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Green Hydrogen and TVET Skills' Role in South Africa's Just Transition

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Executive Summary

Studies of human resources and skills for a green hydrogen economy around the world have so far mainly been restricted to estimating total employment impacts of a green hydrogen economy. Studies on the need for skills taught in Technical and Vocational Education & Training (TVET) colleges are absent. However current estimates for jobs growth around a domestic hydrogen economy for IHS Markit's Super H2igh Road scenario in combination with current shares of TVET level educated employment include consequences of changes not necessarily linked to the hydrogen economy and yet ignores the job potential from export markets. A more dynamic economy-wide assessment of green hydrogen commodities and technologies and exports is therefore needed to consider full job potentials by sector and skills, notably TVET skills, and provide more insights into the timing of market developments.

As a step in the direction of such an analysis the present study analyses how some scenarios for domestic and export market developments translate to increases and decreases in future TVET jobs in South Africa. It takes account of two key international developments: increased international climate change policy and cost decreases of renewables.

The development of a domestic green hydrogen economy requires a pipeline of adequately trained graduates, key industrial sectors are required to inform the skills development roadmap.

While the entire South African economy can be expected to require a significant increase in TVET trained staff between now and 2030, the sectors involved in a transition to a green hydrogen economy are only expected to grow after 2030. To maximise the jobs potential in the TVET sector associated with the green hydrogen economy, one should first consider whether its development could be pulled forward, especially for a transition of skills between petrochemicals and green hydrogen and ammonia production (amongst others). Furthermore, key industrial sectors to target for green hydrogen TVET education, based on our analysis are:

1. Chemicals manufacturing for production of green hydrogen for use as a fuel domestically in fuel cell vehicles or in other industries, and e.g. exported as ammonia.

2. Manufacturing of electrical machinery and automotive components, to allow specialization towards manufacturing and application of fuel cells and electrolyser components;

3. Furthermore, the coal mining sector likely has the right skill sets to match those of PGM mining but differences in timing between a coal phase out and an expected boom in PGM mining require orientation to other sectors as well, notably Power Generation and (green) Iron & Steel require more TVET-skilled employees before 2030.

The finding that several thousands of TVET specialised jobs can be expected for South African fuel cell and electrolyser industries, supports the requirement for involvement of the TVET college system in the development of a green hydrogen economy. Its role could be to develop specific technical courses such as, for example, fuel cell component manufacturing and general occupational safety and health training to make TVET learners suited to work with a volatile gas like hydrogen. More structural problems of the TVET system will need to be dealt with in time as well for the TVET system to contribute to development of renewables and the green hydrogen economy. Bambili Advisory has formulated detailed recommendations in this context for the SAIIA UKPACT 2021 research project.

1. Introduction: Hydrogen and TVET skills

Hydrogen is an energy carrier considered to have a high potential to contribute to South Africa's economic development.[1,2] A hydrogen-based economy is also an essential part of global economies moving to Net Zero greenhouse gas emissions. The IEA predicts that for the world to reach Net-Zero emissions global hydrogen production will need to increase from a present-day supply of 90 Mt/year to 200 Mt/year by 2030 and 500 Mt/year by 2050.[3] A transition to a green hydrogen economy is not a zero-sum game. Past debates around energy transitions in South Africa tended to be characterised by stark oppositional positions, because energy transitions were perceived mainly as a national political choice, e.g., in debates about coal versus renewables.[4] But, international developments are changing the economic outlook for South African sectors relying on fossil fuels, independent of South Africa's decisions. The question which one should ask is how South Africa could benefit from a green hydrogen economy, as its renewable energy endowments position the country as a potential competitive global supplier of hydrogen-based commodities.[5]

Green hydrogen provides perspectives for continued or expanded operations for platinum group metals (PGM) mining, the chemicals sector, and steel making, and it could allow parts of transport (long distance road transport, shipping, aviation) and electricity production to decarbonise entirely.[6] In this context, the South African government will need to plan for, and implement a just transition,[7] and enable infrastructure developments, e.g., of the type described in the IHS Markit's H2igh Road scenario.[8] Additionally, government should ensure that know-how and skills are available, not only through patents and engineering skills, but also through the hands-on technical and operational skills which any industry would need to develop. [9] However, studies of human resources and skills for a green hydrogen economy are scarce and mainly limited to total employment impacts.[10] Moreover, studies on the need for skills taught in Technical and Vocational Education & Training (TVET) colleges[11]

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[1] Hydrogen is a chemical that can serve multiple purposes across the energy sector. It can be used directly as an energy carrier, or in fuel-cells for power generation for transport and electricity demand. Hydrogen can also be utilised as a feedstock to produce liquid or gaseous fuels. Currently hydrogen is mainly produced industrially from coal and natural gas, respectively known as grey and blue hydrogen. Green hydrogen is the cleanest form of hydrogen, produced from water using electricity generated from renewable energy, or alternatively through biomass steam reformation.

[2] IHS Markit, "Super H2igh Road Scenario for South Africa" (Extended report, IHS Markit, June 2021); Jules Schers, Fadiel Ahjum, Caitlin Bergh, Julia Tatham, and Faaiqa Hartley, "Hydrogen economy skills and the just transition", (SAIIA UKPACT and University of Cape Town, Occasional Research Paper, 2021), hereafter: Schers, et al. "Hydrogen economy skills" (2021); Bambili Advisory, "TVET Skills Gap Analysis report" (SAIIA UKPACT, Occasional Research Paper, 2021).

[3] IEA, "Net Zero by 2050" (2020).

[4] Hochstetler, K. (2020). Political Economies of Energy Transition: Wind and Solar Power in Brazil and South Africa (Business and Public Policy). Cambridge: Cambridge University Press. doi:10.1017/9781108920353; Baker, L., & Burton, J. (2018). "The politics of procurement and the low-carbon transition in South Africa". In Handbook of the International Political Economy of Energy and Natural Resources. Cheltenham, UK: Edward Elgar Publishing. doi: https://doi.org/10.4337/9781783475636.00015

[5] IHS Markit, "Super H2igh Road Scenario" (2021).

[6] IEA, "Net Zero by 2050" (2020); IEA, "Future of Hydrogen" (2019); IHS Markit "Super H2igh Road Scenario".

[7] Neva Makgetla, et al, "Nationale Employment Vulnerability Assessment : Analysis of potential climate-change related impacts and vulnerable groups", (Trade & Industrial Policy Strategies, Pretoria, October 2019)

[8] IHS Markit, "Super H2igh Road Scenario", (2021).

[9] Bambili Advisory, "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).

[10] Bambili Advisory, "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).

[11] The TVET college system is the principal educational institution to provide some of the low and medium level technical skills. Their skills are a vital element for the functioning of companies and the economy.

for the hydrogen economy are absent, even internationally.[12] Furthermore, South Africa's TVET college system faces challenges which could complicate the provision of such skills.[13]

This policy insights report therefore discusses to what extent TVET colleges would be required to support provision of skills for a green hydrogen economy in South Africa, and whether these colleges could contribute to a just labour transition between fossil-fuel dependent economic sectors and GHE sectors through up- or re-skilling programmes. This report therefore first identifies consequences for South African TVET employment of a transition to a GHE in South Africa and abroad, based on existing knowledge about TVET skill intensities of sectors and national and international outlooks for a GHE. The focus lies on a few key sectors: coal mining, PGM mining, petrochemistry and automotive manufacturing. Finally, it summarizes existing insights on the scope for a just labour transition between these sectors and sectors in a GHE.

2. Current insights on TVET skilled employment

To estimate the extent to which a green hydrogen economy and TVET colleges could and would need to contribute to a Just Labour Transition, one should have an idea of the economic size and other characteristics of this transition. Partly, this depends on domestic policy choices.[14] For another part, at least some downsides of it, this transition is driven by international developments outside the national policy-making realm, because a sizeable share of South Africa's exports is concentrated in fossil fuel value chains.[15]

A question is how many direct jobs and jobs up- or downstream in value chains of a specific sector are concerned by a Green Hydrogen Economy and by when. For instance, we show below that projections for a global Net Zero pathway to 2050[16] could imply a considerable potential for job growth in platinum group metal (PGM) mining in South Africa. However, future hydrogen economy employment could be bigger if more PGM beneficiation would take place in South Africa, especially if manufacturing for world markets of electrolysers and fuel cell or their components would take place in South Africa. Employment estimates thus require identification of the potential for beneficiation in South Africa.

Until now, the only elaborate estimate of South African Green Hydrogen Economy employment impact comes from IHS Markit. Their study presents an assessment of domestic and international market potential for production of multiple commodities on a hydrogen-basis and hydrogen itself in South Africa. They assume that international market development requires a domestic market first and estimate the net growth to South African jobs due to a domestic hydrogen economy at 50 thousand until 2030, expanding to about 370 thousand jobs by 2050.[17] They do not explore the economic impacts of potential exports from an emerging South African GHE industry.

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[12] Bambili Advisory, "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).
[13] Bambili Advisory, "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).
[14] See for instance the propositions to stimulate hydrogen-based economic development in South Africa by IHS Markit, "Super H2igh Road Scenario", (2021).
[15] Gaylor Montmasson-Clair, "The global climate change regime and its impacts on South Africa's trade and competitiveness: A data note on South Africa's exports" TIPS, 2020 https://www.tips.org.za/research-archive/
[16] IEA, "Net Zero by 2050" (2020).
[17] IHS Markit, "Super H2igh Road Scenario for South Africa", (2021).

2.1 TVET skill intensity of a green hydrogen economy

The question is how potential GHE employment translates to TVET skill level jobs. Internationally there is very little public expertise on skill intensities in the hydrogen economy.[18] The few available publications at best offer lists of professions that could be linked to different types of education, but without a basis for quantification.[19] What these studies expect is that initially the development of a hydrogen economy will be marked by relatively educated labour though not exclusively, and that the hydrogen economy also requires labour at the TVET level, even more so once fully developed.[20]

Without quantitative international estimates of skill intensities, the best indication of TVET skill intensity of employment in a Green Hydrogen Economy comes from current TVET intensity of South African economic sectors similar to those of a green hydrogen economy, as measured by Statistics South Africa's Labour Force surveys.[21] A downside of these numbers is that labour force surveys measure degrees of workers, but this does not guarantee there is a necessity for a worker to hold their specific degree for the job they perform. E.g., UCT analysis shows that TVET educated employees can also work in what Statistics South Africa considers low and high-skilled job types, and not only in medium skill job types.[22] Also, on-the-job training could mean that the real amount of employment at TVET educational level skills might be higher than the actual amount of TVET certificate or diploma holding employees. Lastly, the mandate of TVET colleges is expanding into what up until now would be considered lower tertiary education diplomas.[23]

2.2 Employment trends in SA and the relevance of the TVET Sector

For this analysis we use the Post-apartheid Labour Market Series (PALMS) which is a series of cross-sectional labour force surveys from 1995-2019.[24,25] The number of workers employed in the South African economy has been increasing at a steady pace from 2009 (Figure 1). TVET workers' proportion of the South African labour force remains relatively constant. Figure 2 shows the smoothed educational makeup of the South African labour force from 2000.[26] The trend shows that there has been a significant increase in the proportion of matric and secondary educated individuals as well as a slight increase in lower and tertiary educated individuals while the proportion of TVET educated

18 Roger H. Bedzek, "The Hydrogen Economy and Jobs of the Future", Renew. Energy and Environ. Sustain. 4, no.1 (2019): 1-6, https://doi.org/10.1051/rees/2018005; Schers, et al. "Hydrogen economy skills" (2021); Bambili Advisory, "TVET Skills Gap" (2021).

