ENVIRONMENTAL ASSESSMENT OF WASTE COAL PURIFICATION

Final report

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Environmental assessment of waste coal purification

Report for Changeover Technologies

Prepared by Dr Dawid Hanak

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Dr Hanak's Group

Dr Hanak's group in Sustainable Energy and Process Engineering is an ambitious team of researchers working in the area combining power, process and environmental engineering with economics and computer science to solve global challenges and develop innovative solutions to meet sustainable development goals.

About the author

Dr Hanak has over 8 years expertise in modelling, techno-economic feasibility assessment and environmental impact assessment of advanced power generation systems, industrial processes and net-zero business models. His research interests include advanced heat and power generation systems, industrial processes, thermochemical conversion of solid fuels, sustainable and renewable energy systems, CO_2 capture and utilisation systems, and energy storage.

His research was awarded the Lord Kings Norton Medal, a prize recognising the best PhD thesis across Cranfield University. He has proven the techno-economic feasibility of the innovative direct air capture technology in a project that won Engineer's "*Collaborate to Innovate*" Award in Energy and Environment theme. He also proved the techno-economic feasibility of using breakthrough polymer-based materials for CO_2 capture in the Combined Energy Recovery and CO_2 Capture project that won the "*Clean Environment Award*" for 2019–2020 at the Rushworth Show. His research was also awarded the Early Career Research Poster Prize at UKCSCRC Spring Biannual Meeting and the Carbon Capture and Storage Winter School, and the Best Fossil Fuel Poster Prize during the Energy Sector Early Career Chemists Symposium by Royal Society of Chemistry.

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Executive summary

This consultancy project presents the environmental life-cycle assessment of the Changeover Technologies modular unit and a conventional coal production unit. The data provided by Changeover Technologies included energy and material balances for each step of the process, enabling cradle-to-gate analysis.

The initial assessment of the MetaForm process has revealed that its cradle-to-gate global warming potential (GWP) would be 2.72 $kgCO_{2,eq}$/GJ if the electricity consumed by the process is supplied via the natural gas combined cycle power plant. For the process that produces pellets at 50 t/hr, this corresponds to 3,923.73 $kgCO_{2,eq}$ emitted into the atmosphere over the period of 100 years. In contrast, the GWP of the conventional coal supply in the US was estimated to be 12.76 $kgCO_{2,eq}$/GJ. For the supply of 50 t/hr of bituminous coal, the conventional mine will result in the absolute GWP of 18,392.3 $kgCO_{2,eq}$. Therefore, the MetaForm process, including the harvesting and washing steps, can reduce the GWP by 78.7%. It is also apparent that the pelletised coal produced from the waste coal impoundments can reduce our reliance on fossil fuels, as its contribution to fossil depletion is 83.9% lower than that in conventional coal mining. Considering the endpoint indicators, the coal pellets supplied via the MetaForm process are expected to be associated with less damage to ecosystems, human health and resource availability compared to the coal supplied via the conventional mining process (Table 1).

Table 1: Comparison of environmental performance

Indicator	MetaForm	Conventional	Relative change (%)
Midpoints			
Global warming potential ($kgCO_{2,eq}$/GJ)	2.72	12.76	-78.68
Fossil depletion (kg oil_{eq}/GJ)	5.31	32.96	-83.87
Human toxicity (kg 1,4-DCB_{eq}/GJ)	8.10	53.44	-84.83
Particulate matter formation (kg $PM10_{eq}$/GJ)	0.01	0.03	-79.49
Marine eutrophication (kg N_{eq}/GJ)	0.01	0.03	-79.49
Terrestrial acidification (kg $SO_{2,eq}$/GJ)	0.02	0.11	-77.46
Endpoints			
Damage to ecosystems (points/GJ)	0.05	0.23	-78.68
Damage to human health (points/GJ)	0.22	1.26	-82.40
Damage to resource availability (points/GJ)	0.64	3.96	-83.88

When the MetaForm process is used to replace the conventional coal in the steelmaking plant, the GWP of steelmaking will reduce by 9.5%, from 102.56 $kgCO_{2,eq}$/GJ for the conventional process to 92.82 $kgCO_{2,eq}$/GJ for the MetaForm process. This implies that decarbonisation of the supply chain can bring a meaningful reduction in industrial CO_2 emissions, even before these processes are fully decarbonised.

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Introduction

Scope definition

This consultancy project aims to perform the environmental life-cycle assessment of the Changeover Technologies modular unit and a conventional coal production unit. The outcomes of this work will identify and systematically assess the environmental benefits of the Changeover Technology modular units.

Activity 1: Definition of goal and scope for analysis

- system boundaries for a conventional coal production system
- system boundaries for the Changeover Technologies modular units
- determination of functional unit

Activity 2: Collection of input and output information

- mass and energy balance
- life-cycle assessment inventory
- process set-up in LCA tool

Activity 3: Life-cycle impact assessment and interpretation

- assessment of LCA performance

Methods

Process overview

The coal processing technology developed by Changeover Technologies (MetaForm®) aims to produce a pelletised coal product from waste material found in the coal waste impoundments. The process comprises four distinctive phases, as shown in Figure 1.

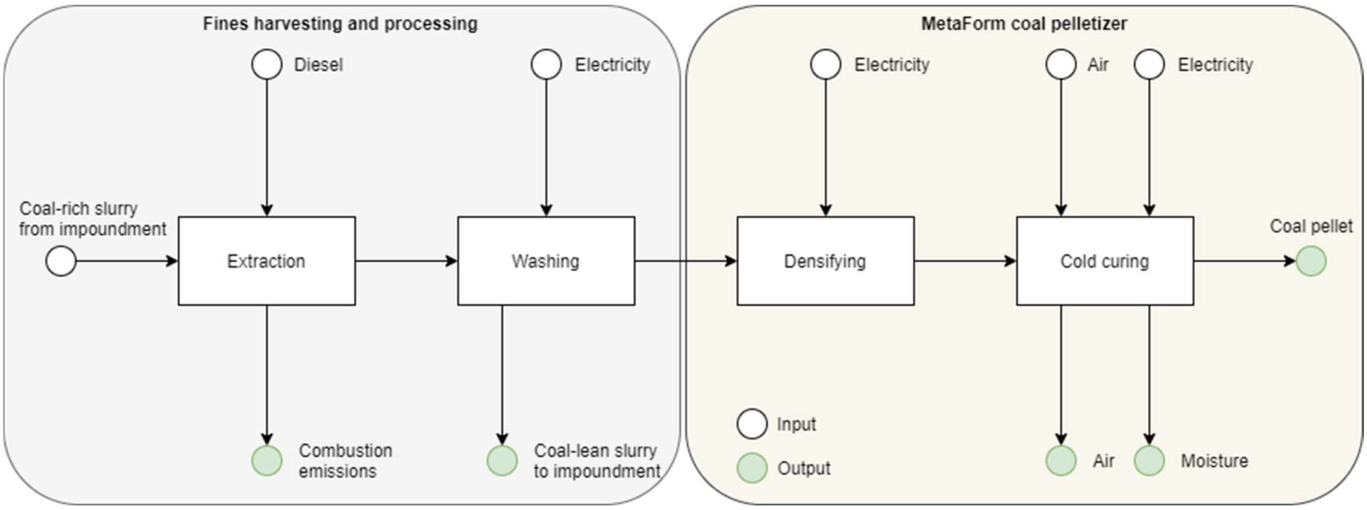

Figure 1: Block flow diagram of MetaForm® coal processing technology by Changeover Technologies

In the first step of the considered process, a coal-rich slurry is extracted from the waste coal impoundment using front-end loaders and pit trucks. The extracted slurry usually comprises 20-25% suspended solid coal waste. Therefore, before the coal waste can be pelletised, it is further processed in the washing unit that uses a combination of scalping screen, 2-stage froth cells and a centrifuge to reduce the moisture content from 75–80% to 20–25%. The washed fines are then transported for treatment with the formula patented by Changeover Technologies and subsequently fed into the densifying unit. In the densifying unit, the formula binds the fines at a molecular level, producing smooth-faced pellets. The produced pellets are then transported to a cold curing unit, where these are exposed to air for an extended period. At this stage, the pellets attain their final strength and water resistance. Moreover, the moisture content is further reduced to 5-18%, depending on the atmospheric conditions. The entire process takes place at atmospheric temperature and pressure. Therefore, the only energy requirement for the process is associated with the electricity required to drive the machinery.

