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Techno-economic Analysis of Methanol and Power Generation from Waste Tires

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Abstract

This work investigates the influence of tire subsidy on the minimum selling price of methanol and electricity produced from a poly generation process utilizing waste tires as feedstock. Waste-to-energy and chemical processes are often not cost-competitive to fossil-based processes due to high carbon taxes, poor or lack of subsidies, and low thermal efficiency. However, since waste tires are an environmental hazard, waste tire conversion processes must be provided with competitive subsidies or levies to make them competitive with fossil-based fuels. This study developed two process models to evaluate the potential to produce electricity and methanol from waste tires. Aspen Plus and Aspen Hysys were used to simulate the processes' detailed heat and material balance. The process modeling results, including the composition, flow rate, temperature, pressure, and enthalpy of different streams, were used to determine the sizes and cost of the process units and related equipment. A high-level economic model was prepared to evaluate the economic viability of the two processes. The actual selling price of methanol and electricity was estimated by setting the NPV equal to $0. A minimum government subsidy of 0.115 $/kg is required to make the process economical and cost-competitive to fossil-fueled plants. With the subsidy, the minimum selling price for electricity would be $ 0.098/kWh and that of methanol at $420/ton.

Keywords
Techno-economic analysis, Polygeneration, Power, Methanol, Aspen Plus, Subsidy

1. Introduction
This work presents a desktop economic study and optimization of a poly-generation process to produce electricity and methanol using waste tires as a carbon source. A techno-economic analysis is conducted to assess the required capital investment as well as the levy necessary to make these waste-to-energy processes cost-competitive to fossil-based plants. Polygeneration systems have an advantage in that multiple processes are integrated into one chemical system to take advantage of synergies between them thus increasing efficiency. For example, exothermic heat from one process drives an endothermic reaction in another. Second, profitability gains can be achieved by operating the plant flexibly enough to change the proportions of feedstocks used and the proportions of products produced in response to fluctuating market prices (Salkuyeh and Adams 2014). The costs have been estimated for a waste tire gasification plant in South Africa. The analysis is based on present-day conventional downdraft gasifier technology. Two cases are simulated, the one converts tire to electricity only, and the second produces methanol and power. For both cases, 550 tons/day of waste tires are fed, corresponding to about 216 MW thermal input. The performance of the developed process will be assessed against the performance targets set up in previously published work (A. Mavukwana et al. 2021; Mavukwana et al. 2020). In prior work, we demonstrated through a high-level process synthesis that waste tire gasification routes are better suited for waste tires than pyrolysis; however, there is a penalty of 45 percent carbon emissions and a high capital cost. Aspen Plus ® and Aspen Hysys ® are used in conjunction for the scale-up and optimization of the power and methanol production. The impact of poly generation, and tire tax, on economic performance, is determined using a sensitivity analysis analysis.

1.1 Objectives
- Use Aspen plus to simulate the optimal tyre conversion to methanol process targets.
- Conduct a techno-economic analysis of the processes developed to assess their profitability.
- Investigate the impact of tire levy on process profitability.

2. Literature Review
Waste tire generation and recycling are still a problem around the world. The USA alone generated over 274 million scrap tires representing over 5 million tons of scrap waste tires in 2021 (U.S. Tire Manufacturers Association, 2022). Europe produced 4.24 million tons of tires in 2020 (European Tyre and Rubber Industry Manufacturers Association, n.d.). The amount of waste tires has also increased in developing countries. For example, in 2022 South Africa generated an estimated 250,000 metric tons of waste tires adding to an existing stockpile of 900,000 metric tons spread across 26 national storage depots without a robust plan for reprocessing or recycling Jenkin (2022a). The Waste Management Bureau (WMB) of South Africa took over the responsibility of waste tire management in 2017 and has made collective efforts to divert waste tires from landfills into 28 depots across the country, where they wait for potential reuse or treatment. However, the WMB has been challenged with the development of processing capacity since it started managing waste tire operations. Many waste tire contracted processors stopped their operations in 2019 due to expired licenses, contract disputes, adherence to emissions standards, and non-profitability and others simply ceased operations post the COVID-19 lockdown.

In South Africa, the recycling and reuse of waste tires is about 20% while the rest are stockpiled (South Africa. Department of Forestry Fisheries & the Environment. National Environment Management: Waste Act, n.d.). Whereas in Europe the recycling and reuse rate is more than 95% (Sebola et al. 2018). The European Tire and Rubber Manufacturers' Association (ETRMA) reported that in 2021, about 95% of waste tires were collected and processed through material and energy recovery initiatives (European Tyre and Rubber Industry Manufacturers Association, n.d.). Additionally, in the United States (US), over 95% of waste tire stockpiles were eradicated by 2021, resulting in increased recycling and reuse consumption rates of more than 71% (U.S. Tire Manufacturers Association 2022). ETRMA statistics show that 48% of waste tires were treated through energy recovery and 52 % through material recycling. However, the energy recovery route produces carbon dioxide and only contributes approximately 37% of the energy necessary to produce a new tire. Waste tire processing to material recycling has been found to contribute insignificantly when implemented at an industrial scale (Formela 2021). Affirmative thermal conversion is still the preferred waste tire management methodology that is more efficient for both material and energy recovery. However, research and circular economy strategies related to the sustainable development of waste tire recycling technologies are still required to meet the rising production.

