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AN ANALYTICAL FRAMEWORK TO ASSESS GREEN TRANSITION JOBS IN SOUTH AFRICA

Authors

Katherine Davidson • Ariane De Lannoy • Joanne Grotte
Arindam Jana • Anda David • Murray Leibbrandt

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An analytical framework to assess green transition jobs in South Africa

Katherine Davidson
SALDRU – University of Cape Town

Ariane De Lannoy
SALDRU – University of Cape Town

Joanne Grotte
SALDRU – University of Cape Town

Arindam Jana
ACEIR, SALDRU – University of Cape Town

Anda David
AFD

Murray Leibbrandt
ACEIR, SALDRU – University of Cape Town

Abstract
The threat of climate change and the resultant catastrophic weather events across the globe underpin the need for a shift away from carbon-intensive modes of production. In South Africa, where the generation of electricity is heavily reliant on coal, this imperative is recognised, and various policies are aimed at supporting the implementation of a Just Energy Transition. This transition to a greener economy can have various impacts on the labour force, with a significant concern being an increase in unemployment. In this paper we propose an analytical framework for profiling workers who are likely to be impacted by the energy transition, based on what work they do and in which industry they work. By combining a bottom-up approach to identify occupations related to the green transition, with a top-down approach to identifying 'brown' industries, we arrive at a matrix that allows us to look at where on the nexus between green transition occupations, and brown industries, workers find themselves. Using South African labour force data, we plot these two dimensions characterising a worker's employment, and provide a nuanced picture of what type of worker may be at risk of, or alternatively better placed to withstand, the potential effects of the green transition. This can ultimately assist in developing efficient and effective policies and interventions to mitigate the potential risks of the green transition. A key feature of the framework is its flexibility with respect to the definition of 'green' jobs and 'brown' industries; the bottom-up and top-down methodologies; as well as the data utilised, extending the usefulness to a global level.

Classification JEL
D02, E24, J2, J24, J44, L94, Q48

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1. Introduction

The imperative to transition towards a greener economy that is less reliant on fossil fuels is globally recognised (European Environment Agency, 2024; US Environmental Protection Agency, 2024). South Africa's heavy reliance on coal makes it one of the largest greenhouse gas emitting countries in the world, highlighting both the importance of, and the difficulties related to achieving a green economic transition in the country (Burton *et al.*, 2018). While South Africa has a number of ambitious policies in place that aim to support the transition, implementation has been slow (Amis *et al.*, 2018). Plans and policies include the *Just Economic Transition Investment Plan (JET IP) 2023-2027* and the *Just Economic Transition Implementation Plan 2023-2027*. The *JET Investment Plan* lays out the investment needed between 2023 and 2027 to meet South Africa's commitment to achieving the National Determined Contribution target range of 350-420 Mt CO_2 by 2030. The *JET Implementation Plan 2023-2027* sets out the actions required within that period to meet this commitment, to be implemented in a manner that will deliver just outcomes for the people affected by the energy transition.

A transition to a greener economy entails significant impacts on employment. In a country such as South Africa which experiences high rates of poverty, inequality and unemployment, the issue of job losses requires careful consideration. While mitigating the impact of a potential increase in unemployment resulting from the green transition is a core principle of the Just Energy Transition mandate (The Presidency, Republic of South Africa; 2023a & 2023b), the effective design and implementation of policies and strategies requires detailed information and statistics on the labour market, particularly on those jobs which are likely to be affected by a green transition: to achieve a just transition, it is important to understand which workers will be affected by the transition, as well as how they will be affected. Aiming to address this need, we seek to provide a holistic, nuanced framework for analysing and contextualising the potential employment effects of the green transition, by profiling workers who are likely to be affected by the transition based on both their occupation (what they do), and the industry in which they work (where they work).

The analytical framework we propose brings together the top-down and bottom-up approaches commonly used to estimate employment in green jobs (OECD, 2023). There are many different definitions and approaches to studying green occupations, and to date studies exploring the notion have not produced any consistent definition of "green jobs". The bottom-up approach we use bases the calculation of green jobs on the occupations in which workers are employed. Numerous methodologies have adopted this bottom-up approach, with the choice of what defines a 'green' occupation differentiating the methodologies. This paper focuses on the definitions provided by the Occupational Information Network (O*NET)'s Green Economy Program, of the United States Department of Labour (Dierdorff *et al.*, 2009). O*NET details three lists of green occupations, based on the potential effects the green transition will have on occupations: 1) Green Increased Demand, 2) Green New and Emerging, and 3) Green Enhanced Skill. We refer to these as 'green transition' occupations, as they are occupations that are associated with, and will potentially be impacted by, the green transition; however, we are not implying whether this impact is positive or negative. The analysis of this relies on the definitions, each of which is distinct and has nuanced policy and intervention implications.

In contrast, the top-down approach attempts to quantify jobs as either brown or green, based on the industry, and as with the bottom-up approach, numerous methodologies have emerged. Green jobs are typically based on the output or production processes of the industry (Becker and Shadbegian, 2009; Elliott and Lindley, 2017; Thomas, 2022; International Renewable Energy Agency and International Labour Organisation, 2023; OECD, 2023; Eurostat, 2024). Other methodologies have also focused on capturing the degree to which industries are contributing to climate change. This paper utilises the latter methodology, relying on CO_2 emissions data to profile workers based on the 'brownness' of the industry in which they work. We outline two measures as part of this approach: 1) pollution intensity, and 2) emissions intensity. Pollution intensity reflects the extent to which the worker is contributing to total carbon emissions in the country more broadly, as determined by the industry they work in. Emissions intensity reflects the carbon emissions efficiency, or lack thereof, of workers in the respective industries. It can be understood as the carbon footprint of the workers employed in the industry.

