures in a pure O_2 stream to create flue gas that is mostly composed of CO_2 and H_2O where CO_2 is then separated via condensation. The advantages and shortcomings as well as economical comparison of different CO_2 capture technologies can be found in Hong [12].

2.1 Chemical absorption process

The most developed and commonly used method of removing CO_2 from flue gas for nearly over a century [13] is known as chemical absorption. This method makes use of a liquid solvent which can be heated up to release the absorbed CO_2. Chemical absorption is employed in both post-combustion and pre-combustion capture systems, whereas physical absorption is mostly used in pre-combustion capture systems due to higher CO_2 partial pressures.

Aqueous alkanolamines, which comprise primary amines like MEA and 2-amino-2-methyl-1-propanol (AMP), secondary amines like diethanolamine (DEA), and tertiary amines, are the most widely used chemical solvents. Since MEA has a high CO_2 absorption capacity (4.09 mol_{CO2} /$kg_{solvent}$), a high CO_2 recovery and a CO_2 purity above 99% vol., it is currently the most widely used solvent for CO_2 capture. However, MEA-based CO_2 absorption has certain disadvantages, including high energy consumption during solvent regeneration and solvent degradation due to the presence of O_2, SO_x and NO_x in the flue gas that might result in solvent loss. Also, the highly corrosive nature of the solvent makes the process expensive to operate.

2.2 Physical absorption process

Unlike chemical solvents which interact with CO_2 via chemical reactions, physical solvents affect absorption based on the principle of Henry's law. Thus, the process efficiency increases with increased pressure and reduced temperature. While a high-pressure inlet stream is beneficial for higher capture rates, it is necessary to ensure that the partial pressure of CO_2 is also high in the inlet stream as compared to the inert elements for better selectivity. Hence, stream concentration is an important factor of solvent performance.

The most commonly used physical solvents with widescale commercial applications are dimethyl ether of polyethylene glycol (DEPG) which is the solvent used in the Selexol process. The Selexol has found wide applications in the industry due to its low vapour pressure, wide operating temperature range (-20 to 40 °C), high CO_2 solubility, non-corrosiveness, environmentally benign nature and well characterized performance characteristics [1, 17]. Typical operating temperature for the Selexol process is around 10°C. One of the disadvantages of DEPG is its viscosity where the viscosity increases with decrease in temperature resulting in poor mass transfer characteristics. Hence, a trade-off between these two phenomena is necessary for optimum process operation.

3. Methods

3.1 Overview of the Decision Support Tool (DST)

Screening and choosing optimal CO_2 capture technologies can involve various factors such as TRL, capture cost and environmental impacts, etc. In order to compare and assess the potential of numerous capture technologies on the same basis, the AHP is implemented in two steps which allow users to express preferences over the criteria as well as over the KPIs. The AHP is a multi-criterion mathematical decision-making method that was introduced by Saaty in 1980 [15]. It is a structural way of representing multi-criteria problems with sets of criteria and alternatives as presented in Fig. 1.

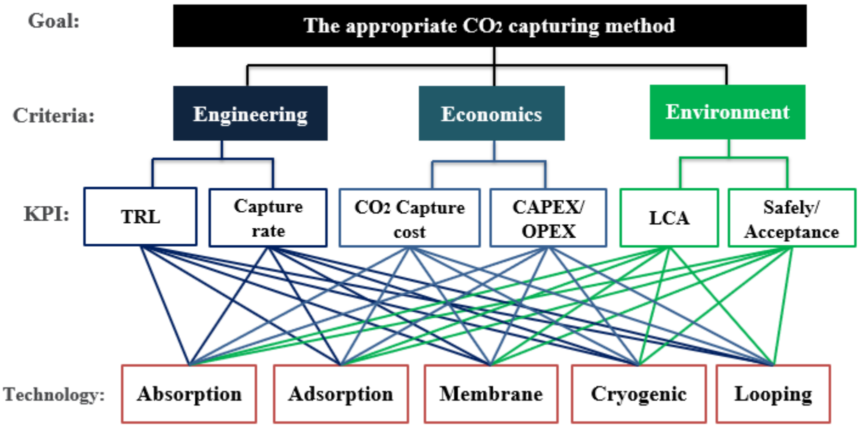


Fig. 1. A schematic of the AHP and corresponding criteria and KPIs

The DST assesses and compares widely available CO_2 capture technologies in terms of three main criteria: engineering, economics, and environment. There are several KPIs under each criterion which will influence the selection process. A decision maker's preferences between technology criteria/KPIs can be translated as weights to calculate the final score of each considered capture technology where more details will be presented in section 3.4.

3.2 Criteria and Key Performance Indicators (KPIs)

Under current development status of the DST, there are nine KPIs which are grouped into the three criteria to evaluate the carbon capture technologies. A summary of criteria and the KPIs used in the DST is presented in Table 1.