Methanol (CH_3OH) is a vital chemical in the chemicals industry; it is utilized as a primary chemical in the production of various compounds such as ethanol, formaldehyde, acetic acid, and ethers (Rashid et al. 2024). Methanol is a favorable blending agent with petrol with the benefits of improving engine performance (SGS Inspire 2020) and is a low-carbon energy source that has the potential to substitute conventional fossil fuels. Moreover, it is easy to store and transport, is biodegradable, and can be produced on a large scale (Wang et al. 2024). Its versatility and eco-friendly nature make it a valuable resource in multiple industries.

In 2018, the global demand for methanol stood at 78 900 000 metric tons per annum owing to its applications in the production of the following chemical industries: (i) fuel (24 %), formaldehyde (21 %), solvents (14%), olefin production (13%), and fuel bending (12%) (Argus Media, 2019).The global methanol market in 2023 stood at USD 30.9 billion and is expected to increase by approximately 4.6 % annually to reach USD 38.0 billion in 2028 (Markets and Markets 2024). In 2021, a methanol market assessment reported that regions such as Saudi Arabia (USD 1.60 million), Trinidad and Tobago (USD1.53 million), USA (USD 0.90 million), Russia (USD 0.63 million), and China (USD 0.14 million) were world leaders in methanol production (SGS Inspire 2020), (Narine et al.2021)(Statista 2023). In response to this, China has created methanol blend standards that are being applied to public transportation vehicles like city buses and taxis. Since 2012, the project has increased the number of vehicles that run on methanol blends. Egypt (with a market value of USD 0.26 million) is one of the few African regions that export methanol. Sasol is the primary producer of methanol in South Africa; however, it also employs 60% of the product in its chemical processes. The remaining methanol quantities are consumed for formaldehyde (31%) and methylamine (6%) production. South Africa consumes approximately 140 000 tons of methanol annually and in 2019 exported approximately 22%, 18%, 12%, and 13% to Nigeria, Taiwan, United Arab Emirates, and Singapore, accordingly (Duma, 2023).South Africa has a minuscule methanol production industry, however, with the use of general waste material (namely waste tires) and the implementation of sustainable thermochemical processes, there is potential for the industry to grow and for South Africa to be a key exporter in Africa.

Since the early 1990's advancements in methanol production from waste materials have been made by several researchers (Dong and Steinberg 1997). Soucie et al. 2023 and Poluzzi et al. 2022 assessed the performance and economic viability of the process. Abrol and Hilton, 2012 evaluated the methanol production process behavior, Haydary et al.2021 employed waste biomass to optimize the gasification agents, whereas Niziolek et al. 2015 employed municipal solid waste as feedstock to produce liquid transportation fuels, Carvalho et al. (Carvalho et al.2018) utilized black liquor to perform a techno-economic assessment to produce methanol. Similarly, successes have been achieved with the use of waste tire feedstock to generate methanol. Mavukwana and Sempuga 2021 investigated the process viability and environmental impact of the waste tire to methanol conversion process to conclude that $ 620/ton of waste tire can be generated, moreover, adversely, 45% of the carbon is converted to carbon dioxide. Additionally, Matveev et al. 2018 demonstrated the high efficiency and applicability of the waste tire-to-methanol synthesis process. Firestone Tires, in the US, carried out successful rubber-to-methanol conversion experiments to produce 300 tons/day of methanol from waste tires. The results showed promising potential for large-scale production in the future. South Africa has had success in the conversion of coal to syngas to liquid fuel technology through Sasol (Nkosi et al. 2021).

However, advances in the technology to produce chemicals such as methanol and to recover energy are still deficient. Affirmatively, several well-established reaction pathways and a variety of waste materials can be exploited to produce methanol at a large scale. In addition to methanol production from waste tires, according to Mavukwana et al., 2020, waste tire gasification to synthesis gas showed an energy output of 10.5 GJ/ton of tire as compared to the conventional conversion of coal to produce 9.6 GJ/ton of coal. Moreover, waste tires are supplied by the government at no cost for processing. This work showed that power generation can be considered as a practical waste tire management strategy in South Africa. The high heating value of WT and the availability of eco-friendly heating techniques make their treatment a feasible option.