Assessment methodology

This work performs the life-cycle impact assessment (LCIA) of the coal pellet production using the technology developed by Changeover Technologies. The assessment was conducted in line with the requirements of the standardised life-cycle assessment approach (ISO14040:2006) in OpenLCA using the US Life Cycle Inventory Database by National Renewable Energy Laboratory[1]. This work used the harmonised method to LCIA (ReCiPe method[2]) and considered the following ReCiPe impact indicators:

- midpoint indicators (Table 1)
    - global warming potential (GWP)
    - fossil depletion
    - human toxicity
    - particulate matter formation
    - marine eutrophication
    - terrestrial acidification
- endpoint indicators
    - damage to ecosystems
    - damage to human health
    - damage to resource availability

Table 1: Overview of the ReCiPe midpoints[2]

Indicator	Description
Global warming potential (kg $CO_{2,eq}$/GJ)	Represents the atmospheric greenhouse gas emissions that lead to increased global warming. Increased temperature causes damage to human health and ecosystems.
Fossil depletion (kg oil_{eq}/GJ)	Represents the increased cost associated with an increase in fossil fuel extraction (i.e. conventional oil is cheaper to extract than enhanced oil recovery).
Human toxicity (kg 1,4-DCB_{eq}/GJ)	Represents environmental persistence, accumulation in the human food chain, and toxicity of a specific chemical. Emission to the environment causes damage to human health and ecosystems.
Particulate matter formation (kg $PM10_{eq}$/GJ)	Represents the air pollution of particulate matter that results in aerosols creation in the atmosphere. Increased aerosols concentration causes damage to human health.
Marine eutrophication (kg N_{eq}/GJ)	Represents runoff of plant nutrients from the soil into riverine or marine systems, causing an increase in nutrients level. Nutrient enrichment can cause damage to ecosystems.
Terrestrial acidification (kg $SO_{2,eq}$/GJ)	Represents the atmospheric deposition of inorganic substances (sulphates, nitrates, phosphates) that can change soil's acidity. Unoptimal level of inorganic substances causes damage to ecosystems.

The ReCiPe method can be performed considering different cultural perspectives representing different expectations of how technology development can mitigate the damage in the future[2]. These cultural perspectives can be summarised as:

- individualist perspective (optimistic) expects that the technology can mitigate damages in the short term;
- hierarchist perspective (baseline) expects that the technology can mitigate damages in the mid-term;
- egalitarian (pessimistic) expects that the Technogym can mitigate damages in the long-term.

The hierarchist perspective was taken as a default cultural perspective in this study. However, in the case of the GWP, the comparison between different perspectives was made to understand how these may influence the GWP of the considered process.

The process included in the scope of this study includes four distinctive stages, as detailed in the process overview above, representing the cradle-to-gate system boundary. The consumption of materials and energy required to construct the machinery and equipment is not included in this study[3]. The functional unit used in this analysis is the design pellet output of 50 t/hr(db). The results shown in this report are normalised, using the calorific value of the final product of 28.85 GJ/t.

Inventory analysis

The inputs and outputs for the analysed MetaForm process have been provided by Changeover Technologies. The data provided included energy and material balances for each step of the process, enabling cradle-to-gate analysis.

At the extraction step, 250 t/hr of coal-rich slurry is harvested from the coal impoundment. This step requires a pit front-end loader, two pit-trucks and a plant front-end loader. Each unit is assumed to consume 7 gallons of diesel per hour (~0.0265 m3/hr)[4]. The emissions associated with diesel combustion were estimated based on the data presented in Table 2.

Table 2: Summary of atmospheric emissions from diesel combustion[5]

Diesel emission (Euro V)	Value (g/L)
CO_2	2684.00
CO	16.08
NO_x	21.44
HC	4.93
PM	0.21

Table 3: Extraction process inputs and outputs

Parameter	Input	Output
Coal-rich slurry impoundment [t/hr]	250	
Diesel [gal/hr]	28	
Coal-rich slurry extracted [t/hr]		250
CO2 emission [kg/hr]		284.48
CO emission [kg/hr]		1.70
NOx emission [kg/hr]		2.27
HC emission [kg/hr]		0.52
PM emission [kg/hr]		0.02

At the washing step, the high moisture content in the extracted coal-rich slurry is reduced to 20%. The only input to this process is electricity to drive the moisture separation equipment. For the washer processing 250 t/hr of coal-rich slurry, the energy requirement has been estimated to be 503.55 kW, as summarised in Table 4.

Table 4: Washing process inputs and outputs

Parameter	Input	Output
Coal-rich slurry extracted [t/hr]	250	
Electricity [kW]	503.55	
Feed conveyor [kW]	18.65	
Scalping screen [kW]	18.65	
Feed slurry pump [kW]	74.60	
Froth cells [kW]	111.90	
Centrifuge [kW]	186.50	
Tailings slurry pump [kW]	74.60	
Product conveyor [kW]	18.65	
Extracted coal, wet [t/hr]		62.5
Coal-lean slurry to impoundment [t/hr]		187.5

Once the coal fines have been harvested and washed, they are transported to the MetaForm pelletiser for densification and cold curing. At the densification step, the coal fines are mixed with a small fraction of the binder (~0.4%). Because of its marginal content and proprietary formulation, the binder has not been included in the analysis. The only input to this process is electricity to drive the process. It is also the case for the cold curing process. The energy requirement for both steps is summarised in Table 5.

Table 5: MetaForm pelletiser inputs and outputs

Parameter	Input	Output
Densifying step		
Extracted coal, wet [t/hr]	62.5	
Electricity [kW]	1443	
Coal pellets, wet [t/hr]		62.5
Cold curing step		
Coal pellets, wet [t/hr]	62.5	
Electricity [kW]	120	
Cured pellets, dry [t/hr]		50
Water vapour [t/hr]		12.5

It is initially assumed that the electricity is supplied via the natural gas combined cycle power plant in the US. The total energy requirement of the MetaForm process is 0.034 kWh/kg$_{drypellet}$. Its environmental impact has been determined using the predefined electricity generation process from natural gas available in the U.S. Life Cycle Inventory Database by National Renewable Energy Laboratory[1].

Environmental impact assessment and interpretation

Assessment under initial design conditions

The initial assessment of the MetaForm process has revealed that its cradle-to-gate global warming potential (GWP) would be 2.73 $kgCO_{2,eq}/GJ$ if the electricity consumed by the process is supplied via the natural gas combined cycle power plant. For the process that produces pellets at 50 t/hr, this corresponds to 3,923.73 $kgCO_{2,eq}$ emitted into the atmosphere over the period of 100 years. To better appreciate the distribution of these emissions, the contribution of each process stage to the total GWP is presented in Figure 2. The extraction and washing stages account for most of the GWP (71.2%), as their operation results in the GWP of 1.94 $kgCO_{2,eq}/GJ$. This is associated with the diesel extraction (1.68 $kgCO_{2,eq}/GJ$) and subsequent combustion (0.25 $kgCO_{2,eq}/GJ$). The MetaForm process developed by Changeover Technologies results in the GWP of 0.78 $kgCO_{2,eq}/GJ$ (28.8%). These emissions stem solely from the electricity required to drive the process equipment.

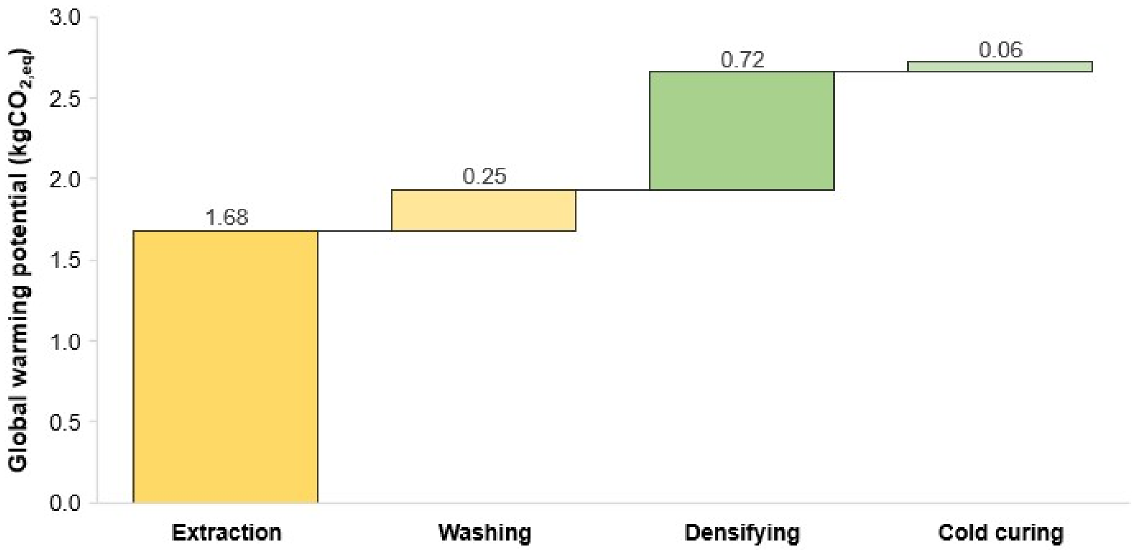

Figure 2: Distribution of global warming potential for the MetaForm process under hierarchist (GWP100a) perspective

The initial analysis of the process implies that a significant reduction in the GWP can be achieved if the front-end loaders and pit trucks are replaced with more environmentally friendly alternatives. Potential options include a fuel switching from diesel to biodiesel or electrification of the process. In the latter case, the electricity should be supplied from a low-carbon source. In the case of the MetaForm process, the majority of the GWP comes from the electricity requirement in the densifying unit. As the initial analysis considered that the electricity is produced in the natural gas combined cycle power plant, low-carbon alternatives, such as renewables and nuclear, should be considered for power generation.