19 Bambili Advisory "TVET Skills Gap" (2021); ILO, "Skills and occupational needs in renewable energy" (final report, EMP/SKILLS, International Labour Office, Geneva, 2011); Naima Rassool, et al., "Assessment of local skills for the South African renewable energy value chain" (Greencape, *forthcoming*); Roger H. Bedzek, "The Hydrogen Economy and Jobs" (REES, 2019); TIPS, "Unpacking the TVET skills demand in the hydrogen economy" (SAIIA and UKPACT, *forthcoming*).

20 Bambili Advisory "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).

21 Source: Kerr, et al. PALMS [dataset v3.3] (2019).

22 Statistics South Africa's Quarterly Labour Force Survey three occupational job type categories consist of: Low skill: Elementary workers, and Domestic workers; Medium skill: Plant & machine operators, Craft workers, Skilled agricultural workers, Service workers, and Clerks; High skill: Technicians, Professionals, and Legislators. See also the Appendix of Schers, et al. "Hydrogen economy skills" (2021);

23 See interview Appendix with Gerda Magnus (TVET expert) in Schers, et al. "Hydrogen economy skills", (2021).

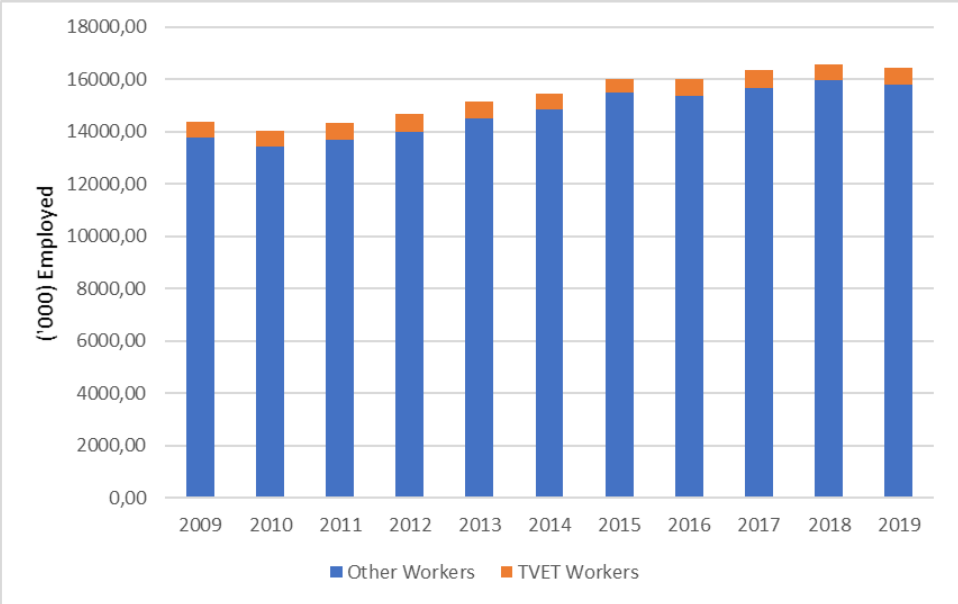
24 Kerr, Andrew, David Lam and Martin Wittenberg (2013), Post-Apartheid Labour Market Series [dataset], Version 2.1, Cape Town: DataFirst [producer and distributor], 2013. [zaf-datafirst-palms-1994-2012-v2.1]

25 The data is weighted using cross-entropy weights created for reliable and consistent data analysis over time.

26 To smooth the movement in the level of education within each industry we generate graphs using the ipoly command on the Stata program. This performs a kernel-weighted local polynomial regression of mean education level on years.

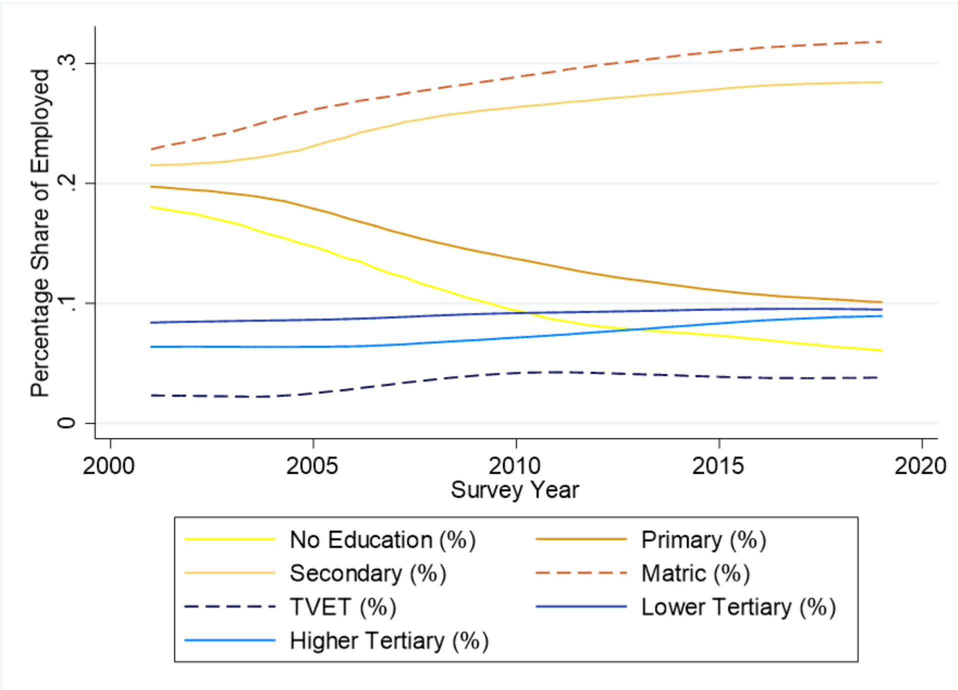
worked in the labour force remains relatively constant increasing slightly between 2005 and 2010 before leveling at between 3% to 4% for the last 10 years.

Figure 1: Employment trends in South African Labour Force [27]



Source:

Figure 2: Smoothed proportion of education categories (2000 – 2019) [27]



Source:

Table 1 shows a 5-year average (2015 – 2019) of the proportion of workers in different tertiary educational categories for different sectors relevant to our analysis. There is quite a bit of variation in the proportion of TVET educated workers between different sectors with coal mining having the largest proportion of their workers with a TVET education level (10.4%), this is followed by electricity (7.84%), and Petro Chemical (5.5%).

Table 1: 5-year average share of tertiary employment by sectors of interest (2015/2019) [27]

Sector	TVET Share	Low Tertiary Share	High Tertiary Share
Coal Mining	10.41%	14.75%	4.43%
Petro Chemical	5.49%	24.02%	18.42%
PGM	4.52%	6.82%	2.72%
Iron and Steel	2.90%	8.70%	4.14%
Land Transport	3.32%	6.81%	3.20%
Electricity	7.84%	31.90%	16.60%
Electric Machinery	3.22%	13.88%	8.44%
Basic Chemicals	4.53%	13.87%	10.90%
Motorised Transport	4.98%	14.74%	5.82%
Labour Force	3.86%	9.41%	8.93%

Source:

To inform policy-making around TVET education it would be good to have further detail about which jobs require what type of TVET education. Labour Force Surveys of Statistics South Africa provide some further disaggregation of sub-categories of TVET-educated labour, but these turn out to lead to sample sizes too small for meaningful interpretation. The only exception is the subdivision of the employed in three job-type skill levels, as in Bhorat et al.[28], which we will use in our analysis presented in the remainder of this report. Bhorat et al. separate employed individuals into different skill levels using a one-digit occupation mapping (see table 2). Workers are either classified as High-skilled, Low-skilled or Semi-Skilled. The majority of the TVET educated workers in South Africa are employed in occupations that are classified as semi-skilled, which made up 55% of TVET workers in 2019, followed by high skilled occupations (36% of TVET workers in 2019).

[27] Source: Author calculations based on: Kerr, et al. PALMS [dataset v3.3] (2019).

[28] Bhorat, H., Naidoo, K., Oosthuizen, M. and Pillay, K., 2015. Demographic, employment, and wage trends in South Africa (No. 2015/141). WIDER Working Paper.

Table 2: *Occupations used un the decomposition analysis* [29]

Broad Task	Occupations
High Skilled	1. Legislators, senior officials and managers
High Skilled	2. Professionals
High Skilled	3. Technical and associate professionals
Semi-Skilled	4. Clerks
Semi-Skilled	5. Service workers and shop and market sales workers
Semi-Skilled	6. Skilled agricultural and fishery workers
Semi-Skilled	7. Craft and related trades workers
Semi-Skilled	8. Plant and machine operators and assemblers
Low-Skilled	9. Elementary Occupation
Low-Skilled	10. Domestic Worker

Source:

3. Improving estimates of employment impacts of a future GHE

As mentioned IHS Markit's study ignores the international dimension for a South African GHE while it also lacks transparency. Their study is furthermore limited in the amount and types of scenarios analysed and considers changes in sectors that might not necessarily be linked to hydrogen, such as faster decarbonization of power generation than in the IRP 2019[30], or electrification of transport. Furthermore, their study uses a static input-output multiplier analysis, albeit with some imposed dynamics in value added to arrive at estimates for economic impacts. This methodology ignores several economic trade-offs, especially related to price changes and technology choice dynamics, e.g., of hydrogen versus battery storage technology.[31,32] Estimates of the job potentials by sector and

[29] Bhorat, H., Naidoo, K., Oosthuizen, M. and Pillay, K., 2015. Demographic, employment, and wage trends in South Africa (No. 2015/141). WIDER Working Paper.