3. Methods

This work considers a poly generation of methanol and power from waste tires through thermochemical conversion. The process discussed herein uses gasification technology to convert waste tires to syngas. This is followed by syngas cleaning and treatment to prepare it for methanol production. The syngas can also be combusted directly in gas turbines to generate electricity. The chemicals intended for study are methanol and power. Quality of syngas is required for each process route and the syngas generated in the gasification step contain tar, particulates, sulphur gases, NO_x, and CO_2 and the H_2/CO ratio is less than 2. Therefore, a sour gas removal unit as well as the water gas shift (WGS) is required during the preparation. Huge amounts of CO_2 are generated during the water-gas shift therefore CO_2 removal is also required. The three waste tire conversion processes are simulated using Aspen Plus which provides the means for mass and energy balance analyses and the models for most of the unit operations in the process, except for the MDEA-based H_2S and CO_2 removal sections that are modeled using a simple separator, based on efficiencies published in the literature (Subramanian et al. 2021).

Table 1. Waste tire thermal properties

Ultimate Analysis wt.%						**Proximate Analysis wt.% (dry basis)**				
C	H	N	O	S	Cl	Moisture	FC	VM	ASH	LHV
77.3	6.2	0.6	7.3	1.8	0	0	25.5	67.7	6.8	33.96

The performance of the processes is assessed using the thermodynamic analysis equations (1) and (2). Table 1 shows the thermal properties of waste tires used fie the study.

Table 2. Process configurations

Configuration	**Description**
WT-P	The main product is electricity. All the syngas is used for power production using an IGCC
WT-Methanol-P	Methanol is the main product, and all the off-gases are burned for electricity generation for all power-consuming units
WT-Methanol-E	Methanol is the main product; electricity is supplied externally for all power-consuming units.

$$\mathrm{LHV_{gas}} = 10.789_{y_{H2}} + 12.625_{y_{CO}} + 35.818_{y_{CH4}} + 56.044_{y_{C2H2}} + 59.034_{y_{C2H4}} \quad \text{(eq.1)}$$

$$\mathrm{CGE} = \frac{\mathrm{LHV_{gas}} \times \dot{V}_{gas}}{\mathrm{LHV_{feed}} \times \dot{m}_{feed}} \quad \text{(eq.2)}$$

$$\eta_{c,eff} = \frac{\mathrm{Carbon_{product}}}{\mathrm{Carbon_{tires}}} \quad \text{(eq.3)}$$

$$\eta_{energy} = \frac{\text{product}_{LHV} + \text{output Power}}{\text{tire feed}_{LHV} + \text{utilities}} \quad \text{(eq. 4)}$$

Economic Analysis

The process modeling results were used to estimate the total capital investment (TCI) and the operating costs in $/ton of waste tire for the two processes. The process profitability is assessed using the Net present value (NPV) which is the difference between the present value of cash inflows and the present value of cash outflows over a period and it is calculated based on the following equation.

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{Rt}{(1+r)^t} - R_o \quad \text{(eq. 5)}$$

Where Rt is the annual cash flow, being the difference between Revenues (R) and Expenditures, Operation, and Maintenance Costs. r is the discount rate and Ro is the total capital costs of investment and is the lifetime of the investment. The actual selling price of methanol and electricity was estimated by setting the NPV equal to $0 (Yakan and Patel 2022).

Equipment Costing

The costing and sizing of the equipment for the two processes were determined based on the parameters resulting from the process modeling, which included the composition, flow rate, temperature, pressure, and enthalpy of the various streams. Some of the units were handled as packages, and their sizes were determined according to the flow rates of the feeds they received. Table 3 shows the turn-key equations used to calculate the capital cost of each of the main units. The capital costs of other different pieces of equipment such as tire pretreatment and crumbing are estimated from data available for similar processing units in established literature sources considering the Chemical Engineering Plant Cost Index (CEPCI). The following equation is used to determine the present desired values.

$$C_{new} = C_{old} \cdot \left(\frac{S_{new}}{S_{old}}\right)^{\tau} \times \frac{CEPCI_{new}}{CEPCI_{old}}, \qquad \text{(eq. 6)}$$

where, C_{old} and C_{new} are the cost of the known scale and desired scale, respectively; S_{old} and S_{new} are the known scale and desired scale, respectively; τ is the power scaling factor.

Table 3. Turnkey cost (TKC) equation and cost functions for the two cases

Unit operation	**Costing equation**	**Reference**
Gasification unit	$= \frac{\text{C.E.Index}}{361.3} \cdot 316{,}800 \cdot \left(\frac{\text{feed}}{\text{1ton/day}}\right)^{0.7}$	(Esmaili et al., 2016a)
ASU	$= \frac{\text{C.E.Index}}{332} \cdot 23116{,}000 \cdot \left(\frac{\text{Oxygen flow}}{\text{3900.1 kmol/hr}}\right)^{0.6}$	(Esmaili et al., 2016b)
Cyclone, scrubber WGS, AGR,	$= 54.3 \times 10^{6} \cdot \left(\frac{\dot{m}_{syngas}}{\text{13400kg/hr}}\right)^{0.65}$	(Rivarolo et al., 2016a)
Combined cycle power plant	$= \frac{\text{C.E.Index}}{392.6} \cdot 40000000 \cdot \left(\frac{\text{Total Net Power}}{\text{69 MW}}\right)^{0.7}$	(Esmaili et al., 2016b)
Compressor, Methanol synthesis reactor, and distillation unit	$= 14.2 \times 10^{6} \cdot \left(\frac{\dot{m}_{syngas}}{\text{54000 kg/hr}}\right)^{0.65}$	(Moellenbruck et al., 2018; Rivarolo et al., 2016b)

The initial working capital is assumed to be 5% of the equipment and installation cost while the land is assumed to be 2% of the equipment and installation cost since land in South Africa is relatively cheaper compared to the more developed world.