Comparison of the MetaForm process and conventional coal mine

The main aim of the MetaForm process is to reduce the environmental impact of the coal supply to the industries that utilise coal as part of their operation, such as the steel industry. Therefore, its environmental performance needs to be compared with the coal supply from the conventional coal mine. The cradle-to-gate GWP100a of the conventional coal supply in the US was estimated to be 12.76 $kgCO_{2,eq}$/GJ (Figure 3), assuming the average calorific value of the bituminous coal is 28.83 GJ/t. These emissions mostly stem from the coal mine operation associated with its diesel, residual oil and electricity requirement, and residual methane emissions (i.e. 4 kg CH_4 per tonne of coal extracted) specified in the NREL database[1]. For the supply of 50 t/hr of bituminous coal, the conventional mine will result in CO_2, CO and CH_4 emissions of 18186.1 $kgCO_2$, 557.8 kgCO and 376.6 $kgCH_4$, respectively, over the period of 100 years. It is equivalent to the absolute GWP of 18,392.3 $kgCO_{2,eq}$ under the hierarchist perspective. Comparing the GWP of the conventional coal process and the MetaForm process, including the harvesting and washing steps, it can be observed that the latter has the potential to reduce the GWP associated with coal supply by up to 78.7%. It is a significant reduction, considering that the operation of the MetaForm process is still driven by diesel and natural gas.

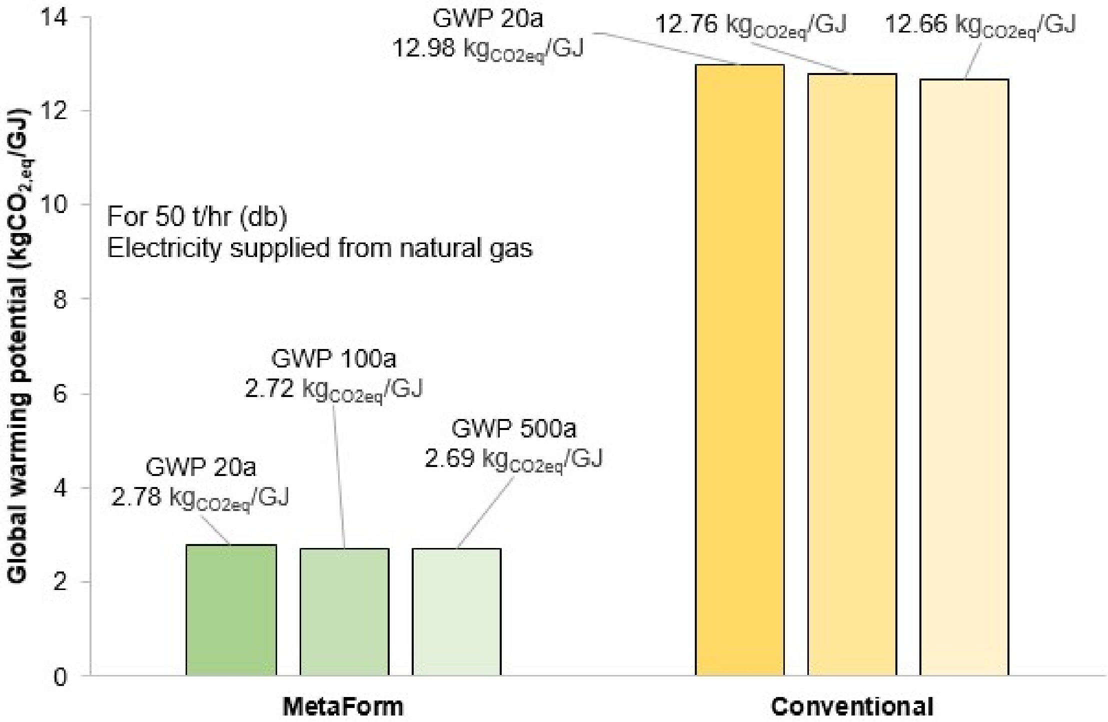

Figure 3: Comparison of global warming potential for pellet coal and conventional coal considering individualist (GWP20a), hierarchist (GWP100a) and egalitarian (GWP500a) perspectives

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Figure 3 also presents different cultural perspectives that were considered in the LCIA. This analysis showed that depending on the cultural perspective taken in the analysis, the GWP varies only by up to 2%. In all considered cases, the reduction in the GWP potential associated with the MetaForm process was up to 78.7%. Therefore, the cultural perspective is deemed insignificant, considering the scope of this analysis and the remaining part of this report takes the hierarchist view (baseline).

To understand the broader environmental performance of the MetaForm process and the conventional coal mining process, a range of midpoint indicators were assessed (Table 6). Considering the cradle-to-gate performance of both processes, it is apparent that the pelletised coal produced from the waste coal impoundments can reduce our reliance on fossil fuels, as its contribution to fossil depletion is 83.9% lower than that in conventional coal mining. It can be explained by a significant reduction in the fossil fuels required to produce the same amount of pellets compared to the conventional coal process (Table 7)[1].

Table 6: Comparison of environmental midpoint impact categories for pellet coal and conventional coal under hierarchist (baseline) perspective

Indicator	MetaForm	Conventional	Relative change (%)
Fossil depletion (kg oil_{eq}/GJ)	6.67	38.78	-82.81
Human toxicity (kg 1,4-DCB_{eq}/GJ)	10.17	62.89	-83.83
Particulate matter formation (kg $PM10_{eq}$/GJ)	0.01	0.04	-78.13
Marine eutrophication (kg N_{eq}/GJ)	0.01	0.04	-82.10
Terrestrial acidification (kg $SO_{2,eq}$/GJ)	0.03	0.12	-75.97

Table 7: Comparison of fossil fuels requirements for pellet coal and conventional coal at the throughput of 50 t/hr

Fossil requirement	MetaForm	Conventional
Bituminous coal, combusted in industrial boiler (kg/hr)	0	21.56
Natural gas, combusted in the industrial boiler (m3/hr)	0	8.08
Gasoline, combusted in equipment (L/hr)	0	41.82
Residual fuel oil, combusted in the industrial boiler (L/hr)	0	43.49
Diesel, combusted in the industrial boiler (L/hr)	0	440.21
Diesel, combusted in equipment (L/hr)	106	0
Electricity (kW)	2066.55	1935.95

In general, the supply chain of pelletised coal is much shorter and simpler than that of conventional coal. As a result, the formation of particulate matter and negative effects on the ecosystems, for example, via eutrophication and acidification routes, and human toxicity reduced by 78–84%. This implies that the recovery of waste fines from coal impoundments is a viable way to improve the overall environmental performance of the coal supply to industrial performance.

Considering the endpoint indicators, the coal pellets supplied via the MetaForm process are expected to be associated with less damage to ecosystems, human health and resource availability compared to the coal supplied via the conventional mining process. Figure 4 indicates that the damage to the ecosystem (*species loss per year due to the environmental impact of a given process*) will be reduced by 78.7%. Similarly, the damage to human health (*disability-adjusted loss of life years due to the environmental impact of a given process*) will be reduced by 82.4%. Finally, the damage to resource availability (*surplus cost of using a given process*) will be reduced by 83.9%.