30 Department of Mineral Resources and Energy, "Integrated Resource Plan for Electricity 2019-2030", (Government Gazette No. 42784, South Africa, 2019).

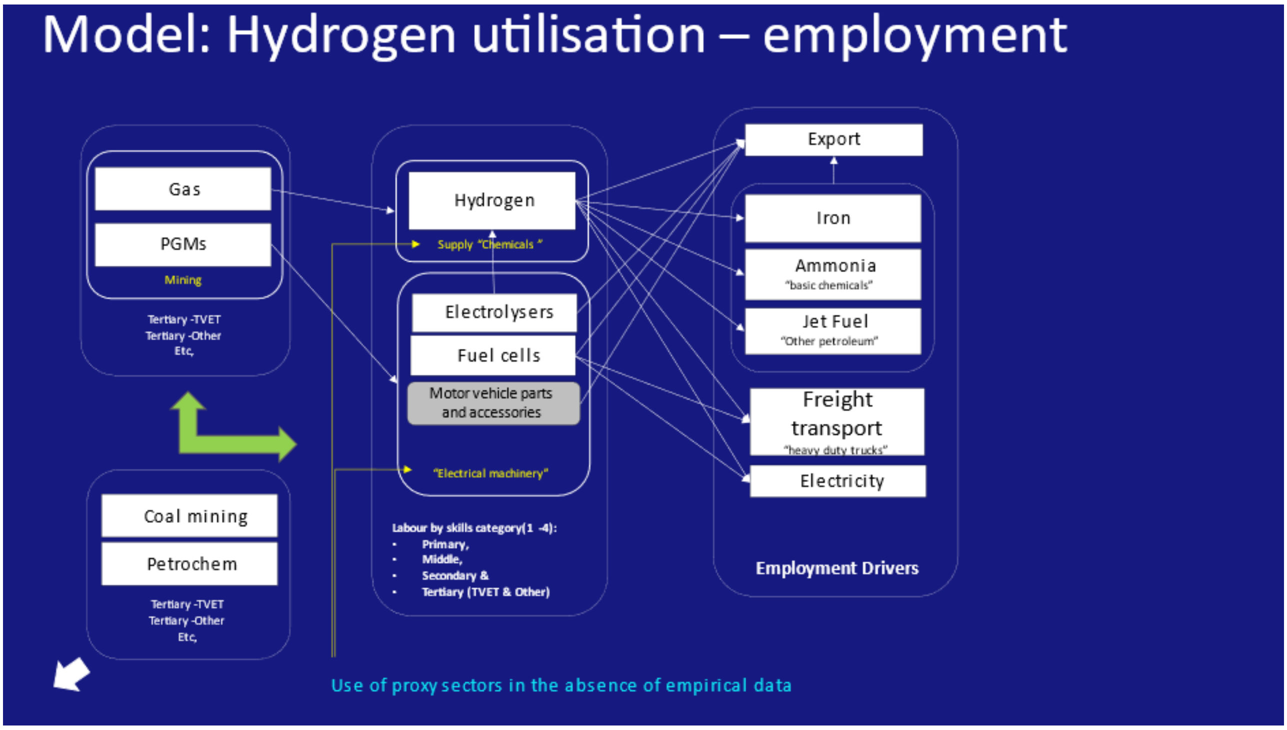
[31] The H2igh Road scenario assumes specific investments and analyses how these would impact the current economic structure, but it does not evaluate whether these investments fit compared to domestic energy demand, with international trade, and relative to alternative technologies.

[32] Acil Allen Consulting, "Opportunities for Australia from hydrogen exports", (Acil Allen Consulting for ARENA, Australia, August 2018), p.96, Box B.1

skill and timing thereof would thus benefit from considering macro-economic behaviour, e.g., the evolution of domestic and foreign demand for certain goods, and from a complete evaluation of possible energy technology choices. This would be needed to provide rational economic insight into the timing of demand and chances relative to competing technologies.[33]

To this end the present and UCT's forthcoming paper on GDP and greenhouse gas emission impacts of a GHE make use of a linked energy systems-computable general equilibrium (CGE) modelling of the SATIMGE model to assess full economic and employment impacts.[34] The two individual models of which it consists, i.e. SATIM and SAGE, account respectively for a full energy-sector description of alternative technologies and a detailed full-sector economy-wide general equilibrium model.[35] Using them in a linked way helps represent an energy-economic transition to provide a comprehensive and holistic picture of the employment impacts of the GHE. Notable additions to the model describing the Green Hydrogen Economy are shown in Figure 3. The figure also shows corresponding sectors data of which techno-economic data was used to describe the economic and employment characteristics of the new GHE sectors.

Figure 3: Schematic representation of modelling of a South African green hydrogen economy in SATIMGE



Source:

[33] This modelling exercise is part of the follow-up paper by UCT under its other workstream (5) for the SAIIA UKPACT 2021 project and will be published in the second half of 2021, combines economic analysis with that of impacts on greenhouse gas emissions.

[34] See also UCT's concept note and its forthcoming UKPACT workstream 5 output for details.

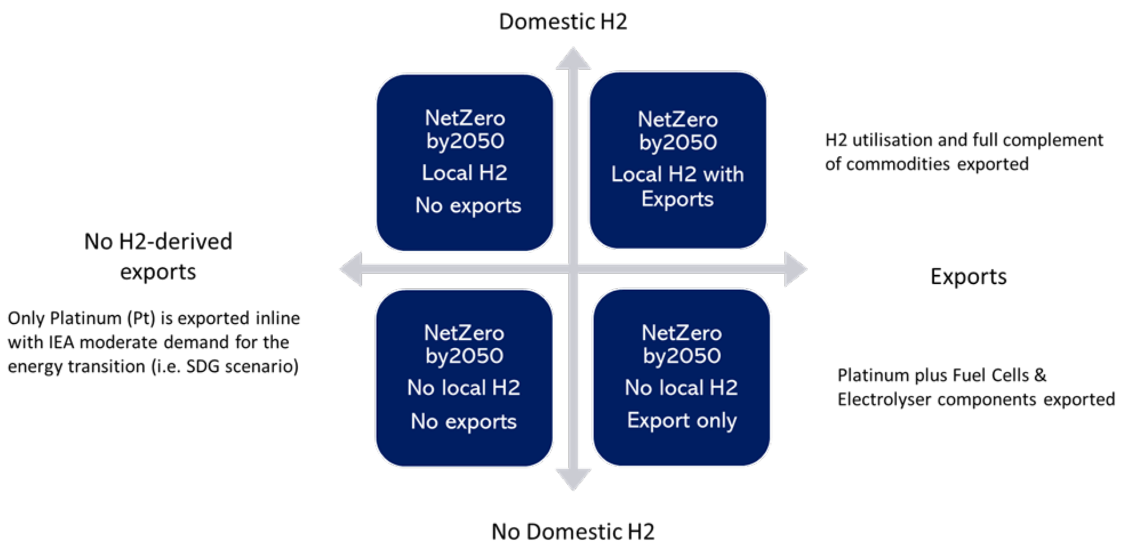
[35] Arndt, C. Davies, R., Gabriel, S., Makrelov, K., Merven, B., Hartley, F. and Thurlow, J. 2016. A sequential approach to integrated energy modelling in South Africa. Applied Energy, 161:591–599. DOI: https://doi.org/10.1016/j.apenergy.2015.06.053; and Merven, B., Arndt, C. and Winkler, H. 2017. The development of a linked modelling framework for analysing the socioeconomic impacts of energy and climate policies in South Africa. WIDER Working Paper, No. 2017/40, ISBN 978-92-9256-264-9, The United Nations University World Institute for Development Economics Research (UNU-WIDER), Helsinki.

3.1 Scenarios for a South African and a global Green Hydrogen Economy

To quantify TVET employment one needs to model the growth of a South African Green Hydrogen Economy in the context of global scenarios of hydrogen demand. To this end scenarios are explored along two axes: (1) one about the extent to which hydrogen would be available as an energy carrier for application in the domestic economy, and (2) another axis about the extent to which South Africa could export hydrogen-derived products and resources and technology for hydrogen production and application.[36] All scenarios have in common that they aim for Net Zero greenhouse gas emissions for South Africa by 2050.

All scenarios assume exports of PGM metals in line with moderate expectations for a global green hydrogen economy described in the next section. This is the only hydrogen-related export in the two scenarios (without & with domestic GHE) of the left two quadrants of Figure 4. The scenario without a domestic GHE but with South Africa expanding its role in the PGM-global GHE value chains (upper-right quadrant of Figure 4) also assumes SA to export fuel cells and electrolyser components. The last scenario (lower-right quadrant) assumes both South Africa to develop a domestic GHE and to exploit supplying a global GHE to an elaborate extend. In this case SA exports not only PGM metals, Fuel Cell and Electrolyser components, but also green (mostly hydrogen-based) Iron & Steel, Jet Fuel, and Ammonia. These exports (except for PGM metals) are assumed to start from zero in 2030 and to linearly increase to 2045 (see Table 3).

Figure 4: Four scenarios for the future of a South African green hydrogen economy



Source:

[36] See UCT's forthcoming UKPACT workstream 5 output for details.

Table 3: *Export assumptions for SATIMGE modelling*

	Units	2035	2045
Export PGMs - Pt	kt	141	348
Export PGMs - Others	kt	104	104
Ammonia to Export Market	PJ	33	94
Exports of Green Iron	Mt	4	11
Exports of Green JetFuel	PJ	0	5
PEM Electrolyser Stack Exports	GW	1.3	12
PEM Fuel Cell Exports	GW	4	159

Source:

4. The global GHE dimension for a just transition and potential value creation

South Africa's economy will likely feel a significant impact from a transition to a GHE around the world. A sizeable share of South Africa's exports is currently concentrated in the fossil fuel value chain,[37] including some of the current biggest exports in value terms, like coal mining and a part of Platinum Group Metals (PGM) mining. Understanding international developments is therefore necessary to estimate future employment and could also inform scenario building for modelling impacts on GDP and employment of a green hydrogen economy.[38] This international dimension is less considered by the IHS Markit super H2igh Road scenario, which only aims to analyses a scenario for domestic market development for a hydrogen economy, with the idea that this would prime[39] export markets for hydrogen-based commodities (ammonia, green steel, methanol) or technology (fuel cells) when these markets mature.