Operating Costs

The results of the process modeling were used to estimate the annual operating cost, which comprises labor, consumables such as chemicals and catalyst and solvent makeup, utilities, maintenance, sales, administrative support, and overhead costs, as well as insurance and taxes.

Table 4. Key economic parameters

Economic parameters	
Basis year for analysis	2020
Waste tire	Free
Supplement methane price	5$/GJ
Methanol Price	$400/ton
Electricity price	$0.078/kWh
CO_2 emissions	$8 /ton
Waste disposal	18
Water	$0.002/l
Plant life	20 yrs
Fixed operating costs	
Direct labor	$19000/person
Maintenance salaries	1% of total capital investment cost
Administrative, support & overhead cost	40% of direct labor cost
Fringe benefits	30% of operators, maintenance,

Operating supplies	2% of total capital investment cost
Insurance and taxes	2% of total capital investment cost

Table 4 provides an overview of the most significant financial parameters considered in the modelling procedure. It was estimated that the labor cost for the methanol process would be 19000 dollars per year, which is equivalent to R350 000, with a total staff of 120 people, whereas the integrated gasification combined cycle (IGCC) facility would require 110 workers. The utilities account for 10% of the total equipment cost (excluding land and working capital).

4. Results and Discussion

This section presents the results of energy, mass, and economic analysis. The main parameters in energy and economic analysis are the process's overall efficiency and total capital investment and minimum selling price. Table 5 provides the performance analysis and the required capacity of each process unit. The capacities in Table 5 are also used to estimate the cost of packages based on delivery to the site (turnkey cost, TKC), based on the equations in Table 3. The methanol route achieved an overall net thermal energy efficiency of 47.12 % compared to 37.32% achieved in the IGCC route. The methanol route also provides savings in carbon emissions. By producing methanol, the carbon that would lead to CO_2 emissions is diverted to methanol. The carbon efficiency from waste tire to methanol was 49.87%, whereas all carbon in the IGCC route is converted to CO_2. The methanol route supplemented with methane produced 2.05 kg CO_2 per kg of waste tire feed compared to 2.8 kg CO_2 per kg of tire feed. However, the methanol route requires an additional 75 MW of thermal input energy since the off-gase (purge gas) combustion does not provide the sufficient energy required to reach the compressive pressure of 110 bar for the methanol synthesis reactor.

The energy is supplied either by procuring electricity or by supplementing it with methane. When methane is used to supplement the energy needed, the carbon efficiency drops from 49.87% to 40.60%. Despite this, the methanol routes still provide better performance than that of the IGCC. Alternative methods can be utilized to deliver the required energy for the methanol process such as solar energy, burning additional tires, or diverting some of the syngas to combustion. However, the carbonation efficiency achieved in this work is lower than the target set in (A. enkosi Mavukwana et al. 2021a) where the carbon efficiency was 54.5%. The current methanol route achieved a carbon efficiency of 49.87% (waste tire to methanol). The conversion of syngas to methanol is a function of pressure, and in the Aspen plus at a pressure of 110 bar, the conversion of CO to methanol is 0.8, whereas in (A. enkosi Mavukwana et al. 2021b) a 100% conversion was assumed. The Aspen Plus flowsheet is closer to the real process than the flowsheet in (A. enkosi Mavukwana et al. 2021b).

Table 5. Comparison of performance analysis waste to methanol and IGCC.

Plant Data	**Unit**	**WT-Methanol-P**	**WT-P**
Thermal input	MW	216.58	216.58
waste tire flowrate	kg/s	6.37	6.37
Supplementary Thermal input	MW	75	0
Additional methane	kg/s	1.5	0
Chemical production			
Methanol	MW	132.1	0
Power generation			
Gas Turbine	MW	27.83	70.05
Steam Turbine	MW	14.01	29.53
Total output power	MW	41.84	99.58
Power consumption			
Pumps	MW	0.09	0.30
Compressors	MW	18.10	0.043
AGR	MW	7.58	7.58
ASU	MW	10.83	10.83
Total power consumption	MW	36.60	18.757
Main output			
Gross thermal output	MW	173.98	99.58
Net output	MW	137.38	80.82

Net thermal Efficiency	%	47.12	37.32
CO_2 emissions	$kgCO_2$/kg tire	2.04	2.82

4.1 Economic performance

Table 6 provides a summary of the overall capital investment based on an estimation of the capital cost associated with each process unit. The TCI that was computed for WT-methanol-E (methanol purchasing electricity), WT-P (IGCC), and WT-methanol-P (methanol-methane) and came out to be 136.37 million dollars, 211.30 million dollars, and 182.16 million dollars, respectively. The capital investment needed for the IGCC is greater than that of methanol because of the increased capacity of the combined cycle power plant. Table 6 further summarizes the operational costs for WT-methanol-E (methanol-additional electricity), WT-P (IGCC), and WT-methanol-P (methanol-additional methane). To determine the operational cost, the methanol selling price was initially believed to be $400/ton, while the minimum selling price for electricity was 0.078$/kWh.