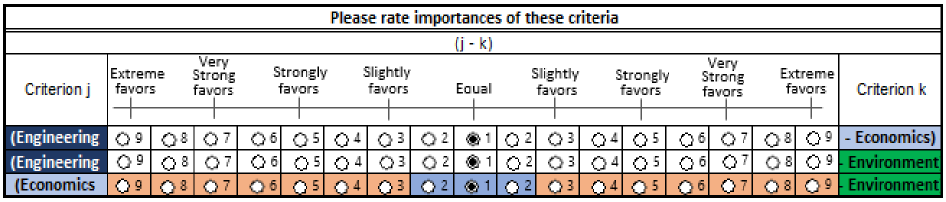
Table 1. Three criteria and their relevant KPIs

KPI / Criteria	Engineering	Economics	Environment
KPI 1	*TRL*	*CO_2 capture cost*	*LCA score*
KPI 2	*Achievable Capture rate*	*Specific CAPEX*	*Safety Issues*
KPI 3	*SO_x and NO_x*	*Specific OPEX*	*Public acceptance*

Under the engineering criterion, the *TRL* shows the maturity level of the technologies and indicates the expected time of commercial deployment. According to the three stages of TRL suggested by IEAGHG 2014 report [8], TRLs 1 to 3 are classified as the research stage, the development stage involves TRLs 4 to 6 and lastly, the demonstration stage covers TRLs 7 to 9. The *achievable capture rate* refers to the ability of a given technology to capture 90% of the CO_2 in the inlet stream while SO_x *and* NO_x KPI indicate whether or not a technology of interest requires pre-treatment to remove impurities prior to the carbon capture. The economics criterion consists of *CO_2 capture cost*, *specific CAPEX* and *OPEX* per tonne of CO_2 captured while the environment criterion contains *LCA score*, *safety issue* and *public acceptance* to assess capture technologies. In this paper, engineering KPIs are developed based on a detailed literature review. In the case of economics KPIs, their thresholds will be described via comprehensive process simulations and CAPEX/OPEX correlations for the chemical and physical absorption processes. Finally, for the environmental KPIs, the methodology framework is presented in section 3.3 where a guideline of thresholds is currently under development.

3.3 Framework of methodology

As mentioned before, the selection of CO_2 capture technology is a complex task since the above-mentioned KPIs can influence the results. Therefore, the DST is designed such that the tool will ask upfront questions which will help to eliminate some of the capture technologies early on. The upfront questions ask if the users are interested in the high TRL technologies, if the process already has a pre-treatment unit, and it asks for process parameters such as CO_2 concentration, flowrates and pressure. After pre-screening the technologies, the user can also express the preferences over the criteria and KPIs as shown in Fig. 2. The preferences are expressed on a scale of 1 to 9 where 1 means equal importance while 9 refers to the extreme favour.



Please rate importances of these criteria

(j - k)

Criterion j	Extreme favors		Very Strong favors		Strongly favors		Slightly favors		Equal		Slightly favors		Strongly favors		Very Strong favors		Extreme favors	Criterion k
(Engineering	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	● 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	○ 8	○ 9	- Economics)
(Engineering	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	● 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	○ 8	○ 9	- Environment
(Economics	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	● 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	○ 8	○ 9	- Environment

Fig. 2. A user preference scale system used in the DST (for criteria)

The user preference inputs are then fed into the DST where the AHP is used to convert these preferences into weights and the details of the weight calculations are presented in section 3.4. These weights are then used with the DST database to calculate the final score of each pre-screened carbon capture technology as shown in Fig.3.