Two key international developments to consider are cost decreases of renewable power generation and increased international climate change policy. Firstly, the sharp decline in costs of photovoltaic power generation (solar PV) of recent years, has made solar PV join natural gas as a strong substitute for coal-based power generation in major power generation markets like the UK,[40] and Germany,[41] and similar developments are taking place in emerging economies like India.[42] Secondly, almost half of existing export trade[43] is with countries or regions that have committed to reduce their economies' greenhouse gas emissions in their NDCs for the Paris Agreement - i.e., EU countries, the UK, and the US, with the EU in the process to develop a Carbon-based Border Tax adjustment.[44] Products like iron

[37] Gaylor Montmasson-Clair, "The global climate change regime and its impacts on South Africa's trade and competitiveness: A data note on South Africa's exports" (TIPS 2020) https://www.tips.org.za/research-archive/
[38] See also footnote 21.
[39] Meaning: create the conditions for South African companies to be able to export
[40] See https://www.iea.org/countries/united-kingdom
[41] See https://www.iea.org/countries/germany
[42] See the outlook for renewables share in power generation of the Stated Policies Scenario by the IEA in IEA, "India Energy Outlook 2021" (2021) https://www.iea.org/reports/india-energy-outlook-2021; and: Carbon Tracker, "Do not revive coal – Planned Asian coal plants a danger to Paris", (2021) https://carbontracker.org/reports/do-not-revive-coal/
[43] See OEC for South African trade figures in goods and services: OEC - The Observatory of Economic Complexity, https://oec.world/en/subnational/#subnational-country-block-zaf Accessed 10 June 2021
[44] IHS Markit, "Super H2igh Road Scenario for South Africa", (2021).

and steel still rely heavily on fossil fuel energy or feedstocks for processing, and those of other sectors are carbon-intensive for as long as South Africa's power generation remains among the most carbon-intensive in the world.[45,46]

4.1 Consequences for coal mining

The mentioned global developments will first and foremost affect coal exports. The G7's recently took an official position against further investment in coal-fired power generation, and the chance exists that international demand for coal peaked in recent years and is now set for a steady decline.[47] Were the world to continue onto this path and meet the requirements for a Net-Zero pathway[48] demand for coal would need to decrease sharply between now and 2040 (see Figure 5).[49] The IEA predicts that coal would also need to be phased out from power generation completely by 2040 globally.[50] The penetration of renewables and gas in power markets, even without climate policy, and a favouring of domestic coal in current export markets will force trade in global coal to decrease even faster than global demand.[51] I.e., several major coal importing countries have committed to prioritising domestic coal, including India, South Africa's largest coal export destination.[52] Expectations for South Africa's future coal exports will very likely need to be revised downward.[53]

Coal mining in South Africa employs an estimated 75 to 90 thousand people in recent years.[54,55] Approximately one fifth of volume and revenue of South Africa's coal was destined for exports in the last decade.[56] Translated to jobs, the described international developments could put about 18 thousand jobs in coal mining at risk if the relation between volume or value of coal and mining jobs is assumed linear. With about 10% of coal mine workers being TVET educated[57] this means that 1,800 TVET level coal mining jobs could be at risk.

45 Alternatives considered economically viable in time have been proposed, see IHS Markit's scenario for green steel production in Saldanha, South Africa: "Super H2igh Road Scenario for South Africa", 2021

46 Climate Transparency, "Climate Transparency report 2020", (Country Profile South Africa, 2020), available at https://www.climate-transparency.org/media/south-africa-country-profile-2020

47 IEA, "World Energy Outlook: Report extract", accessed September 2021 at https://www.iea.org/reports/world-energy-outlook-2020/outlook-for-fuel-supply

48 'Net-zero' means that we reach a point at which CO2 emission sources equal CO2 sinks. The objective of achieving "net zero" greenhouse gas emission status for the world by 2050 is strongly linked to achieving the goal of the world staying below 1.5oC global warming of the Paris Agreement (2015).

49 International Energy Agency, "*Net Zero by 2050: A Roadmap for the Global Energy Sector.*" (IEA, Paris, 2021).

50 Global coal demand would decline ultimately by 90% to only 600Mtce by 2050. IEA, "*Net Zero by 2050*".

51 International Energy Agency (IEA), World Energy Outlook 2020. IEA, Paris 2021

52 India accounted for 37% of South Africa's coal exports value in 2017: Observatory of Economic Complexity (OEC), "Where does South Africa export Coal Briquettes to? (2017)" Online https://oec.world/en/visualize/tree_map/hs92/export/zaf/show/52701/2017/ Accessed 16 June 2021

53 Matthew Huxham, Muhammed Anwar and David Nelson, "Understanding the impact of a low carbon transition on South Africa" Climate Policy Initiative, (2019)

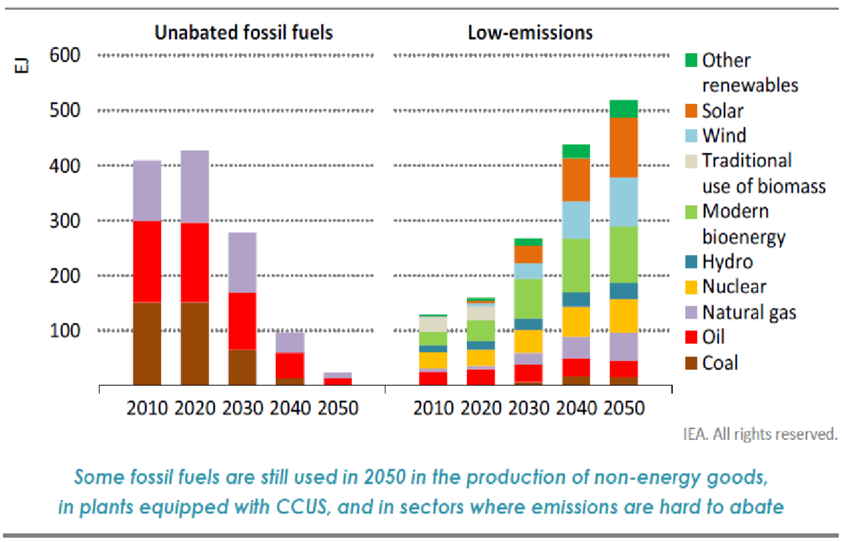
54 Neva Makgetla et al., "Nationale Employment Vulnerability Assessment : Analysis of potential climate-change related impacts and vulnerable groups", (Trade & Industrial Policy Strategies, Pretoria, 2019), p.11-13

55 Author's calculations based on: A. Kerr, D. Lam, D. and M. Wittenberg, *"Post-Apartheid Labour Market Series (PALMS) 1993-2019" [dataset v3.3],* (DataFirst [producer and distributor], . Cape Town, 2019), *DOI: https://doi.org/10.25828/gtr1-8r20*

56 Neva Makgetla and Muhammed Patel, "The Coal Value Chain in South Africa", (Trade & Industrial Policy Strategies, Pretoria, July 2021), p.10

57 Schers, et al. (2021) "Hydrogen economy skills", (2021).

Figure 5: Total energy supply of unabated fossil fuels and low-emissions energy sources in the Net-Zero pathway (NZE) of the IEA's Net Zero by 2050 report (source: IEA, 2020) [58]



Note: Low-emissions includes the use of fossil fuels with CCUS and in non-energy uses.

Source:

4.2 ICE vehicles phase out impact on industry jobs

A global Net-Zero by 2050 pathway requires internal combustion engine (ICE) vehicles to be phased out entirely by 2050, pushing motorized road transport towards electric or fuel cell vehicles.[59] This development has started in high-income economies in recent years, spurred by declining battery costs in combination with government support.[60] Continuation of this trend has implications for refineries and manufacturing of motorized vehicles, vehicle parts, as well as for platinum demand for catalytic converters for ICE vehicles.

About 70% of global oil consumption is for motorized transport and the IEA expects that a shift towards electric vehicles in a Net-Zero pathway would see global oil demand decline from 97 mb/d[61] in 2018 to 24 mb/d by 2050. Gasoline and diesel production are then expected to reduce to only 15% of the crude oil transformation market by 2050 (currently they make up 55%) leading refinery utilisation to decline by 85%.[62] This could create additional challenges for the South African refining sector, with some refineries already on the verge of shutting down due to international cost competitiveness and

[58] IEA, "Net Zero by 2050", Figure 2.6
[59] IEA, "Net Zero by 2050"
[60] By 2020 battery electric vehicles gained market shares in volumes of sales for new small and medium-sized cars reaching as much as 75% in Norway, between 20 and 40% in the Netherlands and Sweden, and between 10 and 14% in the UK, France, and Germany. See: International Energy Agency (IEA), "Global EV Outlook 2021", IEA, Paris https://www.iea.org/reports/global-ev-outlook-2021, 2021
[61] Million barrels per day (mb/d)
[62] IEA, Net Zero by 2050

other pressures.[63] Sooner or later, South African refineries will have to upgrade to facilities for clean or renewable fuels or close as demand for more polluting fuels reduces. Lack of preparation for alternative futures could risk closure of refineries and put tens of thousands of refinery jobs at risk: In 2019 the South African refining industry employed a little more than 40 thousand workers, of which about 5% or 2,000 had TVET certificates, and another 25% (10,000 workers) had lower tertiary diplomas or degrees.[64]

South Africa's vehicle manufacturing sector could get caught between two fires were it not be able to make the transition to battery or (hydrogen) fuel cell-driven vehicles, if the domestic market – good for half of demand, with the other half destined for exports – would lag on international trends and remain stuck on internal combustion engine vehicles.[65] The fact that companies and markets are dominantly multinational adds to this pressure.[66] The South African automotive industry employed about 100 000 workers in recent years, concentrated in Gauteng, Eastern Cape and Kwazulu-Natal.[67] An estimated 5%, or 5,000 of these workers have TVET certificates, and another 15% lower tertiary diplomas or degrees. Factories and jobs will be at risk from competition for a shrinking global ICE vehicle market as far as they are involved in producing internal combustion engine vehicles and parts.[68]

Lastly, the IEA's assessment of metals required for a Net Zero transition suggests a net decline in demand for PGM metals for the specific purpose of catalytic converters.[69] Platinum, rhodium and palladium usage in catalytic converters in the automobile sector comprises approximately a third of global gross demand for PGM metals. E.g., for platinum this global gross demand for use in catalytic converters is expected to peak at approximately 130 tonnes, from present day use of 90 tonnes, before declining to nil by 2050 for a Net-Zero by 2050 scenario.[70] The described developments could thus in theory put 1/3rd of PGM jobs and all catalytic convertor industry jobs at risk.[71] PGM mining currently provides about 170,000 jobs in South Africa[72] while the catalytic converter industry is estimated to provide 5,000 direct jobs.[73] With both sectors having 4,5% to 5% of workers with a TVET

63 For instance, the Engen refinery in Durban: Terence Creamer, "Engen to shut refinery and repurpose KZN site as an import terminal", Engineering News, 23 April 2021, https://www.engineeringnews.co.za/article/engen-to-shut-refinery-and-repurpose-kzn-site-as-an-import-terminal-2021-04-23/rep_id:4136; Bloomberg, "South Africa's refinery woes raise reliance on fuel imports", BusinessTech, 24 November 2020, https://businesstech.co.za/news/business/451140/south-africas-refinery-woes-raise-reliance-on-fuel-imports/

64 A number already down from roughly 50 thousand jobs in prior years. Source: Author calculations based on: Kerr, et al. PALMS [dataset v3.3] (2019).