These figures are based on current market conditions. The cost of power in South Africa is 0.078 kWh, and because the region competes with Asia Pacific, where the methanol price is 395 $/ton, a price of $400/ ton was used to determine the OPEX. WT-methanol-E, WT-P, and WT-methanol-P had total annual OPEX of 57.18 M$, 49.17M$, and **55.70** M$, respectively. WT-methanol-E had an 8.1 M$ higher expense than WT-P and only 1.48 M$ higher than WT-methanol-P..

Table 6. Results of the economic optimization

Capital expenditure				
	WT-Methnol-E	WT-P	WT-Methanol-P	
Tire pretreatment	23.25	23.25	23.25	M$
Downdraft gasifier	43.33	43.33	43.33	M$
ASU	13.79	13.79	13.79	M$
Cyclone, Tar cracker &WGS and AGR	38.58	38.58	38.58	M$
CCPP	0.00	78.53	42.80	M$
Methanol synthesis + distillation	8.50	0.00	8.50	M$
Land	2.55	3.95	3.39	M$
Working capital	6.37	9.87	8.51	M$
Total Capital Investment costs	**136.37**	**211.30**	**182.16**	M$
Operating expenditure				
Direct Wages	1.97	2.09	2.28	M$
Administration	2.75	3.79	3.45	M$
Fringe benefits	2.88	3.98	3.63	M$
Operating supplies	2.73	4.23	3.64	M$
Maintenance cost	4.77	7.40	6.38	M$
Insurance and taxes	2.73	4.23	3.64	M$
Plant overhead	1.46	1.46	1.60	M$
CO_2 emissions TAX	1.96	4.14	3.01	M$
Waste disposal	0.22	0.22	0.22	M$
Utilities	12.74	19.75	17.02	M$
Electricity cost	22.84	0.00	0.00	M$
Methane cost	0.00	0.00	10.80	M$
Total operating costs	**57.18**	**49.17**	**55.70**	M$
Revenues				
Methanol selling	75.42	0.00	75.42	M$
Selling electricity	0	62.14	3.27	M$
Total revenue (100% capacity)	75.42	62.14	78.69	M$
Total revenue (85% capacity)	64.10	52.82	66.88	M$
Gross earnings (85%) capacity	**6.92**	**3.64**	**11.19**	M$
NPV	**-$65.14**	**-$208.1**	**-$60.46**	**M$**

To compare the created designs, the net present value (NPV) was used in the analysis. All the configuration has negative NPV based on the assumed minimum selling price (WT-methanol-E: -\$65.14. WT-P: -\$208.1, WT-methanol-P: -\$60.46). Therefore, none of the processes can produce profit, or be investable at these product prices. The impact of waste tire levies on minimum selling prices of methanol and electricity prices on net present value (NPV) are presented in the sensitivity analysis section (Subramanian et al. 2020)

4.2 Sensitivity Analysis

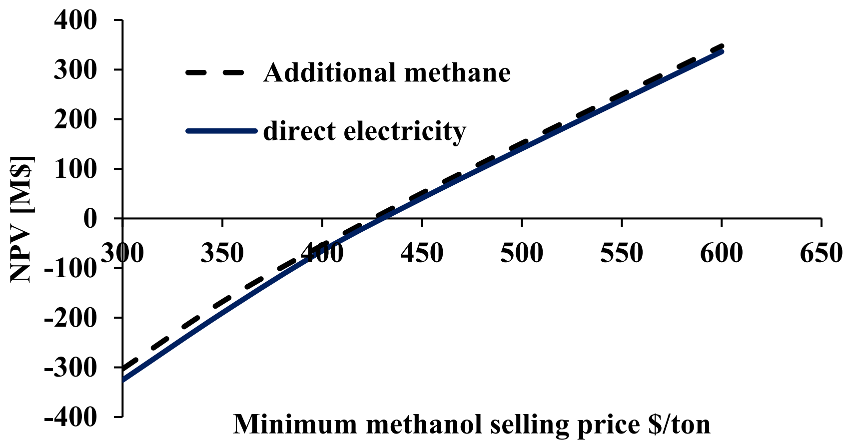

Figure 1. Impact of methanol minimum selling price on NPV.

Figure 1 shows the impact of the minimum selling price on methanol on WT-Methanaol-E and WT-methanol-P designs producing methanol resulting in an NPV of 0 \$. The minimum selling price of methanol, for the two processes, is \$420 /ton. Any price above this value would lead to profits for the two processes.