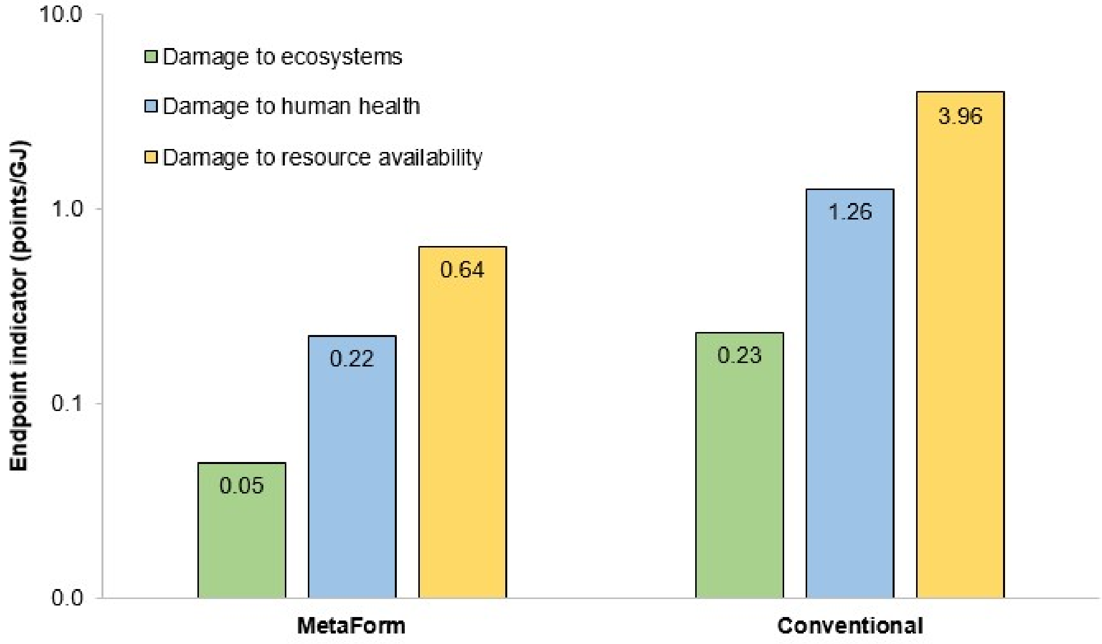


Figure 4: Comparison of environmental endpoint impact categories for pellet coal and conventional coal under hierarchist (baseline) perspective

Effect of coal supply source on global warming potential of industrial processes

To understand the benefits of using the coal pellets produced in the MetaForm process in the industrial processes, the global warming potential of the steelmaking plant is assessed (Figure 5). Based on the ultimate analysis of the MetaForm pellets and conventional coal, the CO_2 emissions associated with coal use in the steel plant were estimated to be 90.1 $kgCO_{2,eq}/GJ$ and 89.8 $kgCO_{2,eq}/GJ$, in line with the data reported in the literature[6]. Transport is not considered at this stage. The analysis has shown that the overall GWP of steelmaking will be 92.82 $kgCO_{2,eq}/GJ$ when the coal is supplied from the MetaForm process. This is 9.5% less than the GWP for the conventional process (102.56 $kgCO_{2,eq}/GJ$). This implies that decarbonisation of the supply chain can bring a meaningful reduction in industrial CO_2 emissions, even before these processes are fully decarbonised.

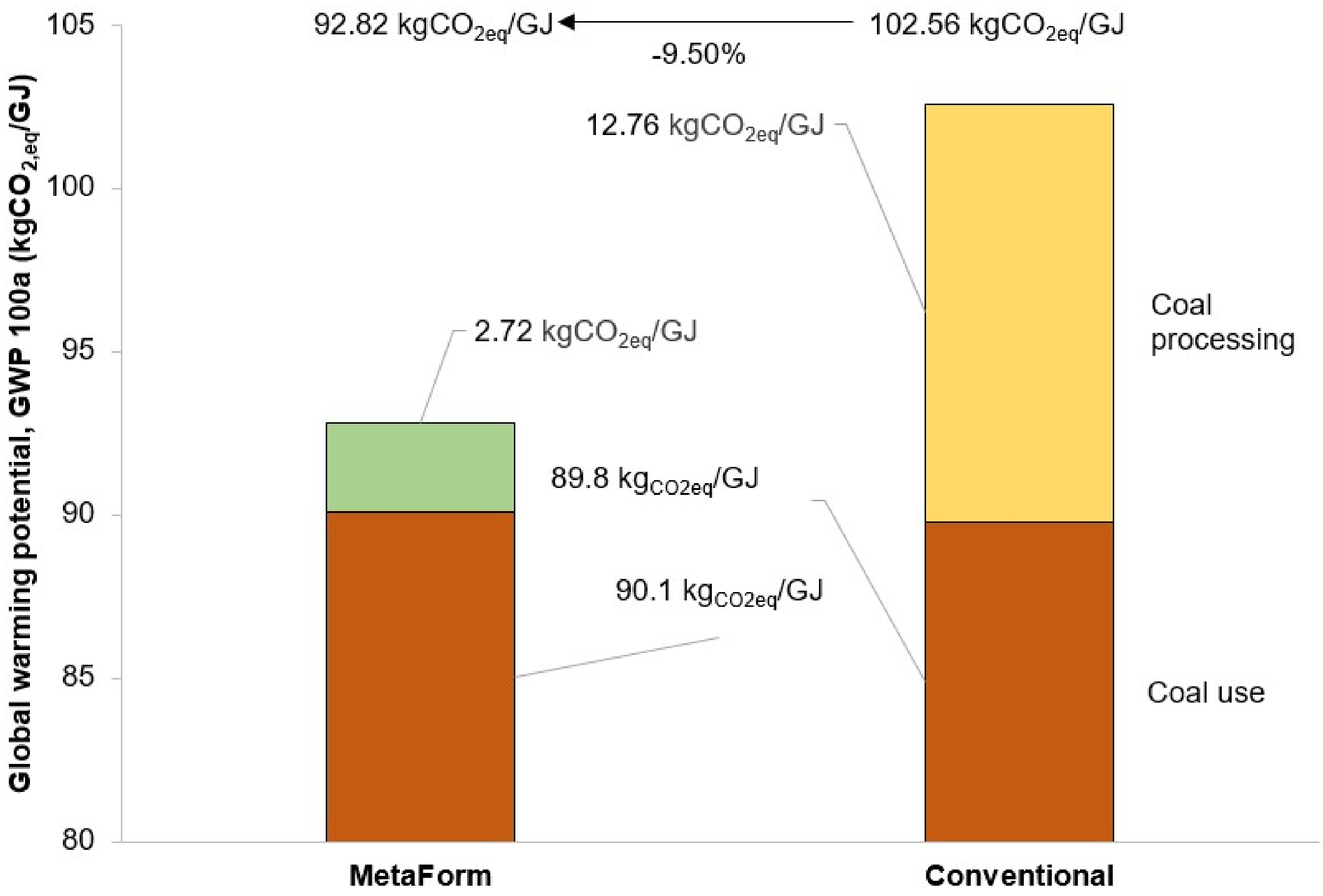
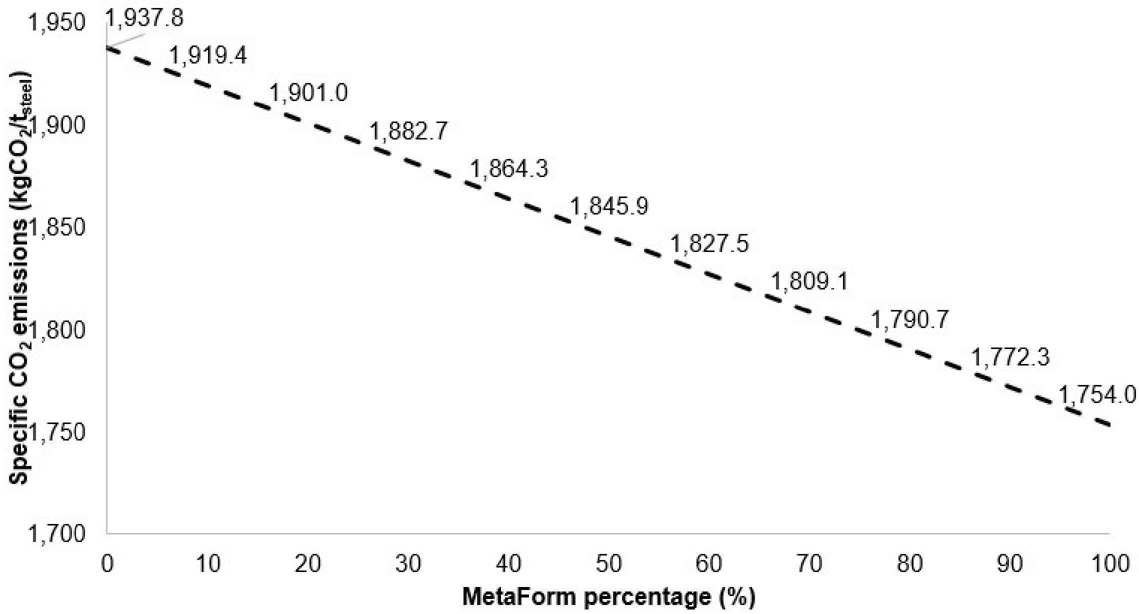