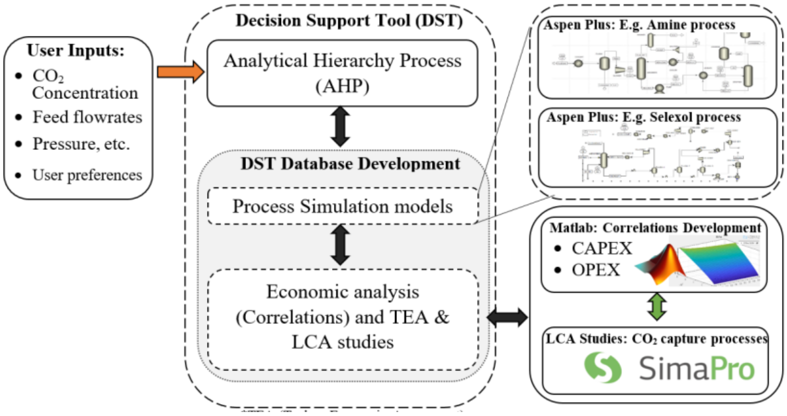


Fig. 3. Framework of methodology for DST

The DST database consists of a list of selected carbon capture technologies and each technology is given a score between a minimum of 0 to a maximum of 3 for each KPI. The score thresholds are based on the literature review and process simulations in order to minimize the subjectivity of the technology evaluation process. Regarding the process simulations, the simulation results are used to perform techno-economic assessment (TEA) of a given carbon capture technology and correlations describing capital expenditures (CAPEX) and operating expenses (OPEX) are developed. The correlations are a function of both CO_2 concentration and process flowrate and they are coupled with the DST database which will interact with the user inputs (CO_2 concentration and flowrates). This database will play an important role in assessing various carbon capture technologies on the same basis. The details of thresholds development of engineering and economics KPIs, as well as the correlations are presented in sections 3.5 and 3.6 respectively. For environmental KPIs, LCA studies can be conducted using software like SimaPro to quantify the environmental impact and the results can be linked to the DST database (work in progress).

3.4 Weight calculations for criteria and KPIs

There are two sets of weights in the AHP. The first set involves criteria weights (w_{crit}) where user comparison values indicating which criteria, engineering, economics, or environment is preferable with respect to others are used to calculate and provide the first set of weights to each criterion. The second set consists of KPIs weights (w_{KPI}) where user comparison values expressing which KPI within a criterion is preferred with respect to others are used to calculate w_{KPI}. In order to calculate the weights, a pairwise comparison matrix (**B**) is developed for the 3 criteria and 3 KPIs within each KPI individually. A general format of the pairwise matrix is presented in Eqn. 1.

$$\boldsymbol{B} = \begin{vmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{vmatrix} \tag{1}$$

Where *n* is the number of criteria or KPIs considered and b_{ij} refers to the user comparison value between *i* criterion (or KPI) and *j* criterion/ KPI. The lower triangular matrix can be defined as Eqn. 2.

$$b_{ij} = 1/b_{ji} \tag{2}$$

The pairwise matrix can then be used to calculate the weights using Eqn. 3.

$$w_{crit} = \frac{\sqrt[n]{\prod_{j=1}^{n} b_{ij}}}{\sum_{j=1}^{n} \sqrt[n]{\prod_{j=1}^{n} b_{ij}}} \tag{3}$$

The same equation is used to calculate w_{KPI}. Note that both w_{crit} and w_{KPI} are 3-dimensional column matrices since there are three criteria and three KPIs considered in this study. More details on the equations and AHP theory can be found in the work of Saaty [15]. The calculated weights are then used in the final technology score calculation which can be used to establish rankings between the selected carbon capture technologies. As described in section 3.3, a database describing each technology's performances across each KPI within a criterion is required to calculate the final technology score. The final score is calculated as follows:

$$\text{Final score} = \sum_{crit} w_{crit} \cdot \{\sum_{KPI} w_{KPI} \cdot S_{KPI}\} \tag{4}$$

Where S_{KPI} is the database score for each KPI. Eqn. 4 is used with the DST database across the selected carbon capture technology to calculate the final score and then a rank can be established. The details of the DST database are described next.

3.5 Database development and thresholds for KPIs

There are databases and literature describing various carbon capture facilities globally [5, 10, 16]. However, many studies have different scopes and base cases, various capture sizes, different costing years and assumptions. When the costs were available, often costs of carbon capture were included in the total plant cost and consequently, it is difficult to extract the capture cost alone. Therefore, it was crucial to develop a database of various carbon capture technologies in terms of the aforementioned criteria and KPIs on the same basis and this task is an ongoing process of the current study. For each KPI within each criterion, scoring guides for engineering and economics KPIs are presented in Tables 2 and 3 respectively to specify thresholds of each KPI scoring system (score scale from 0 to 3 where 0 indicates a poor performance while the maximum score of 3 indicates a good performance) for a given technology. The KPIs under the engineering criteria are based on the literature review of the selected carbon capture technologies while the economics KPIs are based on both literature review and process simulations and TEA of the selected technologies. For the purpose of the tool demonstration, the environmental criterion is included but the environmental KPIs scores are one of the ongoing studies and the environmental KPI scores used in this study are so far only based on literature review and authors' insights.