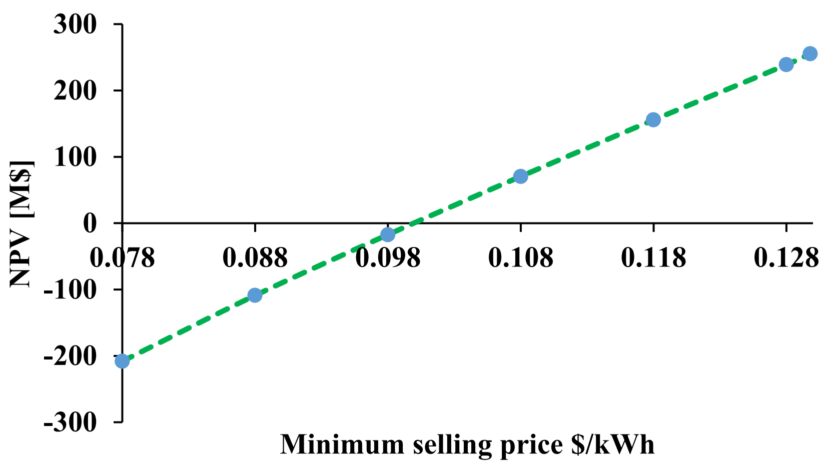

Figure 2. Impact of electricity minimum selling price on NPV

Figure 2 shows the impact of the minimum selling price of electricity for WT-P designs resulting in an NPV of 0 \$. The price of electricity should be above 0.098 \$/kWh to make the IGCC process investment ready. Currently, the South African state-owned utility Eskom has a purchase agreement with independent power producers where it procedures additional electricity at prices ranging from 0.109 to 0.272 \$/kWh over 20 years. Therefore, is enough potential for the process to generate profit. The other way to make these processes profitable is to consider the tire levies as direct revenue

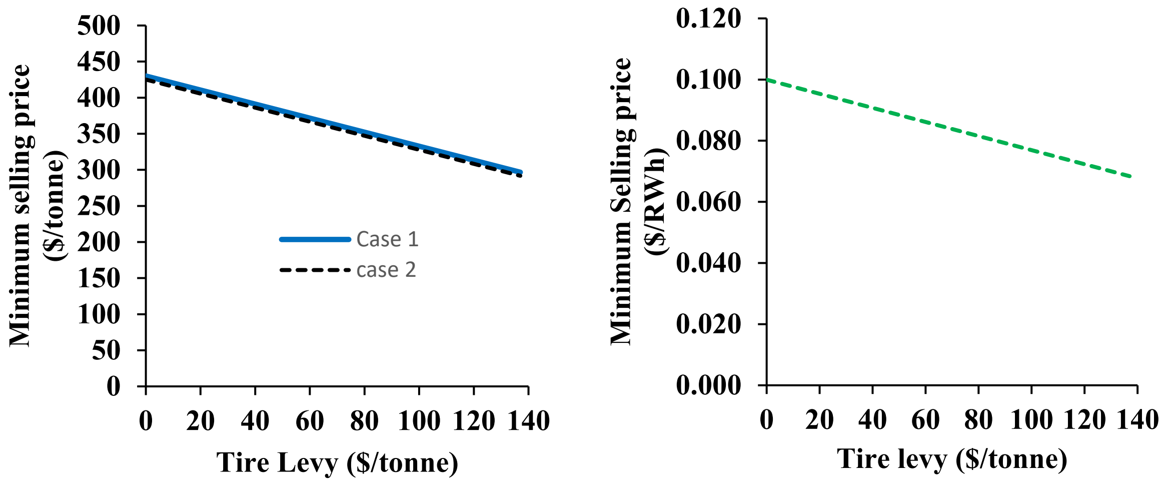

Figure 3. Impact of waste tire levies on the minimum selling price (a) methanol, (b) electricity.

Figure 3 shows the impact of the tire levy on the minimum selling price. The waste tire levy in South Africa is R2.31/kg (0.132 $ /kg) of which only R0.31/kg (0.0177 $/kg) is given to processes that handle over 1000 tonnes. Increasing the levy paid to processes greatly impacts the selling price. Increasing the tire levy from 0.0177$/kg to 0.115 $/kg, the IGCC and methanol processes have profit with NPV of $39.99 and $164.17, respectively. Therefore, producing methanol has better financial performance than the IGCC route.

5. Conclusion

The study examines the technological and economic feasibility of producing methanol and power from waste tires. Two process models were created in Aspen Plus ® and Aspen Hysys ®, where the base WT-methanol-P was the production of methanol and electricity with an additional supply of methane. The other was WT-P, which was the exclusive conversion of waste tires to energy. WT-methanol-E was an alternate technique that produced methanol but required additional electricity for compression. WT-methanol-P had a greater thermal efficiency of 47.12% than WT-P, which had 37.32%. When compared to WT-P, CO_2-specific emissions in WT-methanol-P were reduced by 0.78 kg CO_2/kg tire feed (780-kilogram CO_2/ton of tire). This meant producing methanol has significant carbon emissions saving power production only. The economic analysis revealed that the total investment cost for a ton of waste tire (TCI/ton of tire) in WT-P was 1051 $/ton and 907 $/ton in WT-methanol-P. Furthermore, the minimum selling prices of methanol were discovered to be 430 $/ton and 0.098 $/kWh for power, both of which are within the range of current market values. We also observed that tire tipping fees significantly affect the minimum selling price. The minimum levy necessary to make the processes economical is 0.115 $/kg.