Figure 5: Comparison of the global warming potential for pellet coal and conventional coal application in steelmaking plant under hierarchist (GWP100a) perspective

Steelmaking and cement industries need to be fully decarbonised, as these industries are crucial to achieving the sustainable growth of our economy. Even though the operation of renewable energy sources does not result in CO_2 emissions, the manufacturing of their components and foundations requires steel and cement. For example, approximately 150 (onshore) to 250 (offshore) tonnes of coal is required to produce the steel for manufacturing a single wind turbine. A complete substitution of the conventional coal used in the metallurgical processes with the MetaForm pellets can reduce the specific CO_2 equivalent emissions by 9.5%, from 1937.8 $kgCO_{2eq}/t_{steel}$ to 1754.0 $kgCO_{2eq}/t_{steel}$ (Figure 6a). Such a reduction will contribute to the production of net-zero wind turbines (Table 8). Importantly, a partial substitution of, for example, 40% MetaForm pellets in the coke oven will result in a 3.8% reduction in the lifetime CO_2 equivalent emissions of steelmaking, considering both coal processing and coal use (Figure 6b). Similar conclusions can be drawn for the cement industry (see Appendix A)



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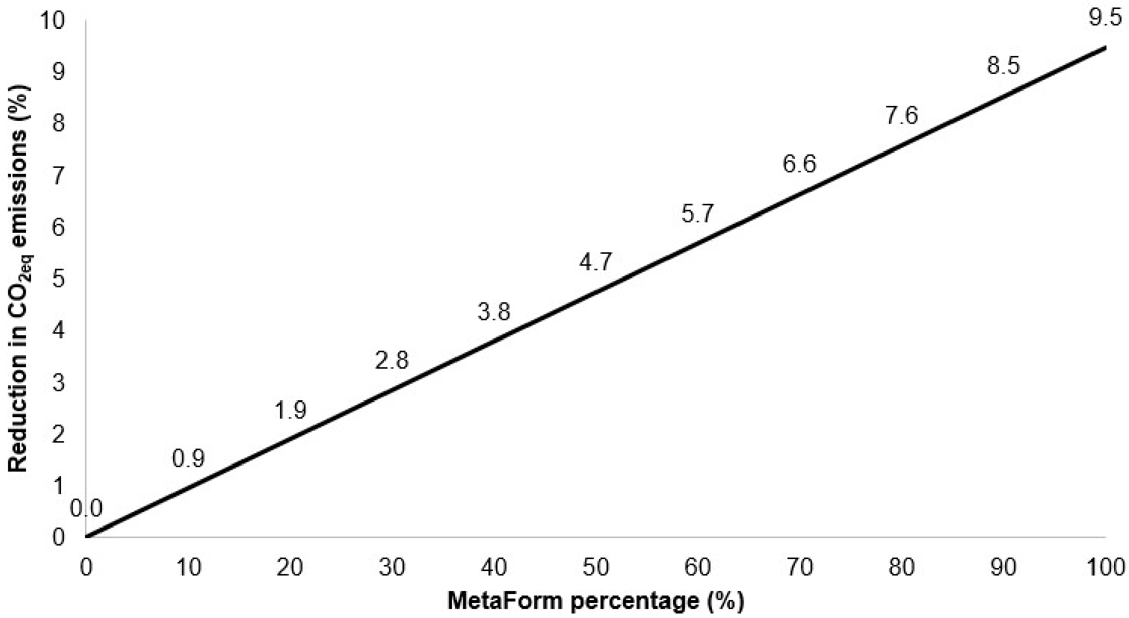

b)

Figure 6: Effect of MetaForm percentage use in the steelmaking plant on specific CO_2 emissions

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Table 8: Comparison of lifetime emissions for onshore and offshore wind turbines made with steel that was produced from MetaForm pellets and conventional coal

Parameter	Onshore wind turbine	Offshore wind turbine
Coal requirement for steel manufacturing (t_{coal}/turbine)	150.0	250.0
CO_2 emissions per turbine made with MetaForm ($kgCO_2$/turbine)	401,602.4	669,337.3
CO_2 emissions per turbine made with conventional coal ($kgCO_2$/turbine)	443,389.7	738,982.8
Average turbine output (MW)	2.5	4.0
Average load factor (-)	0.3	0.3
Annual operating time (h)	2,190.0	2,628.0
Lifetime (years)	20.0	20.0
Electricity produced (MWh)	109,500.0	210,240.0
Specific lifetime emissions [MetaForm] ($kgCO_2$/MWh)	3.7	3.2
Specific lifetime emissions [Conventional ($kgCO_2$/MWh)	4.0	3.5

Effect of electricity source on environmental impact

The analysis presented above assumed that the electricity required to drive the MetaForm process was supplied from a natural gas combined cycle power plant. Although the environmental performance of such a process is improved compared to the conventional coal process, it is worth exploring if the use of other electricity sources would result in a further improvement in environmental performance. For comparison purposes, coal, biomass, nuclear and wind are considered as potential electricity sources for the MetaForm process.

Figure 7 demonstrates that if the MetaForm process is driven by the electricity produced in an unabated coal-fired power plant, its GWP will be 28.8% higher than that of the process driven by natural gas. Yet, the MetaForm process still remains competitive to the conventional coal process, offering a 72.6% reduction in the GWP. A further reduction in the GWP to 1.68–1.77 $kgCO_{2,eq}$/GJ can be achieved if renewables (biomass and wind) or nuclear are considered as the electricity sources. However, the influence of the cost of electricity on the economic viability of the MetaForm process needs to be assessed before these sources are considered.

It can be observed that the GWP for the MetaForm process driven by wind electricity stems solely from the extraction step. It means that the MetaForm pelletiser operation does not contribute to global warming if it is driven by wind energy. A further reduction in the GWP can be achieved by replacing diesel used as a fuel in the front-end loaders and pit trucks with low-carbon alternative fuels, such as biodiesel, hydrogen or low-carbon synthetic fuels. However, the influence of the cost of low-carbon fuel and replacing the existing equipment on the economic viability of the MetaForm process needs to be assessed before these changes are considered.