65 Neva Makgetla, et al., "National Employment Vulnerability Assessment" *(TIPS, 2019)*, p.69-71

66 Makgetla, et al., "National Employment Vulnerability Assessment" *(2019)*, p.74

67 Makgetla, et al., "National Employment Vulnerability Assessment" *(2019)*, p.72-74

68 Additionally, a part of the current 130,000 jobs (in 2017) in petrol stations will be under pressure, though the present share of TVET educated workers is low in transport & trade/retail (3,3% - source: Author calculations based on: Kerr, et al. PALMS [dataset v3.3] (2019)), and hydrogen re-fuelling and battery charging allow a yet to be estimated extent of refuelling stations to remain operational. See also: Makgetla, et al, "National Employment Vulnerability Assessment" *(2019), p.72*

69 IEA, "The Role of Critical Minerals in Clean Energy Transitions", (IEA, Paris, 2021).

70 IEA, "Net Zero by 2050", at less ambitious climate policy they would plateau to 2050, as in the SDS scenario.

71 Based on an assumption of average labour productivity for PGM mining and assuming it constant until 2050.

72 Chamber of Mines, "Mine SA 2016, Facts & Figures" (Chamber of Mines South Africa, Johannesburg, January 2017); Minerals Council, "National Platinum Strategy for South Africa: Fact sheet" (Minerals Council of South Africa, 11 June 2019).

73 Source: Author calculations based on: Kerr, et al. PALMS [dataset v3.3] (2019); K. Dewar, "The Catalytic Converter Industry in South Africa", The Southern African Institute of Mining and Metallurgy, 2012.

certificate, that could put about 2,800 former TVET learners back into unemployment for the two sectors combined.[74]

4.3 International hydrogen economy opportunities for PGM mining

Low costs of solar PV and other renewables offer an opportunity for South Africa too. Firstly, through lowering the future costs of electricity, which benefits GDP growth and hence the majority of sectors in the national economy and their employment.[75] Additionally, cheap renewable energy could enable South Africa to become a producer of cheap green hydrogen and, on that basis, of green steel and green variants of basic chemicals, like ammonia and methanol.[76] An international green hydrogen economy also has opportunities for platinum group metal (PGM) mining, and for beneficiation further down the value chain, as platinum is one of the key materials for the electrodes in electrolysers which produce hydrogen, as well as for proton exchange membranes (PEM) in fuel cells. A part of the motorized vehicle and equipment market, and off-grid power generation systems (e.g., in shipping) can be expected to shift to the use of hydrogen fuel cells, for which platinum group metals are an important resource. Potential losses in PGM exports for auto-catalysts and their associated demand for platinum could thus be compensated by PGM demand for a hydrogen economy. Fuel-cell vehicles are expected to contribute to a sharp increase in demand for platinum due to their higher platinum group metals material loading compared to conventional vehicles.[77] The need for PEM fuel-cells and for electrolysers could thus multiply global platinum demand compared to present-day demand.[78]

Concretely, the IEA's Net-Zero 2050 pathway requires hydrogen production to increase from the present-day supply of 90 Mt/year to 200 Mt/year by 2030 and 500 Mt/year by 2050.[79] This outlook for hydrogen would require 850 GW electrolyser capacity by 2030 and 3,000 GW by 2050 worldwide[80]. A more moderate energy transition in IEA's Sustainable Development Scenario would lead to a more moderate increase in electrolyser capacity[81], but still projects a requirement for 150 GW of electrolysers by 2030 and 1,400 GW by 2050.

The IEA projects demand for PGM metals in 2040 to be predominantly for fuel-cells rather than electrolysers.[82] However, the extent of future fuel cell utilisation is more uncertain as electric batteries continue to make inroads in applications touted for hydrogen such as a light duty vehicles, trucks, off-grid power, and grid balancing. Under the IEA's moderate Sustainable Development Scenario, growth from the current 1 GW of fuel cell capacity is projected to reach 500 GW by 2030 and 20,000 GW in 2050 for stationery and predominately transport applications.

[74] Source: Author calculations based on: Kerr, et al. PALMS [dataset v3.3] (2019).
[75] Merven et al., "Improved representation of coal supply for the power sector for South Africa", (SA-TIED working paper #84, University of Cape Town, Cape Town & South Africa – Towards Inclusive Economic Development programme, October 2019).
[76] IHS Markit, "Super H2igh Road Scenario", (2021).
[77] Schers, et al "Hydrogen economy skills" (2021).
[78] ibid.
[79] IEA, "Net Zero by 2050"
[80] ibid
[81] IEA, "The Role of Critical Minerals in Clean Energy Transitions"
[82] ibid

Translated to PGM output, we estimate that a rapid global energy transition to Net-Zero by 2050 could in an optimistic case imply an *eight-fold* increase in demand of platinum in South Africa, assuming the country maintains its supply dominance and that platinum-based PEMs remains the preferred technology for fuel cells.[83] Under a more moderate scenario, a global hydrogen economy's use of electrolysers and fuel cells could potentially double demand for South African platinum by 2050 compared to global demand over the period 2018 to 2020, despite a phase out of catalytic convertors in motorized vehicles.[84]

In 2016 direct employment in PGM mining stood at about 170,000 jobs, but the industry was under pressure of reduced demand in the jewellery market and for diesel cars.[85] Would labour productivity remain constant and employment increase like output, then an additional 170,000 jobs could be added, would labour productivity increase by 1.5% per year for the entire labour force than this number reduces to about 74,000 jobs (see below).[86] PGM mining's current TVET intensity is estimated at 4,5%, meaning the sector could add between 3,300 and 7,650 TVET jobs until 2050.[87]

4.4 Value creation from international opportunities for a SA Green Hydrogen Economy

As mentioned, the approach of the IHS Markit Super H2igh Road scenario was to propose economic interventions, driven by public policy, leads to the establishment of an initial but sizeable South African hydrogen-based economy, as a condition to be able to export hydrogen-based products or technology.[88] The present paper turns this approach around, and assumes that these conditions for establishment of export-oriented production in South Africa will be met for certain green hydrogen-based products, and from there arrives at a provisional estimate of future demand for TVET labour in some key hydrogen economy sectors: PGM mining, hydrogen production, and electrolyser and fuel cell manufacturing.[89] We therefore estimate the potential future value of South African exports for the sectors of interest and derive the amount of labour in these sectors.

Schers et al. estimate potential export market sizes for green hydrogen related products, depending on global ambitions and South African shares in comparable markets.[90] We combine these with estimates for export prices to arrive at an estimate of the 2050 export market value in today's money, shown in Table 4.

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83 Schers, et al "Hydrogen economy skills" (2021).

84 Schers, et al "Hydrogen economy skills" (2021)., Fig.9/page 31.

85 Chamber of Mines, "Mine SA 2016, Facts & Figures" (Chamber of Mines South Africa, Johannesburg, January 2017); Minerals Council, "National Platinum Strategy for South Africa: Fact sheet" (Minerals Council of South Africa, 11 June 2019)

86 Assuming a scenario corresponding to IEA's relatively moderate Sustainable Development Scenario, see: Schers, et al. (2021) "Hydrogen economy skills and the just transition", Occasional Research Paper 2021, Fig.9/page 29-32. In a faster transition to Net Zero this number could in theory become much higher. Automatisation or other reasons for increased labour productivity could reduce that employment projection.

87 This estimate is of similar size as expectations by the Minerals Council, which foresee that PGM mining employment could grow by 2% a year in an optimistic "High" PGM scenario in relation to fuel cell deployment, which takes PGM employment beyond 300,000 persons and possibly up to 370,000 jobs. See: Minerals Council, "National Platinum Strategy" (2019)

88 IHS Markit, "Super H2igh Road Scenario for South Africa", (2021).

89 We consider full-sector dynamic integrated modelling necessary to arrive at full employment estimates, as will be performed under UCT's workstream 2 for the SAIIA UKPACT 2021 project, see also footnote 21.

90 Schers, et al. (2021) "Hydrogen economy skills", (2021).

From these estimates it becomes clear that there if the South African market shares in the given export markets were to be realised, this leads to very significant new export potentials, ranging from 83,5 billion Rand for PGM metals to around 200 billion Rand each for hydrogen, fuel cells and electrolysers (see Table 4)[91]. These numbers would imply that these sectors have the potential to become comparable in size to the current biggest export sectors (Gold, Platinum, Cars, Iron ore, and Coal).[92]

Table 4: *Estimates of future export market value for key hydrogen-based commodities and products*

Commodity or product:	**Platinum**	**Hydrogen**	**Hydrogen (as ammonia)**	**Fuel cells**	**Electrolysers**
Moderate 2050 world market estimate	226 tonne /year	88 million tonne /year	18 (89)[93] million tonne /year	6,200 Gigawatt /year	420 Gigawatt / year
SA market share; volume	65%; 147 tonne /year	10%; 9 million tonne /year	10%; 1.8 (9) million tonne/year	5%; 310 Gigawatt /year	5%; 21 Gigawatt /year
Assumed export price in USD (and ref. year)	42,72 million USD/tonne (2017) [94]	1.35 USD (2020)/kg H2 (2050)[95]	1.35 USD (2020)/kg H2 (2050)	50 USD /kilowatt (long term future)[96]	650 USD /kilowatt (long term future)[97]

[91] For export volume assumptions see: Schers, et al. (2021) "Hydrogen economy skills", (2021).

[92] OEC, "South Africa" (Observatory of Economic Complexity (OEC), Datawheel, Cambridge (MA, US), 2021).