Table 2. Engineering KPIs and the scoring threshold guidelines

Engineering KPIs	Evaluation method	Scale	Score
TRL	Use literature and TRL scale [8]	< 4	0
		5 - 6	1
		7- 8	2
		9	3
Achievable capture rate	Use literature or data from simulation models (if applicable)	< 50 %	0
		79 – 50 %	1
		94 – 80 %	2
		≥ 95 %	3
SOx NOx	Use of open data from literature or use engineering judgement	Need pre-treatment(s)	0
		SOx and NOx degrade the process (E.g. products, equipment, etc.)	1
	When the process can run without any pre-treatment, the score is 3. When the process may need pre-treatment for better product quality, the score is 2. When the presence of SOx and NOx may degrade some parts of equipment, the score is 1.	Can work independently but may need pre-treatment for higher purity products	2
		No need of pre-treatment(s)	3

Table 3. Economics KPIs and the scoring threshold guidelines

Economics KPIs	**Evaluation method**	**Scale**	**Score**
CO_2 Capture Cost	Use literature or data from simulation models (If applicable) $CO_2\ Capture\ Cost\ (Annual) = \frac{CAPEX + OPEX}{CO_2\ captured}$	> 81 €/tonne CO_2	0
		61 ~ 80 €/tonne CO_2	1
		41 ~ 60 €/tonne CO_2	2
		20 ~ 40 €/tonne CO_2	3
Specific CAPEX per tonne of CO_2 captured	Select a base case and calculate CAPEX of the base case for selected technologies.	> 367 €/tonne CO_2 per year	0
		254 ~ 366 €/tonne CO_2 per year	1
		142 ~ 253 €/tonne CO_2 per year	2
		29 ~ 141 €/tonne CO_2 per year	3
Specific OPEX per tonne of CO_2 captured	Select a base case and calculate OPEX of the base case for different technologies.	> 46 €/tonne CO_2 per year	0
		35 ~ 45 €/tonne CO_2 per year	1
		24 ~ 34 €/tonne CO_2 per year	2
		13 ~ 23 €/tonne CO_2 per year	3

The scoring guide shows the four-level thresholds for scoring capture technologies and evaluation methods for each KPI, making the DST a transparent tool. These thresholds for each KPI are used to score selected capture technologies in the DST database. The next section will now specifically describe TEA studies on the chemical and physical absorption system and CAPEX/ OPEX correlations development which are implemented in the DST to calculate capture cost, specific CAPEX and OPEX KPIs.

3.6 Economic assessment of absorption systems and correlation development

In order to study the feasibility of CO_2 capture technologies on the same foundation and allow the DST to connect with the user inputs, a correlation format presented in Hasan et al. [11] has been adopted to quantitatively assess CAPEX and OPEX at any given CO_2 concentrations and feed flowrates. The proposed correlation format is:

$$Cost = \alpha + (\beta \cdot {x_{co_2}}^{n} + \gamma) \cdot F^{m}$$

Where $\alpha, \beta, \gamma, n,$ and m are the fitting parameters while x_{co_2} and F are the feed CO_2 volume concentration and flow rate respectively. The estimated fitting parameters and the boundaries are presented in Table 4.

Table 4. Estimated parameters for the chemical and physical absorption processes

Process	α	β	γ	n	m	x_{co_2} **[%]**	F **[mol/s]**
				CAPEX [M€]			
Chemical	102.2	-0.0256	0.001443	1.682	1.135	$1 \leq x_{co_2} \leq 95$	$840 \leq F \leq 79550$
Physical	20.14	4.68	-3.785	-0.2177	0.4222	$15 \leq x_{co_2} \leq 95$	$840 \leq F \leq 5280$
				$OPEX \left[\frac{M€}{yr}\right]$			
Chemical	42.61	0.00249	0.001176	0.4493	0.9753	$1 \leq x_{co_2} \leq 95$	$840 \leq F \leq 79550$
Physical	52.04	10.81	-15.92	-0.2718	0.2748	$15 \leq x_{co_2} \leq 95$	$840 \leq F \leq 5280$

In order to obtain the fitting parameters shown above, process simulation results were used to obtain CAPEX and OPEX at various CO_2 concentrations and flue gas flowrates. Each variation was treated as a single datapoint and a group of data points was used to perform multi-variable regression on Matlab. In the case of the chemical absorption process using MEA at CO_2 capture of 1 Mt/yr, CAPEX and OPEX were validated with the work of Sultan et al., [18] while physical absorption's costing using Selexol was validated as reported in Zhang et al., [24].

The fitting parameters can be used, within the provided boundaries in Table 6, to calculate estimations for the CO_2 capture cost at different capture sizes and CO_2 concentrations for chemical and physical absorption processes. In this way, economical trade-offs between different CO_2 capture technologies can be compared on the same basis. In this study, chemical and physical absorption systems are considered but can be expanded to include various technologies such as membrane, calcium looping, temperature swing adsorption, DAC, etc. An example of CO_2 capture costs of chemical (the grey lines) and physical absorption (red lines) processes at different capture sizes (solid line: 1.5 Mt/yr, -·- dashed line: 1 Mt/yr, and … dotted line: 0.8 Mt/yr) over a range of CO_2 concentrations at a fixed total pressure (1 bar, post-combustion scenario) is presented in Fig. 4.