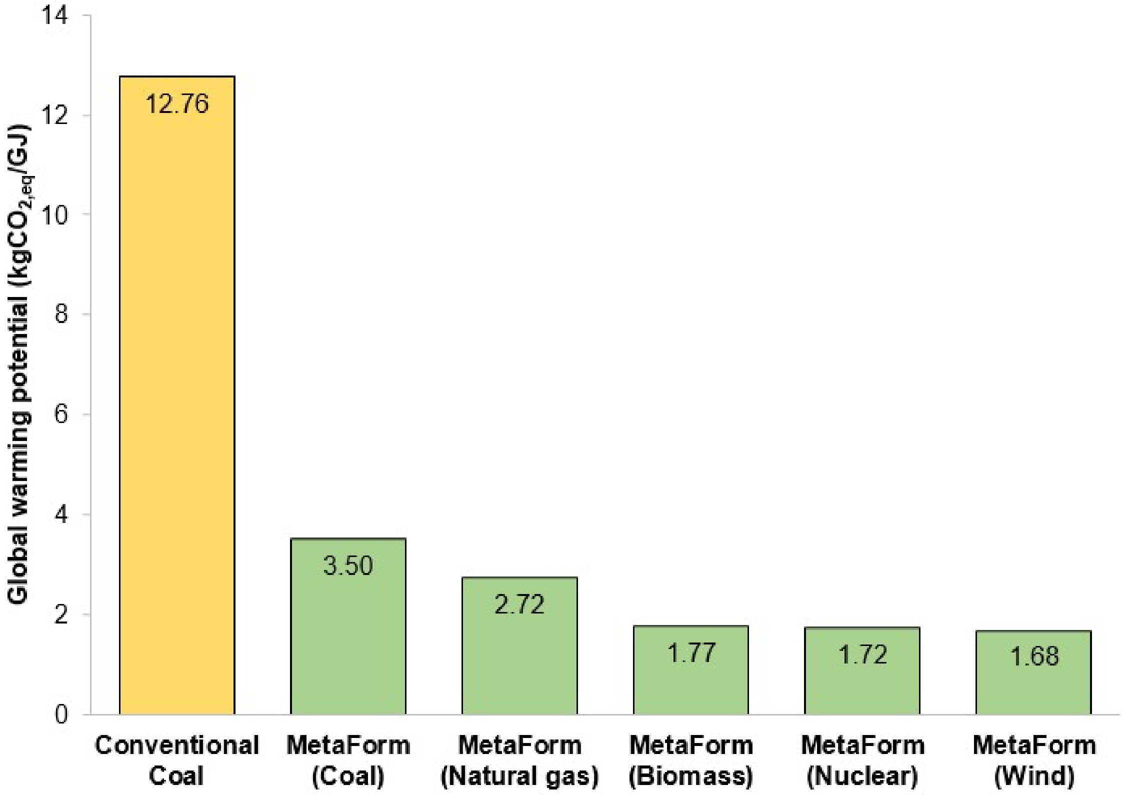
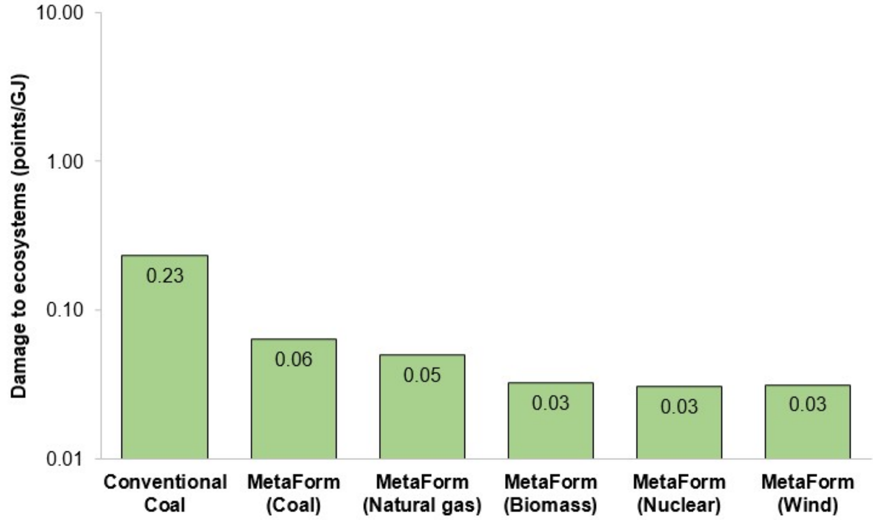


Figure 7: Effect of electricity source on the global warming potential of the MetaForm process under hierarchist (baseline, GWP100a) perspective

The effect of the electricity source on the environmental midpoint impact categories is presented in Table 9. It can be concluded that the use of renewables and nuclear sources will bring a further reduction in fossil depletion and human toxicity. The potential reductions in eutrophication, acidification and particulate matter formation are less pronounced. This is because those stem mostly from the diesel requirement in the extraction and washing steps. For this reason, the added environmental benefits of using low-carbon electricity sources are small in terms of the potential reduction in the damage to ecosystems, human health, and resource availability (Figure 8). Therefore, it is recommended that the cost-benefit analysis is undertaken to understand whether such low-carbon options are economically viable.

Table 9: Comparison of environmental midpoint impact categories for pellet coal and conventional coal under hierarchist (baseline) perspective

Indicator	Conventional	MetaForm (Coal)	MetaForm (Natural Gas)	MetaForm (Biomass)	MetaForm (Nuclear)	MetaForm (Wind)
Fossil depletion (kg oil_{eq}/GJ)	32.96	5.61	5.31	4.62	4.62	4.56
Human toxicity (kg 1,4-DCB_{eq}/GJ)	53.44	9.13	8.10	7.49	7.49	7.38
Particulate matter formation (kg $PM10_{eq}$/GJ)	0.03	0.01	0.01	0.00	0.00	0.00
Marine eutrophication (kg N_{eq}/GJ)	0.03	0.01	0.01	0.01	0.01	0.01
Terrestrial acidification (kg $SO_{2,eq}$/GJ)	0.11	0.03	0.02	0.01	0.01	0.01



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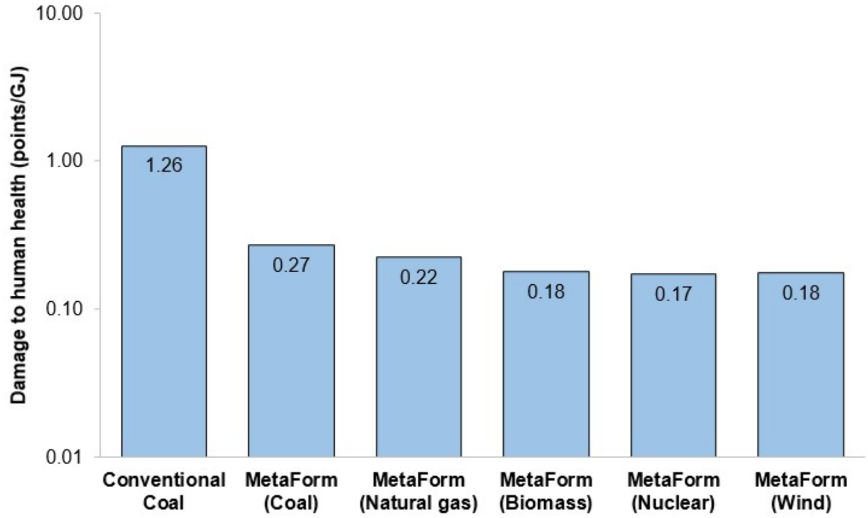

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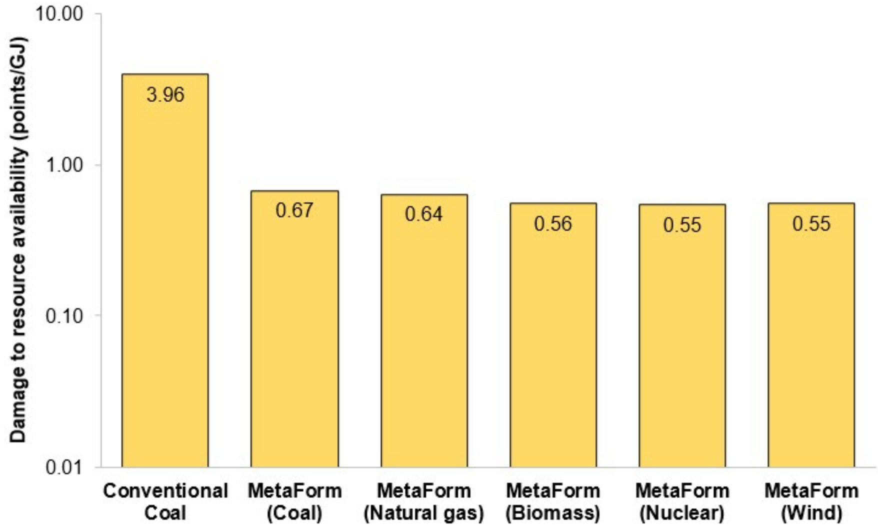

c)

Figure 8: Effect of electricity source in the MetaForm process on damage to a) ecosystem, b) human health, and c) resource availability under hierarchist (baseline) perspective

Effect of electricity mix on environmental impact

It is likely that the MetaForm process will be driven by electricity from the grid. Therefore, it is worth examining how this process will perform under different grid conditions. Using the predefined processes in the database by the US Life Cycle Inventory Database by National Renewable Energy Laboratory[1], the grids in Kansas, Texas and California were considered. Figure 9 presents the distribution of the electricity sources in selected local grids. It can be noted that the Kansas grid represents a scenario that is highly dependent on coal, natural gas and nuclear sources. On the contrary, the California grid represents a more balanced scenario that mostly relies on natural gas, nuclear, and various renewables. The Texas grid represents a scenario of high dependency on fossil fuels, but with natural gas as the main source of electricity.