[93] Assuming 20% of ammonia's weight would be required in hydrogen to produce the ammonia. In molar weight hydrogen represents 17% of ammonia's weight, but due to process efficiency the real amount required could be higher, e.g. Finsnes et al (2020) propose a hydrogen to ammonia ratio of 140:588 for their green ammonia process [Source: K.A. Finsnes, J.P. Kwon, D.M. Wallach, "Renewable Ammonia", (Senior Design Reports (CBE), 125, University of Pennsylvania, (2020), at: https://repository.upenn.edu/cbe_sdr/125

[94] This is considered a representative pre-pandemic platinum export price for a typical mix of unwrought and semi-manufactured platinum, based on 2017 data using: 220 tonne of PGM metals exported in 2017 [Source: Chamber of Mines, "Mine SA 2017 – Facts and Figures Pocketbook", (Chamber of Mines, 2017)] estimating about half (110 tonne) was platinum [Source: Chamber of Mines, "Facts and Figures 2013-2014" (Chamber of Mines, 2014)], at a value totalling USD 4.7 in 2017 (USD 2.5 billion for unwrought or powder platinum + USD 2.2 billion in semi-manufactured form [Source: OEC, "South Africa" (Observatory of Economic Complexity (OEC), Datawheel, Cambridge (MA, US), 2021)]. https://oec.world/en/profile/country/zaf?depthSelector1=HS6Depth&yearSelector1=exportGrowthYear23]

[95] Choosing a mid-range value for IHS Markit's estimate for 2050 SA Hydrogen costs, and we exclude conversion and storage before shipping – which might not necessarily be done by hydrogen as an economic sector [Source: IHS Markit, "Super H2igh Road Scenario" (2021)].

[96] Assuming optimistic price decreases based on: IEA "The future of Hydrogen" (2019), p.131

97 ibid

Assumed price in ZAR (and ref. year)	568 million ZAR/tonne (2017)[98]	19.5 ZAR(2019) /kg H2 (2050)[99]	19.5 ZAR(2019) /kg H2 (2050)[100]	1,080 ZAR(2019)/ kilowatt[101]	9,380 ZAR(2019)/ kilowatt[102]
Estimated 2050 export market value at ZAR price	**83.5 *billion* ZAR(2017)**	**176 billion ZAR(2019)**	**35 billion ZAR(2019)**	**223 *billion* ZAR(2019)**	**196 *billion* ZAR(2019)**

Source:

In a next step, data in Table 4 is combined with estimates of labour shares in the macro-economic cost structures of the producing/manufacturing sectors of concern, as presented in Table 4. The resulting estimated labour earnings for 2050 exports for the selected sectors then becomes: 16 billion Rand in Platinum mining; 18 billion Rand in Hydrogen production; 11 billion Rand in Fuel cell manufacturing; and 22 billion Rand in Electrolyser manufacturing (see Table 5). Table 2 below gives our estimates of how much of this export value would translate into value added for capital (capital rents / write-offs and returns) and labour (wages and social security).

98 Assuming an exchange rate of 13.30 ZAR/USD, see: https://www.exchangerates.org.uk/ZAR-USD-spot-exchange-rates-history-2017.html
99 Assuming an average exchange rate as in 2019: 14.43 ZAR/USD, see: https://www.exchangerates.org.uk/ZAR-USD-spot-exchange-rates-history-2019.html
100 ibid
101 ibid
102 ibid

Table 5: *Estimated macro-economic cost structures of selected sectors for a SA green hydrogen economy* (*)

	PGM mining	**Hydrogen production**(***)	**Fuel-cell manufacturing**(***)	**Electrolyser manufacturing**(***)
Intermediate inputs	49%	87%	71%	69%
VA - Labour	19,5%	8,5%	5%	11%
VA - Capital	34,5%	4,5%	24%	20%
Total(**)	100%	100%	100%	100%

Source: * Compiled by authors based on SAM South Africa 2012[103]; Quantec data[104]; the PALMS dataset v3.3[105]; ** Cost structures here exclude taxes & subsidies, imports, and trade & transport margins; *** For hydrogen production numbers are based on existing data for the Chemicals sector; for Fuel Cell manufacturing and Electrolyser manufacturing numbers are based on data for manufacturing of electrical machinery and information from E4Tech[106].

5. GHE TVET employment and TVET system's role for a Just Transition

5.1 Future TVET jobs estimates of the GHE and their timing

The trends above are descriptions of developments outside a context of an entire developing economy. The modelling of the described scenarios with SATIMGE allows to analyse a domestic hydrogen economy development with that of an international green hydrogen economy and take into account the feedback mechanisms, e.g. on investment and exchange rates, as well as links to other sectors of different hydrogen economy developments. We show results for a medium (2030) and long-term time horizon (up to 2045).[107] Combining the results of our four scenarios, the picture

[103] Dirk van Seventer, Faaiqa Hartley, Sherwin Gabriel, and Rob Davies, "A 2012 Social Accounting Matrix (SAM) for South Africa" (WIDER Working Paper 2016/26, UNU-WIDER, Helsinki, 2016).

[104] Quantec EasyData, "RSA industry data" (accessed September 2021), www.easydata.co.za,

[105] A. Kerr, D. Lam and M. Wittenberg, "Post-Apartheid Labour Market Series 1993-2019 [dataset]" (Version 3.3, DataFirst [producer and distributor], Cape Town, 2019), DOI: https://doi.org/10.25828/gtr1-8r20

[106] E4Tech, " Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies", (Findings Report for FCH 2 JU, E4tech (UK) Ltd, Ecorys and Strategic Analysis Inc, London (UK), September 2019), https://www.fch.europa.eu/sites/default/files/Findings%20Report%20v4.pdf

[107] See UCT's forthcoming UKPACT workstream 5 output for details.

which arises is one in which in which job opportunities of a GHE will ultimately be higher than the number of jobs that will be lost (see Table 6). The role of Green Hydrogen Economy sectors in the total South African economy starts around 2030 under our scenarios.

However, coal and the petrochemical sectors already face reductions in output and jobs in the current decade (the 2020'ies), which can be explained from changing economics in both the power generation and refinery markets, where South Africa faces. For the economy as a whole these job losses can be expected to be compensated by growth in jobs in other sectors (see Table 6). Two in the context of our analysis relevant sectors that show already significant growth in the medium term before 2030 in all four Net Zero scenarios are the Power Generation (electricity) sector and the Iron & Steel sector. The first may not come as a surprise. The second one is one of the main suppliers of the construction sector and other industries that supply the materials and equipment for a growing economy. In the Full GHE Exports scenario the Iron & Steel sector furthermore exports green steel towards the end of the projection horizon (see Table 6, lower-right panel).

For TVET employment specifically, all scenarios show the entire South African economy increasing jobs for TVET educated employees, with between 2019 and 2030 an expected increase of 17%. In 2045 their number is expected to be between 68% and 83% higher than in 2020 (see Table 7). However, total TVET employment in the for our analysis of a Just Labour Transition to a GHE relevant sectors (highlighted in Table 7) is foreseen to decrease slightly until 2030 before increasing again slowly to 2040 and then strongly until 2045. The exception is the scenario in which both a domestic Green Hydrogen Economy and hydrogen-based exports to the Rest of the World take off (lower-right panel of Table 7), leading already to a strong increase in TVET employment in relevant sectors.

Near future losses in selected sectors for TVET employment would come for the account of coal mining and refineries. Power generation however sees TVET jobs increase by around 40& to 50% by 2035 relative to nowadays, and also at the TVET level, the Iron & Steel sector (I&S) could cushion job losses elsewhere (Table 7). These I&S and power sector TVET jobs continue to increase thereafter, and from 2040 onwards a stark rise in TVET jobs in PGM mining is expected (Table 7).

When comparing the contribution of a domestic green hydrogen economy only, one can observe that the scenario of a domestic GHE without a specific hydrogen-related exports (lower-left panel in Table 6) adds up to 1,6 thousand TVET jobs by 2045 compared to the no-green-hydrogen-economy future (upper-left pane in Table 6) in total for selected sectors. Besides in power generation, growth in these TVET jobs will be found in Fuel cell manufacturing and hydrogen production, which by 2040 together would employ about a thousand TVET educated staff, and by 2045 about 1500 persons with TVET education.

Table 6: *Resulting jobs by sector (x1000) for scenarios without (upper panels) and with (lower panels) a SA hydrogen economy, without (lefthand panels) & with (righthand panels) hydrogen-based exports*

Net Zero scenarios		**Exports / Year**									
		PGM Exports only					**PGM,Fuel Cell , and Electrolyser Exports**				
SA Hydrogen Economy?	**Jobs x1000 by sector**	**2019**	**2030**	**2035**	**2040**	**2045**	**2019**	**2030**	**2035**	**2040**	**2045**
No SA GHE	**Total**	**16 944**	**19 836**	**22 333**	**25 455**	**29 607**	**16 944**	**19 844**	**22 350**	**25 464**	**29 493**
	Refineries (incl.CTL)	39	10	6	2	2	39	10	6	2	2
	Hydrogen	0	0	0	0	0	0	0	0	0	0
	Ammonia	5	5	4	4	5	5	5	4	4	5
	FuelCells	0	0	0	0	0	0	0	3	7	140
	Electrolysers	0	0	0	0	0	0	2	16	29	144
	Iron & Steel	136	170	186	210	225	136	170	187	209	230
	PGM mining	184	162	178	191	398	184	162	178	191	430
	Coal mining	75	50	33	25	19	75	50	33	25	19
	Power Gen, and T&D	76	89	110	125	146	76	89	110	125	144
	Agriculture	851	971	1 076	1 160	1 275	851	971	1 072	1 154	1 199
	Other Mining	172	201	214	224	235	172	201	213	222	213
	Other Industries	3 812	4 520	4 975	5 450	6 109	3 812	4 520	4 969	5 442	5 970
	Tertiary sector	11 594	13 658	15 551	18 064	21 193	11 594	13 664	15 559	18 054	20 997
		PGM Exports only					**Full Exports (PGM,FC,ELT,Ammonia, and I&S)**				
SA Hydrogen Economy?	**Jobs x1000 by sector**	**2019**	**2030**	**2035**	**2040**	**2045**	**2019**	**2030**	**2035**	**2040**	**2045**
Yes, with a SA GHE	**Total**	**16 944**	**19 865**	**22 431**	**25 174**	**28 553**	**16 944**	**19 899**	**23 064**	**26 727**	**31 308**
	Refineries (incl.CTL)	39	9	5	1	0	39	9	5	1	1
	Hydrogen	0	0	2	10	13	0	1	9	26	38
	Ammonia	5	5	4	4	4	5	5	21	34	49
	FuelCells	0	0	1	18	29	0	0	5	28	172
	Electrolysers	0	0	0	0	0	0	2	16	30	151
	Iron & Steel	136	170	186	201	214	136	224	407	581	760
	PGM mining	184	162	178	190	398	184	161	177	188	450
	Coal mining	75	52	34	24	19	75	51	34	25	18
	Power Gen, and T&D	76	86	110	131	154	76	88	116	146	177
	Agriculture	851	971	1 083	1 158	1 241	851	946	1 012	1 081	1 127
	Other Mining	172	201	213	224	231	172	196	198	209	210
	Other Industries	3 812	4 522	4 969	5 317	5 819	3 812	4 469	4 870	5 307	5 781
	Tertiary sector	11 594	13 686	15 646	17 896	20 431	11 594	13 747	16 194	19 071	22 373

Source:

The biggest change comes when the employment potential of developing green hydrogen-related export markets are taken into account. By 2045, depending on whether these export markets are limited to PGM, and Electrolysers and Fuel Cell components, or whether they would also include green hydrogen-based steel and ammonia, the TVET employment impact in selected sectors could be around 300 TVET jobs by 2030 (excluding PGM mining and I&S), and between 800 and about 2000 thousand TVET jobs by 2035, up to between 9 and 15 thousand more TVET jobs by 2045 in GHE sectors (excluding PGM mining and I&S) (see Table 7).