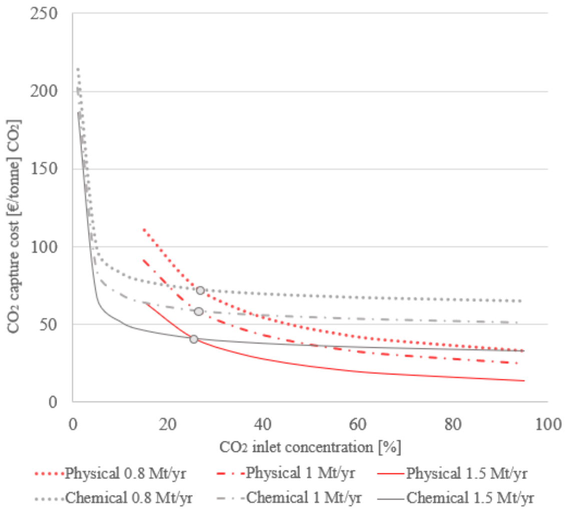


Fig. 4. Chemical absorption vs. physical absorption at different CO_2 concentration and capture sizes

It was found that for all capture sizes presented in Fig. 4, capture costs for chemical absorption system are favoured below CO_2 concentration of 25% (with slight variations with the capture size changes, indicated with grey circle markers) but when the concentration becomes very low (close to 1%), the capture cost using chemical solvent increased rapidly as depicted in the figure. It was observed that when the concentration becomes high, physical absorption is more favoured as described also in the literature [24]. Moreover, these results also show the boundary zone between chemical and physical absorption, and it seems that chemical absorption units extend their range of interest when the capture plant size is decreased. In terms of the capture sizes, an increase in the capture size results in higher CAPEX for all technologies but since more CO_2 is captured, this resulted in an inverse effect on the capture cost and therefore, increased capture size induced a decrease in capture cost in general. For both technologies, errors between the correlation predictions and the simulation results at various CO_2 concentrations and flowrates were $\pm 10\%$ and according to Hasan et al. [11], errors occurring during a scale-up process can be as high as 20%. Therefore, the correlations are considered justified and further implemented in the DST. More data will be generated using process simulations at different capture sizes and it is aimed to validate the results to improve the correlations. In the next section, these correlations are coupled with the DST and the results of the DST are discussed.

4. Results and discussion

To elaborate on the results and performance of the DST, two case studies have been developed. The first is the selection of CO_2 capture technology for a power generation plant and the second study is for iron and steel industries. The case studies are presented below:

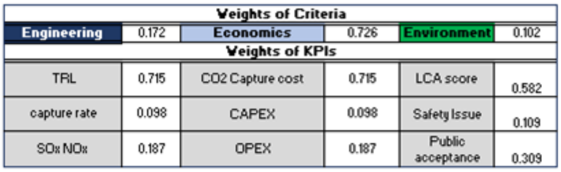
- Power Plant

In this case, a gas-fired power production plant is chosen as a case study. The total flue gas being released from the plant is 6150 mol/s. The amount of CO_2 to be captured is 1 Mt/year with a fixed 90% capture rate. The working hours of the plant per year are 8760 h. The composition of flue gas being released is given in Table 5 [24]. Here, the flue gas flow rate and composition of the CO_2 flue gas are taken as user inputs.

Table 5. Flue gas characteristics for the case of power plant [24]

Flue gas characteristics	Value
CO_2 mole fraction [%]	13
O_2 mole fraction [%]	12
N_2 mole fraction [%]	75

Users can express the preferences over the criteria and KPIs and in this case study, the weights presented in Fig. 5 are used to demonstrate the DST and its applicability:

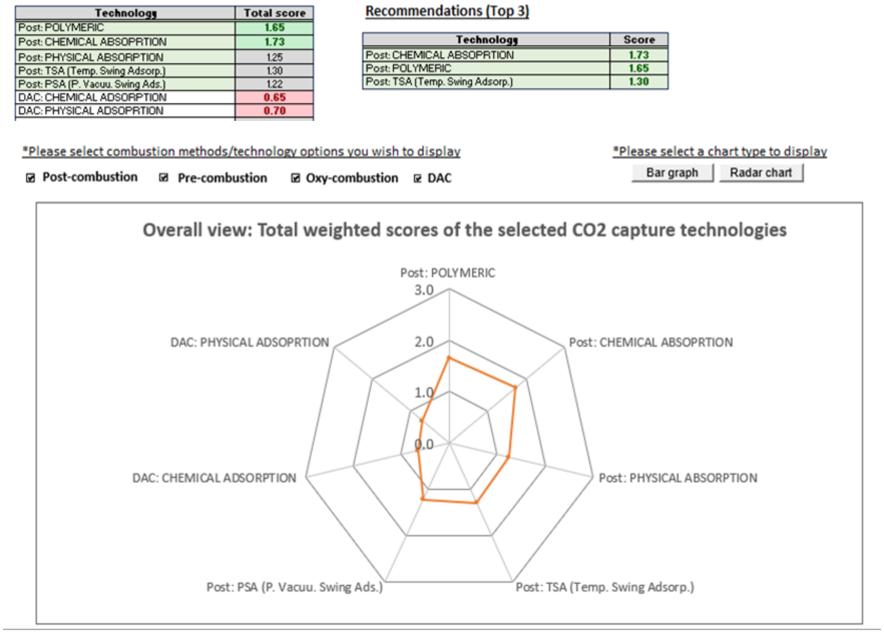


Veights of Criteria					
Engineering	0.172	**Economics**	0.726	**Environment**	0.102
Veights of KPIs					
TRL	0.715	CO2 Capture cost	0.715	LCA score	0.582
capture rate	0.098	CAPEX	0.098	Safety Issue	0.109
SOx NOx	0.187	OPEX	0.187	Public acceptance	0.309

Fig. 5. User preferences and the resulting weights for criteria and KPIs

Here it is evident that the user has expressed more preferences over the economics than the engineering and environment. Hence, the weight for the economic criterion has the highest weight of 0.726 followed by engineering (0.172) and environment (0.102) summing up to a total weight of 1. The same theory is applied to the KPIs within each criterion and the user's preferences are translated as weights and the value of KPI weights are shown in Fig.6. These weights are then coupled together to calculate the final score of the capture technologies using Eqn. (4). The capture technologies considered within the DST then have the final scores based on the user preferences provided by the user and the DST database. Fig. 6 presents the results of the DST where the top 3 suitable technologies are suggested as well as a spider web curve to graphically display results. According to the results, the power plant with a lower concentration of CO_2 in flue gas and with the specific user preferences on the economics criterion, chemical absorption is the most suitable technology, before polymeric membranes and temperature swing adsorption. This is an apparent result as described in the literature. However, this case study shows the ability of the DST to screen and pick the most suitable capture technologies based on the user inputs and the DST database developed via in-house process models and literature review.

Figure 6. A screenshot of DST where it presents the AHP score of different technologies, and results of DST in the form of the top three suitable technologies and a spider web curve (Power plant case study).



Technology	Total score
Post: POLYMERIC	1.65
Post: CHEMICAL ABSOPRTION	1.73
Post: PHYSICAL ABSORPTION	1.25
Post: TSA (Temp. Swing Adsorp.)	1.30
Post: PSA (P. Vacuu. Swing Ads.)	1.22
DAC: CHEMICAL ADSORPTION	0.65
DAC: PHYSICAL ADSOPRTION	0.70

Recommendations (Top 3)

Technology	Score
Post: CHEMICAL ABSOPRTION	1.73
Post: POLYMERIC	1.65
Post: TSA (Temp. Swing Adsorp.)	1.30

*Please select combustion methods/technology options you wish to display

☑ Post-combustion ☑ Pre-combustion ☑ Oxy-combustion ☑ DAC

*Please select a chart type to display

- Iron and steel industries

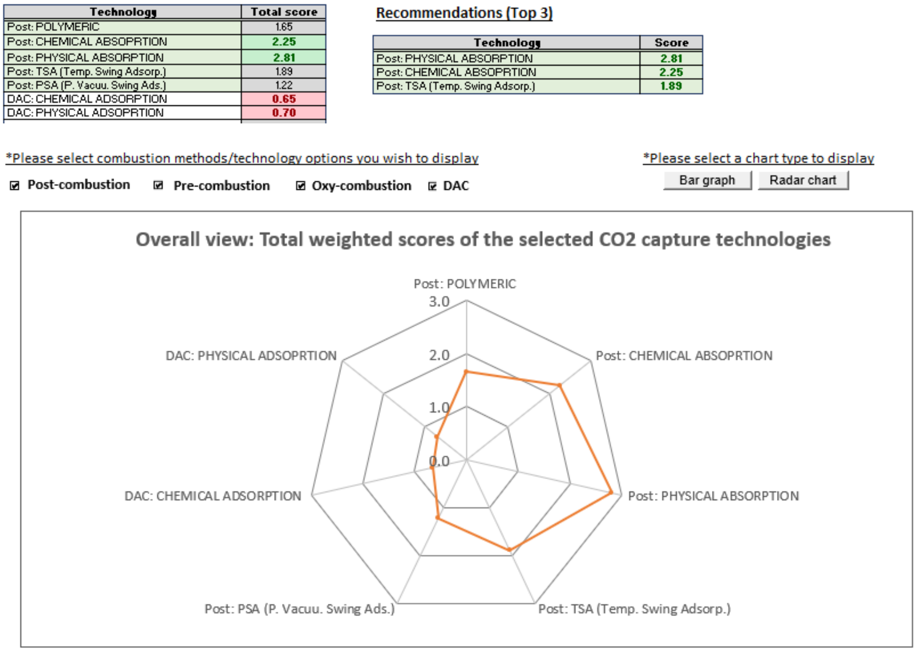
The next case study is for the iron and steel industries. In this case, the user input is as follows: flue gas rate is 1780 mol/s, 1 Mt/year capture size, 90% capture rate and 8760 working hours of plant per year. The same user preferences used in the power plant case study are implemented and therefore, the same weights for the criteria and KPIs are also used in this case study. Table 6 presents the flue gas compositions.