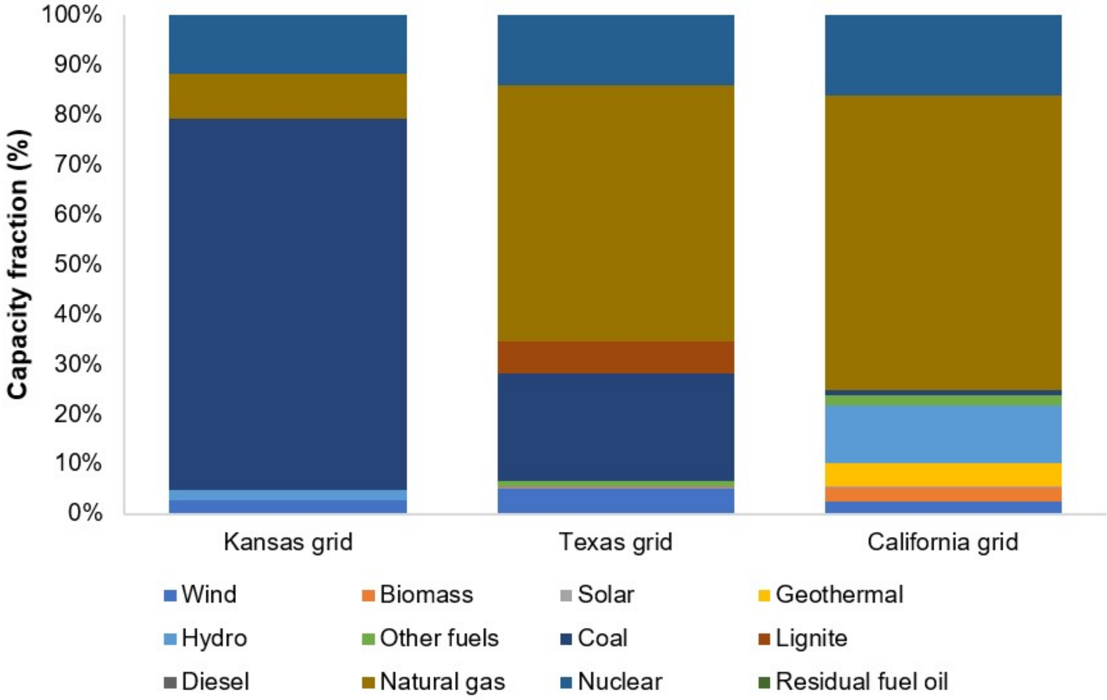

Figure 9: Distribution of electricity sources in Kansas, Texas and California grids[1]

The results presented in Figure 10 are in line with the discussion presented above. Namely, the GWP of the MetaForm process will be lower in the grids with a higher penetration of renewable energy, such as the California grid (2.33 $kgCO_{2,eq}$/GJ). This is 25.8% lower than in the case of the coal-reliant Kansas grid. Nevertheless, this proves that the MetaForm process can be viable, considering the realistic grid conditions.

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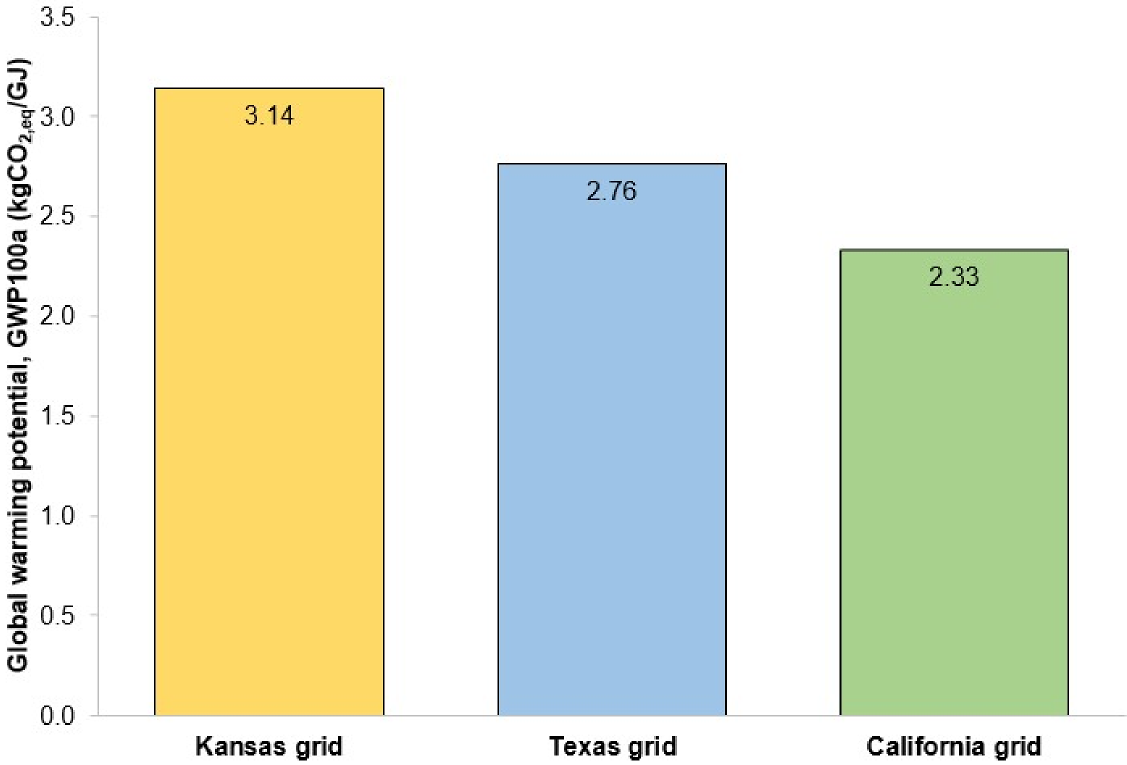

Figure 10: Effect of electricity mix on the global warming potential of the MetaForm process under hierarchist (baseline, GWP100a) perspective

Effect of process uncertainty on environmental impact

The environmental performance of the MetaForm process presented before relied on the deterministic assumptions provided by Changeover Technologies. Such an approach to environmental assessment does not account for any uncertainties and inaccuracies in the input/output data representing the process performance. As the environmental impact of the considered process depends on diesel and electricity consumption, these were considered as stochastic variables. It is assumed that each variable will be normally distributed with a coefficient of variation of 20% (Table 10). The stochastic assessment is performed for the MetaForm process driven by the electricity from the natural gas combined cycle power plant.

Table 10: Assumptions for the stochastic modelling

Parameter	Mean value	Coefficient of variation
Diesel consumption at extraction stage (m^3/kg slurry)	4.2397E-7	20%
Electricity requirement at washing stage (kWh/kg extracted coal)	0.008060	20%
Electricity requirement at densifying stage (kWh/kg coal pellets)	0.023088	20%
Electricity requirement at cold curing stage (kWh/ kg cured pellets)	0.002400	20%

The stochastic assessment (Figure 11) has indicated that the mean value of the GWP, and hence the most likely value for this indicator, was shown to be 2.72kg$CO_{2,eq}$/GJ with a standard deviation of 0.34 kg$CO_{2,eq}$/GJ. There is a 95% probability that the GWP of the MetaForm process driven by natural gas will fall within 2.05 kg$CO_{2,eq}$/GJ and 3.39 kg$CO_{2,eq}$/GJ (2σ interval). The estimated mean value is in line with the deterministic assessment. The full range for the GWP considering the ±20% variation in the electricity and diesel requirement was estimated to be between 1.38 $kgCO_{2,eq}/GJ$ and 4.17 $kgCO_{2,eq}/GJ$.