References

Abrol, S., Hilton, C.M., Modeling, simulation and advanced control of methanol production from variable synthesis gas feed. Comput Chem Eng 40, 117–131,2012. https://doi.org/10.1016/j.compchemeng.2012.02.005

Argus Media, 2019. Argus Global Methanol Demand 2018.

Carvalho, L., Lundgren, J., Wetterlund, E., Wolf, J., Furusjö, E.,Methanol production via black liquor co-gasification with expanded raw material base – Techno-economic assessment. Appl Energy 225, 570–584, 2018. https://doi.org/10.1016/j.apenergy.2018.04.052

Dong, Y., Steinberg, M., Hynol - An economical process for methanol production from biomass and natural gas with reduced CO_2 emission. Int J Hydrogen Energy 22, 971–977, 1997. https://doi.org/10.1016/s0360-3199(96)00198-x

Duma, Z., 2023. The case of green methanol in South Africa.

Esmaili, E., Mostafavi, E., Mahinpey, N., Economic assessment of integrated coal gasification combined cycle with sorbent CO_2 capture. Appl Energy 169, 341–352, 2016. https://doi.org/10.1016/j.apenergy.2016.02.035

Esmaili, E., Mostafavi, E., Mahinpey, N., Economic assessment of integrated coal gasification combined cycle with sorbent CO2 capture. Appl Energy 169, 341–352,2016b. https://doi.org/10.1016/j.apenergy.2016.02.035

European Tyre and Rubber Industry Manufacturers Association, n.d. European Tyre and Rubber Industry Statistics 2021. Belgium, Brussels. Report No. 11, 2021. Available at: https://www.etrma.org/wp-content/uploads/2021/12/20211215-Statistics-booklet-2021VF.pdf.

European Tyre and Rubber Industry Manufacturers Association, n.d. European Tyre and Rubber Industry Statistics 2021. Belgium, Brussels. Report No. 11, 2021. Available at: https://www.etrma.org/wp-content/uploads/2021/12/20211215-Statistics-booklet-2021VF.pdf.

Formela, K.,Sustainable development of waste tires recycling technologies – recent advances, challenges and future trends. Advanced Industrial and Engineering Polymer Research 4, 209–222, 2021. https://doi.org/10.1016/j.aiepr.2021.06.004

Haydary, J., Šuhaj, P., Husár, J., Waste biomass to methanol–optimisation of gasification agent to feed ratio. Biomass Convers Biorefin 11, 419–428, 2021. https://doi.org/10.1007/s13399-020-00692-3

Jenkin, N., 2022. Industrial usage opportunities for products derived from waste tyres in South Africa, Trade & Industrial Policy Strategies (TIPS). Trade & Industrial Policy Strategies (TIPS). South Africa, Gauteng, Pretoria, 2022. Available at: https://www.tips.org.za/research-archive/sustainable-growth/green-economy/item/4350-industrial-usage-opportunities-for-products-derives-from-waste-tyres-in-s.

Markets and Markets, 2024. Methanol Market (Global focust for 2028) [WWW Document]. URL https://www.marketsandmarkets.com/Market-Reports/methanol-market-425.html (accessed 1.30.24).

Matveev, A., Dubinin, A., Shcheklein, S., Steam gasification of waste tires for the purpose of methanol production. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 18, 175–182, 2018. https://doi.org/10.5593/sgem2018/4.2/S18.023

Mavukwana, A. enkosi, Llane, E., Fox, J., Sempuga, B.C., Methanol and power production from waste tyres: a process synthesis approach. Computer Aided Chemical Engineering 50, 387–392,2021 . https://doi.org/10.1016/B978-0-323-88506-5.50061-9

Mavukwana, A. enkosi, Llane, E., Fox, J., Sempuga, B.C., Methanol and power production from waste tyres: a process synthesis approach. Computer Aided Chemical Engineering 50, 387–392, 2021 b. https://doi.org/10.1016/B978-0-323-88506-5.50061-9

Mavukwana, A., Stacey, N., Fox, J.A., Sempuga, B.C., 2021. Thermodynamic comparison of pyrolysis and gasification of waste tyres. J Environ Chem Eng 9, 105163. https://doi.org/10.1016/j.jece.2021.105163

Mavukwana, A.E., Fox, J.A., Sempuga, B.C., 2020. Waste tyre to electricity: Thermodynamics analysis. J Environ Chem Eng 8. https://doi.org/10.1016/j.jece.2020.103831