Table 6. Flue gas characteristics for the case of iron and steel industries [24]

Flue gas characteristics	Value
CO_2 mole fraction [%]	45
N_2 mole fraction [%]	34
CO mole fraction [%]	21

Based on the user preferences and the user inputs, the DST result shows that for this given scenario, a physical absorption carbon capture is most suitable. Since the inlet CO_2 concentration is high (45%), the result from the DST is in good agreement with the literature [24].

Figure 7. A screenshot of DST where it presents the AHP score of different technologies, results of DST in the form of the top three suitable technologies and a spider web curve (iron and steel industries case study).



Technology	Total score
Post: POLYMERIC	1.65
Post: CHEMICAL ABSOPRTION	2.25
Post: PHYSICAL ABSORPTION	2.81
Post: TSA (Temp. Swing Adsorp.)	1.89
Post: PSA (P. Vacuu. Swing Ads.)	1.22
DAC: CHEMICAL ADSORPTION	0.65
DAC: PHYSICAL ADSOPRTION	0.70

Recommendations (Top 3)

Technology	Score
Post: PHYSICAL ABSORPTION	2.81
Post: CHEMICAL ABSOPRTION	2.25
Post: TSA (Temp. Swing Adsorp.)	1.89

*Please select combustion methods/technology options you wish to display

☑ Post-combustion ☑ Pre-combustion ☑ Oxy-combustion ☑ DAC

5. Conclusion and perspectives

5.1 Conclusion

In this work, a decision support tool for identifying and selecting a viable carbon capture technology has been developed where users are allowed to enter flue gas characteristics such as CO_2 concentration and flowrates which are then coupled with the DST to provide interactive results. Also, users can express preferences over the engineering, economics and environmental criteria as well as the aforementioned KPIs where these preferences are translated into weights and then used in the final technology score calculation to rank selected carbon capture technologies. The DST database can be updated with new technologies and new advancements in the industry/research field to produce more realistic results. In the presented framework, chemical and physical absorption processes are compared and through case studies, it was observed that the preliminary results of the DST agree with the general literature guidelines for the selection of the aforementioned capture technologies. The current results may seem obvious. However, when the DST is combined with many capture technologies, the tool can compare the technologies on the same basis across the previously mentioned criteria/KPIs and the tool can guide the users with the complex selection process using a rational basis. Overall, this paper presents a methodology for developing coherent database and thresholds for engineering and economics KPIs and simple DST case studies are demonstrated.

5.2 Perspective

DST is an informative tool for the selection of suitable technologies and the above studies presented its extensive prospect. The current version of the DST entails database and in-house built process models of chemical and physical absorption. It is aimed to detail more technologies such as membranes, calcium looping, vacuum swing adsorption, DAC, etc. Also, chemical/physical absorption processes with various blends of new solvents will be added to the DST database to enrich the results of the tool and establish a platform to compare various carbon capture technologies on the same basis. Moreover, apart from the TEA of the technologies, the DST will be incorporated with life cycle assessment (LCA) to assess various carbon capture methods in terms of environmental criteria. DST in its final form will be released as an open access tool which will be a great support in selecting suitable capture technologies for large-scale pilot plants in the Walloon region, Belgium. Further case studies will be performed with a robust version of DST to present the prospect of its performance to screen out the most suitable technologies. Lastly, the current version of the tool is best fitted for large-scale carbon capture (e.g. 1Mt/yr). In order to address medium and smaller capture sites, the DST database will be expanded to describe different capture sizes.