Our analysis leads to the view that the first sector that could benefit from a global transition to a GHE would be the South African Iron & Steel sector. The Electrolyser industry would also require TVET trained employees by 2030 already, while Fuel Cell component production for exports is estimated to start growing between 2030 and 2035 (Table 7).

Table 7: *Resulting TVET jobs by sector (x1000) for scenarios without (upper panels) and with (lower panels) a SA hydrogen economy, without (lefthand panels) & with (righthand panels) hydrogen-based exports*

Net Zero scenarios		**Exports / Year**									
		PGM Exports only					**PGM,Fuel Cell , and Electrolyser Exports**				
SA Hydrogen Economy?	**TVET jobs (x1000) by sector**	**2019**	**2030**	**2035**	**2040**	**2045**	**2019**	**2030**	**2035**	**2040**	**2045**
	Total	**662,6**	**772,1**	**868,1**	**988,5**	**1 150,5**	**662,6**	**772,4**	**868,6**	**988,6**	**1 144,3**
	Selected sectors subtotal	***28,4***	***25,2***	***26,0***	***27,4***	***38,3***	***28,4***	***25,3***	***26,6***	***28,6***	***48,9***
	Refineries (incl.CTL)	2,1	0,5	0,3	0,1	0,1	2,1	0,5	0,3	0,1	0,1
	Hydrogen	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Ammonia	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
	FuelCells	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2	4,5
	Electrolysers	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,5	0,9	4,6
No SA GHE	Iron & Steel	3,9	4,9	5,4	6,1	6,5	3,9	4,9	5,4	6,1	6,7
	PGM mining	8,3	7,3	8,0	8,6	18,0	8,3	7,3	8,0	8,6	19,4
	Coal mining	7,8	5,2	3,4	2,6	2,0	7,8	5,2	3,4	2,6	2,0
	Power Gen, and T&D	6,0	7,0	8,6	9,8	11,4	6,0	7,0	8,6	9,8	11,3
	Agriculture	32,8	37,5	41,5	44,8	49,2	32,8	37,5	41,4	44,6	46,3
	Other Mining	6,6	7,8	8,3	8,6	9,1	6,6	7,8	8,2	8,6	8,2
	Other Industries	147,1	174,5	192,0	210,4	235,8	147,1	174,5	191,8	210,1	230,4
	Tertiary sector	447,5	527,2	600,3	697,3	818,0	447,5	527,4	600,6	696,9	810,5
		PGM Exports only					**Full Exports (PGM,FC,ELT,Ammonia, and I&S)**				
SA Hydrogen Economy?	**Jobs x1000 by sector**	**2019**	**2030**	**2035**	**2040**	**2045**	**2019**	**2030**	**2035**	**2040**	**2045**
	Total	**662,6**	**773,3**	**871,9**	**977,9**	**1 110,0**	**662,6**	**774,1**	**894,5**	**1 034,8**	**1 210,9**
	selected sectors subtotal	***28,4***	***25,2***	***26,2***	***28,5***	***39,9***	***28,4***	***26,9***	***34,8***	***44,0***	***72,6***
	Refineries (incl.CTL)	2,1	0,5	0,3	0,1	0,0	2,1	0,5	0,3	0,1	0,1
	Hydrogen	0,0	0,0	0,1	0,5	0,6	0,0	0,0	0,4	1,2	1,7
	Ammonia	0,2	0,2	0,2	0,2	0,2	0,2	0,2	1,0	1,5	2,2
	FuelCells	0,0	0,0	0,0	0,6	0,9	0,0	0,0	0,2	0,9	5,5
Yes, with a SA GHE	Electrolysers	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,5	1,0	4,9
	Iron & Steel	3,9	4,9	5,4	5,8	6,2	3,9	6,5	11,8	16,9	22,0
	PGM mining	8,3	7,3	8,0	8,6	18,0	8,3	7,3	8,0	8,5	20,3
	Coal mining	7,8	5,5	3,5	2,5	1,9	7,8	5,3	3,6	2,6	1,9
	Power Gen, and T&D	6,0	6,7	8,6	10,3	12,1	6,0	6,9	9,1	11,4	13,9
	Agriculture	32,8	37,5	41,8	44,7	47,9	32,8	36,5	39,1	41,7	43,5
	Other Mining	6,6	7,7	8,2	8,6	8,9	6,6	7,6	7,6	8,1	8,1
	Other Industries	147,1	174,6	191,8	205,2	224,6	147,1	172,5	188,0	204,8	223,1
	Tertiary sector	447,5	528,3	603,9	690,8	788,7	447,5	530,7	625,1	736,1	863,6

Source:

5.2 Skill matching and timing of a Just Labour Transition

Many skills of labour required for these industries are already present in South Africa. For example, Sasol produces 2% of the world's hydrogen and have operated hydrogen systems for decades with specific skills embedded in their operations through in-company training. Beyond Sasol, the skills required for producing and using hydrogen can be expected to resemble those needed for production, storage, and distribution of chemicals and gases.[108]

As part of a just labour transition to a GHE, potential transition of skilled labour from diminishing fossil-fuel oriented sectors or productive activities to the value chains of a green hydrogen economy will most likely take place between similar industries, for example from automotive and electronic manufacturing to fuel cell/electrolyser industries. Table 8 below summarizes our estimation of industry similarity offering scope for employment transitions between sectors.

[108] Bambili Advisory "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).

Table 8: *Comparison of Aspects of a Green Hydrogen Economy to Existing Domestic Industries (Source: Schers et al. 2021)* [109]

Green Hydrogen Economy Aspects	Similar Industries
Fuel cells	Automotive, Electronic Parts, Manufacturing and Chemicals
Industrial Electrolysers	Heavy Industry/Chemicals
Hydrogen Storage and Distribution Facilities (grey hydrogen to green hydrogen)	Refining/Chemicals
Renewable Energy Facilities	Renewable Power
Fossil Fuel Coal Mining	Mining
PGM Mining	Mining

Source:

For the refineries and chemicals sectors job transitions would largely remain within sector and the mentioned 40 thousand workers in refineries could potentially find a place in hydrogen production and processing and downstream sectors like green chemicals.

However, from our analysis we however observe that the petrochemical sector might already suffer output decreases (mainly due to market forces) before 2030. This is sooner than the current expectation of the more chemistry-side development of the Green Hydrogen Economy in the form of hydrogen production and ammonia production, which under current outlooks only takes starts to develop between 2030 and 2035. A major question would therefore be whether there is room to speed-up the development of a Green Hydrogen Economy, and to find a way to bridge the skills from the petrochemical industry to a growing green hydrogen economy between 2025 and 2035.

As part of a just labour transition to a Green Hydrogen Economy there also is opportunity for lower-skilled workers from the coal mining industry to be deployed to the construction, operation, and maintenance environment.[110] Alternatively, platinum group metals mining could offer a future to younger miners. Our scenario analysis shows that this would be possible from somewhere 2030 onwards, when growth in PGM mining TVET employment can be expected to outperform decreases in coal mining TVET employment (see Table 7 above).[111]

It is therefore interesting to consider a just labour transition to industries which require skill sets that are a little bit more distant to those expected for coal mining, but which nevertheless could require strong mechanical, teamwork, and logistics skills. For this reason our analysis considers the skill-subtypes of the Power Generation and Iron&Steel sectors too, see Table 7 below. Here we observe that even though coal mining is the most-TVET intensive sector of the sectors analysed for the present study, the total of power generation and Iron & Steel could make use of a large part of the necessary medium- and high-skill TVET-educated staff that would be lost in coal mining already in the transition period

[109] Schers, et al. "Hydrogen economy skills" (2021).

[110] Bambili Advisory "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).

[111] Potential for mechanisation and automatization remain uncertain factors for total future employment in this sector

up to 2030, especially in the case of a domestic Green Hydrogen Economy with a strong export orientation (see Table 9 below, lower-right panel). Beyond 2030 there is even more room for such a job transition. However more detailed study of the requirements for upskilling or reskilling would be needed, as well as a careful analysis of the age profiles of these labour forces, and the willingness to move among workers.

Nevertheless, even when considering differences in geographical location, and the observed difference in timing, there is still a strategy for alternative economic development required in coal mining areas in the years 2022 to 2030. One option is to prioritize pilots for up- or re-skilling in coal mining communities, and besides to envision new careers, outside a green hydrogen economy, e.g. through improved teaching of mathematics and digital literacy.[112]

[112] Bambili Advisory "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).