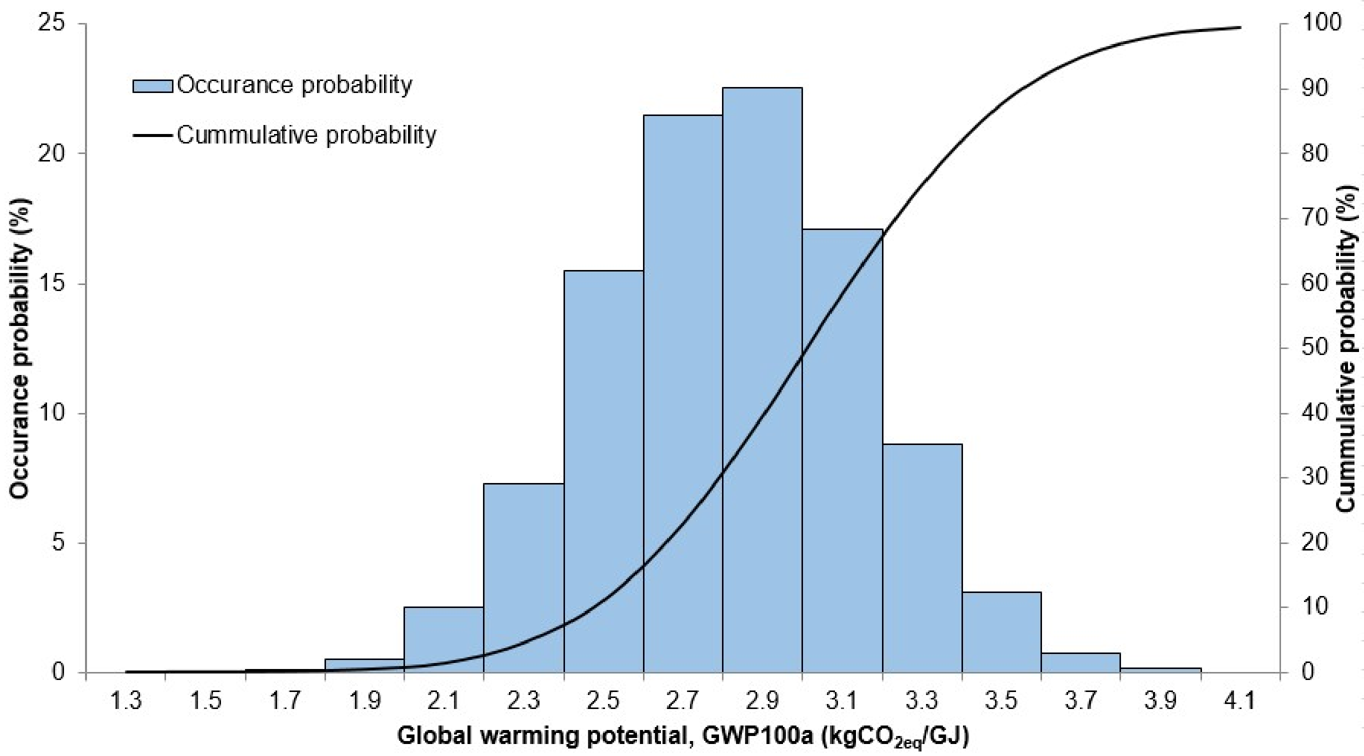

Figure 11: Effect of uncertainty on global warming potential of the MetaForm process under hierarchist (baseline, GWP100a) perspective

Conclusions and recommendations

This study aimed to perform the life-cycle environmental impact assessment of the coal pellet production using the technology developed by Changeover Technologies and compare it with the performance of the conventional coal process. It is concluded that:

- the cradle-to-gate global warming potential of the MetaForm process (2.72 kg$CO_{2,eq}$/GJ) is 78.7% lower than that of the conventional coal process (12.76 kg$CO_{2,eq}$/GJ);
- the uncertainty analysis has indicated that the GWP of the MetaForm process driven by natural gas will fall within 2.05 kg$CO_{2,eq}$/GJ and 3.39 kg$CO_{2,eq}$/GJ (95% probability)
- the MetaForm process with the throughput of 50 t/hr will emit 3,923.73 kg$CO_{2,eq}$ into the atmosphere over the period of 100 years, compared to 18,392.3 kg$CO_{2,eq}$ for the conventional coal process;
- use of the waste coal from impoundments can reduce our reliance on fossil fuels as the MetaForm process can reduce the fossil depletion by 83.9% compared to that in conventional coal mining;
- the use of the coal pellets produced in the MetaForm process can result in an immediate reduction of the industrial greenhouse gas emissions, for example, by 9.5% in the case of steelmaking.

To achieve net-zero production of coal pellets, the recommendations from this study are:

- to consider alternative low-carbon fuels or energy vectors in place of the diesel-driven front-end loaders and pit trucks at the extraction stage; and
- to consider low-carbon sources of electricity (wind, biomass) to meet the requirement of the MetaForm process.

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Appendix A: Potential CO_2 emission reductions in the cement industry

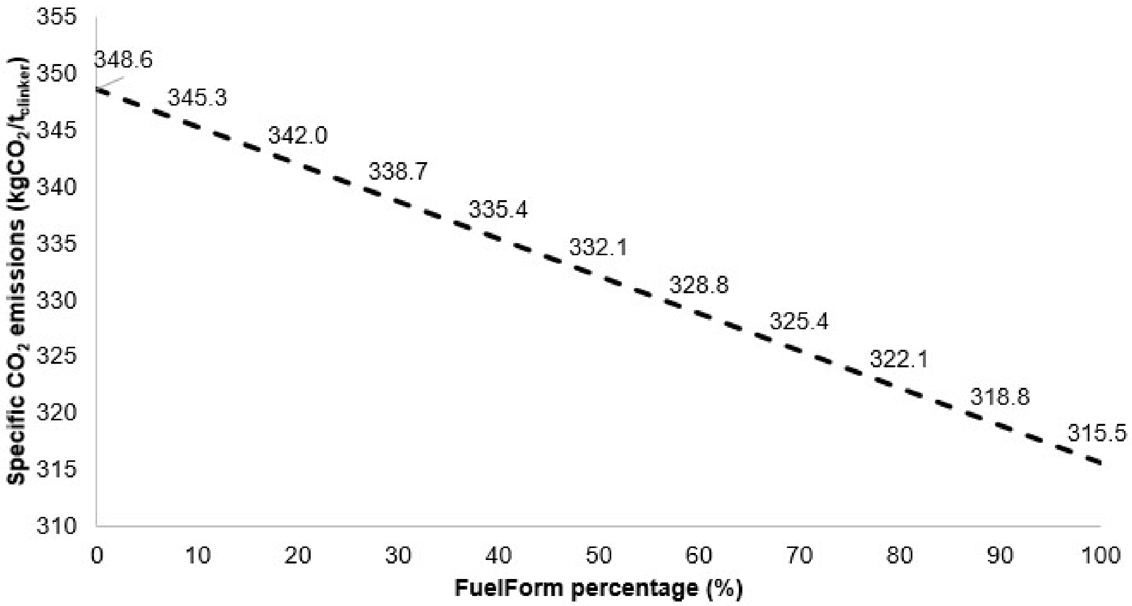

Figure A-1: Effect of FuelForm percentage use in the cement plant on specific CO_2 emissions

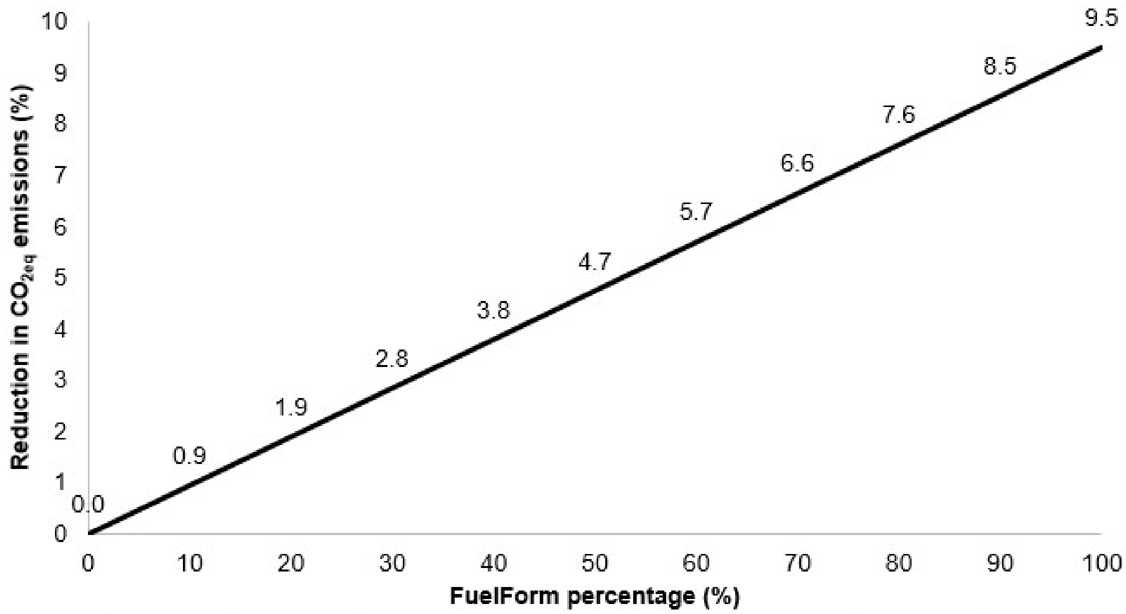

Figure A-2: Effect of FuelForm percentage use in the cement plant on CO_2 emission reduction

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