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References

[1] Ashkanani, H.E., Wang, R., Shi, W., Siefert, N.S., Thompson, R.L., Smith, K., Steckel, J.A., Gamwo, I.K., Hopkinson, D., Resnik, K. and Morsi, B.I., 2020. Levelized cost of CO2 captured using five physical solvents in pre-combustion applications. *International Journal of Greenhouse Gas Control*, *101*, p.103135.
[2] Eide, L.I. , Bailey, D.W. , 2005. Precombustion decarbonisation processes. Oil Gas Sci. Tech- nol. –Rev. IFP 60, 475–484 .
[3] EPA, 2015, Literature survey of carbon capture technology, Available at: https://19january2017snapshot.epa.gov/sites/production/files/2015-11/documents/tsd-cps-literature-survey-carbon-capture-technology.pdf (Accessed: 26/08/2022)
[4] Global CCS Institute. Global status of CCS report 2020. Available at: https://www.globalccsinstitute.com/wp content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf (Accessed: 26/08/2022)
[5] Global CCS Institute, 2018, CO2RE database, Available at: https://co2re.co/ (Accessed: 26/08/2022).
[6] IEA. Exploring clean energy pathways: the role of CO2 storage. 2019. https://iea. blob.core.windows.net/assets/fc698d6d-1f9d-4c46-9293-e67a600d01c6/Exploring_Clean_Energy_Pathways.pdf
[7] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2020
[8] IEAGHG, 2014. Assessment of emerging CO 2 capture technologies and their potential to re- duce cost, 2014/TR4. https://ieaghg.org/docs/General_Docs/Reports/2014-TR4.pdf .
[9] Mettam GR, Adams LB. How to prepare an electronic version of your article. In: Jones BS, Smith RZ, editors. Introduction to the electronic age. New York: E-Publishing Inc; 1999. p. 281-304.
[10] MIT, 2016, Carbon Capture & Sequestration Technologies @ MIT, Available at: https://sequestration.mit.edu/tools/projects/ (Accessed: 26/08.2022)
[11] Hasan, M.F., Baliban, R.C., Elia, J.A. and Floudas, C.A., 2012. Modeling, simulation, and optimization of postcombustion CO2 capture for variable feed concentration and flow rate. 2. Pressure swing adsorption and vacuum swing adsorption processes. *Industrial & engineering chemistry research*, *51*(48), pp.15665-15682.
[12] Hong, W.Y., 2022. A techno-economic review on carbon capture, utilisation and storage systems for achieving a net-zero CO2 emissions future. *Carbon Capture Science & Technology*, p.100044.
[13] Osman, A.I., Hefny, M., Abdel Maksoud, M.I.A., Elgarahy, A.M. and Rooney, D.W., 2021. Recent advances in carbon capture storage and utilisation technologies: a review. *Environmental Chemistry Letters*, *19*(2), pp.797-849
[14] Osman AI, Abu-Dahrieh JK, Cherkasov N, Fernandez-Garcia J, Walker D, Walton RI, Rooney DW, Rebrov E (2018) A highly active and synergistic Pt/Mo2C/Al2O3 catalyst for water-gas shift reaction. Mol Catal 455:38–47. ISSN 2468-8231. https://doi. org/10.1016/j.mcat.2018.05.025
[15] Saaty TL. Analytic hierarchy process. New York, NY: McGraw-Hil; 1980
[16] SCCS, 2022, Scottish Center for Carbon Capture CCS Database, Available at: https://www.geos.ed.ac.uk/sccs
[17] Smith, K.H., Ashkanani, H.E., Morsi, B.I. and Siefert, N.S., 2022. Physical solvents and techno-economic analysis for pre-combustion CO2 capture: A review. *International Journal of Greenhouse Gas Control*, *118*, p.103694.
[18] Sultan, H., Bhatti, U.H., Muhammad, H.A., Nam, S.C. and Baek, I.H., 2021. Modification of postcombustion CO2 capture process: A techno-economic analysis. *Greenhouse Gases: Science and Technology*, *11*(1), pp.165-182.
[19] Strunk Jr W, White EB. The elements of style. 3rd ed. New York: Macmillan; 1979.
[20] Van der Geer J, Hanraads JAJ, Lupton RA. The art of writing a scientific article. J Sci Commun 2000;163:51-9.
[21] Wang, Y., Liu, X., Kraslawski, A., Gao, J. and Cui, P., 2019. A novel process design for CO2 capture and H2S removal from the syngas using ionic liquid. *Journal of Cleaner Production*, *213*, pp.480-490.
[22] Wang, X. , Song, C. , 2020. Carbon capture from flue gas and the atmosphere: A perspective. Front. Energy Res. 8, 560849
[23] Yadav S, Mondal SS. A complete review based on various aspects of pulverized coal combustion. Int J Energy Res 2019;43(8):3134–65. https://doi.org/ 10.1002/er.v43.810.1002/er.4395.
[24] Zhang, X., Song, Z., Gani, R. and Zhou, T., 2020. Comparative economic analysis of physical, chemical, and hybrid absorption processes for carbon capture. *Industrial & Engineering Chemistry Research*, *59*(5), pp.2005-2012.