Mavukwana, A.E., Sempuga, C., Gasification of waste tyres: Thermodynamic attainable region approach. Materials Science Forum 1045 MSF, 179–185, 2021. https://doi.org/10.4028/www.scientific.net/MSF.1045.179

Moellenbruck, F., Kempken, T., Dierks, M., Oeljeklaus, G., Goerner, K., Cogeneration of power and methanol based on a conventional power plant in Germany. J Energy Storage 19, 393–401, 2018. https://doi.org/10.1016/j.est.2018.08.018

Narine, K., Mahabir, J., Koylass, N., Samaroo, N., Singh-Gryzbon, S., Baboolal, A., Guo, M., Ward, K., Climate smart process design for current and future methanol production. Journal of CO2 Utilization 44, 2021. https://doi.org/10.1016/j.jcou.2020.101399

Niziolek, A.M., Onel, O., Hasan, M.M.F., Floudas, C.A., Municipal solid waste to liquid transportation fuels - Part II: Process synthesis and global optimization strategies. Comput Chem Eng 74, 184–203, 2015. https://doi.org/10.1016/j.compchemeng.2014.10.007

Nkosi, N., Muzenda, E., Gorimbo, J., Belaid, M., Developments in waste tyre thermochemical conversion processes: gasification, pyrolysis and liquefaction. RSC Adv 11, 11844–11871, 2021. https://doi.org/10.1039/D0RA08966D

Poluzzi, A., Guandalini, G., Guffanti, S., Elsido, C., Moioli, S., Huttenhuis, P., Rexwinkel, G., Martelli, E., Groppi, G., Romano, M.C., 2022. Flexible Power & Biomass-to-Methanol plants: Design optimization and economic viability of the electrolysis integration. Fuel 310, 122113. https://doi.org/10.1016/j.fuel.2021.122113

Rashid, M.I., Benhelal, E., Abbas, M.M., A Critical Analysis on Transformation of Renewable Energy to Green Chemicals: Opportunities and Challenges. ChemBioEng Reviews 1–24, 2024. https://doi.org/10.1002/cben.202300050
Rivarolo, M., Bellotti, D., Magistri, L., Massardo, A.F., Feasibility study of methanol production from different renewable sources and thermo-economic analysis. Int J Hydrogen Energy 41, 2105–2116, 2016a. https://doi.org/10.1016/j.ijhydene.2015.12.128
Rivarolo, M., Bellotti, D., Magistri, L., Massardo, A.F., Feasibility study of methanol production from different renewable sources and thermo-economic analysis. Int J Hydrogen Energy 41, 2105–2116, 2016b. https://doi.org/10.1016/j.ijhydene.2015.12.128
Salkuyeh, Y.K., Adams, T.A., A new power, methanol, and DME polygeneration process using integrated chemical looping systems. Energy Convers Manag 88, 411–425, 2014. https://doi.org/10.1016/j.enconman.2014.08.039
Sebola, M.R., Mativenga, P.T., Pretorius, J.,A Benchmark Study of Waste Tyre Recycling in South Africa to European Union Practice. Procedia CIRP 69, 950–955,2018. https://doi.org/10.1016/j.procir.2017.11.137
SGS Inspire, 2020. Methanol: Properties and Uses.
Soucie, H., Elam, M., Mustain, W.E., Practical Assessment for At-Scale Electrochemical Conversion of Methane to Methanol. ACS Energy Lett 8, 1218–1229, 2013. https://doi.org/10.1021/acsenergylett.2c02586
South Africa. Department of Forestry Fisheries & the environment. National Environment Management: Waste Act, 2008 (Act No. 59 of 2008), n.d. Consultation on the draft industry waste tyre management plan.
Statista, 2023. Export value of methanol worldwide in 2021, by country [WWW Document]. Statista Research Department. URL https://www.statista.com/statistics/1296243/global-methanol-export-value-by-country/#statisticContainer (accessed 2.8.24).
Subramanian, A.S.R., Gundersen, T., Adams, T.A., 2021. Optimal design and operation of a waste tire feedstock polygeneration system. Energy 223, 119990. https://doi.org/10.1016/j.energy.2021.119990
Subramanian, A.S.R., Gundersen, T., Adams, T.A., Technoeconomic analysis of a waste tire to liquefied synthetic natural gas (SNG) energy system. Energy 205, 117830,2020. https://doi.org/10.1016/j.energy.2020.117830
U.S. Tire Manufacturers Association, 2022. 2021 US Scrap Tire Management Summary.
Wang, Sheng, Li, C., Hu, Y. jie, Wang, H., Xu, G., Zhao, G., Wang, Shiyuan, 2024. Assessing the prospect of bio-methanol fuel in China from a life cycle perspective. Fuel 358, 130255, 2024. https://doi.org/10.1016/j.fuel.2023.130255
Yakan, C., Patel, B., 2022. Techno-economic Study and Environmental Analysis for the Production of Bio-methanol Using a Solar-aided Dual-bed Gasifier.

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