Table 9: *Estimated evolution of TVET jobs (x1000) by job type in Coal and PGM mining, the electricity sector and Iron & Steel for scenarios without (upper panels) and with (lower panels) a SA hydrogen economy, without (lefthand panels) & with (righthand panels) hydrogen-based exports*

	Net Zero scenarios		Exports / Year									
			PGM Exports only					PGM,Fuel Cell , and Electrolyser Exports				
SA Hydrogen Economy?	**Sector**	**TVET Jobs by type x1000 by sector**	**2019**	**2030**	**2035**	**2040**	**2045**	**2019**	**2030**	**2035**	**2040**	**2045**
	Coal	TVET low skilled	0,3	0,2	0,1	0,1	0,1	0,3	0,2	0,1	0,1	0,1
	Coal	TVET semi skilled	6,7	4,5	2,9	2,3	1,7	6,7	4,5	2,9	2,3	1,7
	Coal	TVET high skilled	0,8	0,5	0,4	0,3	0,2	0,8	0,5	0,4	0,3	0,2
	Coal	**TVET total**	**7,8**	**5,2**	**3,4**	**2,6**	**2,0**	**7,8**	**5,2**	**3,4**	**2,6**	**2,0**
	PGM	TVET low skilled	1,5	1,3	1,4	1,5	3,2	1,5	1,3	1,4	1,5	3,4
	PGM	TVET semi skilled	5,9	5,2	5,7	6,2	12,8	5,9	5,2	5,7	6,2	13,9
	PGM	TVET high skilled	0,9	0,8	0,9	0,9	2,0	0,9	0,8	0,9	0,9	2,1
	PGM	**TVET total**	**8,3**	**7,3**	**8,0**	**8,6**	**18,0**	**8,3**	**7,3**	**8,0**	**8,6**	**19,4**
	Power	TVET low skilled	0,1	0,1	0,1	0,1	0,2	0,1	0,1	0,1	0,1	0,1
No SA GHE	Power	TVET semi skilled	4,2	4,9	6,1	6,9	8,1	4,2	4,9	6,1	6,9	8,0
	Power	TVET high skilled	1,6	1,9	2,4	2,7	3,2	1,6	1,9	2,4	2,7	3,1
	Power	**TVET total**	**5,9**	**6,9**	**8,6**	**9,8**	**11,4**	**5,9**	**6,9**	**8,6**	**9,8**	**11,2**
	Iron & Steel	TVET low skilled	0,3	0,4	0,4	0,5	0,5	0,3	0,4	0,4	0,5	0,5
	Iron & Steel	TVET semi skilled	3,2	4,0	4,4	4,9	5,3	3,2	4,0	4,4	4,9	5,4
	Iron & Steel	TVET high skilled	0,5	0,6	0,6	0,7	0,8	0,5	0,6	0,6	0,7	0,8
	Iron & Steel	**TVET total**	**3,9**	**4,9**	**5,4**	**6,1**	**6,5**	**3,9**	**4,9**	**5,4**	**6,1**	**6,7**
	All 4	**TVET low skilled**	**2,1**	**1,9**	**2,1**	**2,2**	**3,9**	**2,1**	**1,9**	**2,1**	**2,2**	**4,1**
	All 4	**TVET semi skilled**	**20,1**	**18,6**	**19,1**	**20,3**	**27,9**	**20,1**	**18,6**	**19,2**	**20,2**	**29,0**
	All 4	**TVET high skilled**	**3,8**	**3,8**	**4,2**	**4,6**	**6,1**	**3,8**	**3,8**	**4,2**	**4,6**	**6,2**
	All 4	**TVET total**	**26,0**	**24,4**	**25,4**	**27,1**	**37,9**	**26,0**	**24,4**	**25,4**	**27,1**	**39,4**
			PGM Exports only					**Full Exports (PGM,FC,ELT,Ammonia, and I&S)**				
SA Hydrogen Economy?	**Sector**	**TVET Jobs by type x1000 by sector**	**2019**	**2030**	**2035**	**2040**	**2045**	**2019**	**2030**	**2035**	**2040**	**2045**
	Coal	TVET low skilled	0,3	0,2	0,1	0,1	0,1	0,3	0,2	0,1	0,1	0,1
	Coal	TVET semi skilled	6,7	4,7	3,0	2,2	1,7	6,7	4,6	3,1	2,2	1,6
	Coal	TVET high skilled	0,8	0,6	0,4	0,3	0,2	0,8	0,6	0,4	0,3	0,2
	Coal	**TVET total**	**7,8**	**5,5**	**3,5**	**2,5**	**1,9**	**7,8**	**5,3**	**3,6**	**2,6**	**1,9**
	PGM	TVET low skilled	1,5	1,3	1,4	1,5	3,2	1,5	1,3	1,4	1,5	3,6
	PGM	TVET semi skilled	5,9	5,2	5,7	6,1	12,8	5,9	5,2	5,7	6,1	14,5
	PGM	TVET high skilled	0,9	0,8	0,9	0,9	2,0	0,9	0,8	0,9	0,9	2,2
	PGM	**TVET total**	**8,3**	**7,3**	**8,0**	**8,6**	**18,0**	**8,3**	**7,3**	**8,0**	**8,5**	**20,3**
	Power	TVET low skilled	0,1	0,1	0,1	0,1	0,2	0,1	0,1	0,1	0,2	0,2
'es, with a SA GH	Power	TVET semi skilled	4,2	4,8	6,1	7,3	8,5	4,2	4,9	6,4	8,1	9,8
	Power	TVET high skilled	1,6	1,9	2,4	2,8	3,3	1,6	1,9	2,5	3,2	3,8
	Power	**TVET total**	**5,9**	**6,7**	**8,6**	**10,2**	**12,0**	**5,9**	**6,9**	**9,1**	**11,4**	**13,8**
	Iron & Steel	TVET low skilled	0,3	0,4	0,4	0,4	0,5	0,3	0,5	0,9	1,3	1,7
	Iron & Steel	TVET semi skilled	3,2	4,0	4,4	4,7	5,0	3,2	5,3	9,5	13,6	17,8
	Iron & Steel	TVET high skilled	0,5	0,6	0,6	0,7	0,7	0,5	0,8	1,4	2,0	2,6
	Iron & Steel	**TVET total**	**3,9**	**4,9**	**5,4**	**5,8**	**6,2**	**3,9**	**6,5**	**11,8**	**16,9**	**22,1**
	All 4	**TVET low skilled**	**2,1**	**1,9**	**2,1**	**2,2**	**3,9**	**2,1**	**2,0**	**2,5**	**3,0**	**5,5**
	All 4	**TVET semi skilled**	**20,1**	**18,7**	**19,2**	**20,3**	**28,1**	**20,1**	**19,9**	**24,7**	**30,0**	**43,8**
	All 4	**TVET high skilled**	**3,8**	**3,8**	**4,3**	**4,7**	**6,2**	**3,8**	**4,0**	**5,1**	**6,3**	**8,8**
	All 4	**TVET total**	**26,0**	**24,4**	**25,5**	**27,2**	**38,1**	**26,0**	**26,0**	**32,4**	**39,3**	**58,1**

Source:

5.3 Current and future provision of TVET hydrogen skills

The current grey hydrogen produced in South Africa requires the same skills as are needed for any chemical or gas production and distribution system. However, the TVET system does not have the ability to fully supply these needs, so companies provide additional training in-house for quality upgrades and specific content required. Basic skills such as electrical, mechanical skills and the like as supplied by the TVET college system currently need to be built on with specialised content and equipment training, and digital skills.[113]

The additional skills required for green hydrogen, above current TVET curriculums, are equipment and process specific and largely technical in nature.[114] We think that it should be recommended that companies with already fully developed in-house training for grey hydrogen, partner with TVET institutions to support the skills curriculum needed in this forecasted growth sector.

Where renewable energy is converted via electrolysis to produce green hydrogen, specialist content knowledge and work experience is required in the primary conversion stage. However, water electrolysis is a mature technology and well established at an industrial level. A curriculum for TVET colleges can be developed for supplemental technical and cross cutting skills. Occupations in the fuel cell manufacturing industry would require additional skills specific to equipment and process, above current TVET curriculums. [115]

We think electrical machinery manufacture, for example, can be used as a proxy to map skills where in-house or additional training already exists, with supplemental hydrogen and technical details for fuel cell technology curriculum development. At the TVET level, skills needed are linked to manufacturing of components, assembly at various points, system integration, installation, maintenance and possibly recycling. Similarly, we also think that in-house training provided by PGM mining companies to TVET graduates can be emulated, and mapped for job transitioning of TVET occupations in coal mining, together with fourth industrial revolution requirements. Besides in-company training within bigger companies, the wider green hydrogen economy could be served by TVET specialisation courses in hydrogen safety and technology specific topics, so that TVET graduates are prepared to work with the gasses, fluids and equipment in the hydrogen economy.[116]

6. Recommendations for the TVET system

The development of a domestic green hydrogen economy requires a pipeline of adequately trained graduates and as summarised in Table 4 before, key industrial sectors are required to inform the skills development roadmap. While the entire South African economy can be expected to require a significant increase in TVET trained staff between now and 2030, the sectors involved in a transition to a green hydrogen economy are only expected to grow after 2030. To maximise the jobs potential in the TVET sector associated with the green hydrogen economy, one should first consider whether its development could be pulled forward, especially for a transition of skills between petrochemicals and green hydrogen and ammonia production (amongst others). Furthermore, key industrial sectors to target for green hydrogen TVET education, based on our analysis are:[117]

[113] Bambili Advisory "TVET Skills Gap" (2021).
[114] ibid.
[115] ibid.
[116] Bambili Advisory "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).
[117] The numbers presented here are provisional, in the sense that they are estimates depending on several assumptions outlined above. Also, as mentioned, they are not yet set in a holistic economy-wide analysis which accounts for economic feedbacks through the exchange rate and changing prices and wages. This update of these job estimates as well as numbers for induced employment will follow under UCT's 2nd workstream for the SAIIA UKPACT project.

1) Chemicals manufacturing for production of green hydrogen for use as a fuel domestically in fuel cell vehicles or in other industries, and e.g. exported as ammonia.

2) Manufacturing of electrical machinery and automotive components, to allow specialization towards manufacturing and application of fuel cells and electrolyser components;

3) Furthermore, the coal mining sector likely has the right skill sets to match those of PGM mining but differences in timing between a coal phase out and an expected boom in PGM mining require orientation to other sectors as well, notably Power Generation and (green) Iron & Steel require more TVET-skilled employees before 2030.

The Bambili Advisory report also highlighted the need to develop a green skills Master plan for South Africa.[118] The findings in this report support that need, due to the several thousands of TVET specialised jobs that can be expected for the South African fuel cell and electrolyser industries.[119] Given the fact that besides Sasol, emerging companies in a green hydrogen economy will not be able to provide much in-company education, a nascent hydrogen and fuel cell industry is likely served by the public TVET college system.[120] Its role could be to develop specific technical courses for example in fuel cell component manufacturing and general occupational safety and health training to make TVET learners suited to work with a volatile gas like hydrogen.[121] Currently the TVET system is however characterised by poor industry engagement resulting in graduates with mismatched skills to industry needs. More structural problems of the TVET system will need to be dealt with in time as well. Mathematics and digital skills, starting with digital literacy, are probably most urgent and advantageous to address.[122] However, experiences of DHET in cooperation with GIZ have shown that TVET colleges can supply these skills.[123]

[118] Bambili Advisory "TVET Skills Gap" (2021).
[119] HS Markit, "Super H2igh Road Scenario", (2021).
[120] Bambili Advisory "TVET Skills Gap" (2021); Schers, et al. "Hydrogen economy skills" (2021).
[121] ibid.
[122] ibid.
[123] See for instance GIZ/DHET projects at GIZ's website: https://www.giz.de/en/worldwide/29860.html; and https://www.giz.de/en/worldwide/17848.html; and https://www.giz.de/en/worldwide/35089.html.

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