We then combine the bottom-up and top-down approaches in a broader framework which uses both elements to analyse the potential effects of the transition to a greener economy on a worker in South Africa. We profile workers at the individual level, considering the greenness of *what* a worker does (their job, as identified by the bottom-up approach), as well as *where* a worker works (the industry they work in, as identified by the top-down approach). Considering the industrial sector and occupation in conjunction can provide us with a clearer idea of what the overall impact might be on the worker. While it does not necessarily provide a count of the jobs that will be lost, for example as a result of a shift away from coal extraction, it can facilitate evidence-based policy and intervention planning in the context of the Just Energy Transition.

One of the key features of the framework is its flexibility in the definition of 'green jobs', the top-down and bottom-up methodologies employed, as well as the data used. This broadens the applicability of the framework beyond the South African context.

The rest of the paper is laid out as follows: Section 2 details the bottom-up approach to estimating green transition employment. Section 3 outlines the top-down approach to estimating the pollution intensity of industrial sectors, and the emissions intensity of workers. Section 4 combines these approaches into an analytical framework for assessing green transition jobs. Section 5 concludes by looking ahead to future work.

2. The Bottom-up Approach: Estimating Green Occupations

There are two leading methods used to estimate 'green' occupations using the bottom-up approach. The first is the 'occupational greening' approach, where the calculation is based on whether an occupation is determined to be 'green' or not. The second approach relies on the extent to which a worker performs green tasks, known as 'green task intensity', and captures the effect that occupations have on the environment.[4] A key focus for South Africa, and this paper, is the employment effects of the green transition, rather than the impact of an occupation on the environment. We thus utilise the 'occupational greening' approach to identifying green employment.

2.1 Identifying green occupations

The most widely used classification system in bottom-up approach research regarding green occupations is the Occupational Information Network (O*NET)'s Green Economy Program, of the United States Department of Labour, which identifies green occupations within the O*NET system. The research conducted by Dierdorff et al. (2009) forms the basis of this green occupation identification. The authors define three occupational categories which highlight the varied effects that the greening of the economy can have:

1. Green Increased Demand Occupations (GID)

These are existing occupations which are expected to see an increase in employment demand due to the green transition, without the need for significant changes to their task content or worker requirements. These occupations are defined as expected to see increased demand as they support the broader green economy. One example of this would be bus drivers. The green transition will lead to a greater reliance on

[4] For studies using the task intensity approach see for example: Bluedorn et al. (2022a); Elliot et al. (2021); Granata and Posadas (2024); Vona et al. (2019); Mosomi and Cunningham (2024); OECD (2023)

public transport as people reduce their use of private vehicles. Thus, there may be an increased demand for bus drivers as the move to public transport supports the green economy, but bus drivers themselves are not directly involved in reducing the carbon emissions of the economy.

2. Green Enhanced Skills Occupations (GES)

These are existing occupations that are expected to see a significant change to their task content and worker requirements but may not necessarily see an increase in employment demand due to the green transition. One example of this would be architects. While moving to a greener economy, the construction of buildings must switch to more environmentally friendly models. Architecture as an occupation is expected to continue to exist, but architects will likely need new skills or knowledge to implement these greener models.

3. New and Emerging Green Occupations (GNE)

These are new occupations created due to the unique needs of the green transition. One example would be Chief Sustainability Officers who "communicate and coordinate with management, shareholders, customers, and employees to address sustainability issues." This occupation would likely not exist if not for the need to transition to a greener economy.

Dierdorff et al (2011) term this the 'occupational greening approach' in a review of the literature after having published the work on the three green occupation categories. They argue it is unique, as other approaches focus on the consequences of an occupation on the greenness of the economy. This approach to defining green occupations has been used primarily in research focusing on the employment effects of the green transition. Utilising these three green occupation categories, Bowen, Kuralbayeva and Tipoe (2018) and Bowen and Handcke (2019) look at the impact of greening on jobs in the United States and the European Union respectively. For the United States, the authors find that 19.4% of employment is in occupations that are expected to be impacted by the green transition. Similar figures were found for the European Union at 35.5% of total employment in 2006 in green occupations, and 40% in 2016. For the United Kingdom, Valero et al. (2021) found 17% of employment to be in green occupations in 2019. The definition of a green occupation utilised in these studies focuses on the impact of the green transition on occupations.

There have been few studies of green jobs in the South African context, and to our knowledge none that use the 'occupational greening' method. Mosomi and Cunningham (2024) apply a task-based methodology developed by Granata and Posadas (2024) to South African data, with some adjustment made to the dictionary of green terms to make it applicable to the local context. They define a 'green occupation' as one with positive green task intensity, producing two definitions of green occupations: strict and broad. Strict green occupations are those with at least one task which is directly linked to the environment based on it containing a green term. Broad green occupations are those with tasks that could reduce environmental harm if they utilise green technology or processes, based on containing a green potential term. These definitions of green occupations do not make a distinction between tasks which are positive or those which are negative for the environment. Green task intensity for the 4-digit level International Standard Classification of Occupations (ISCO) 1988 occupations is calculated using this updated dictionary of green terms. They go on to use a series of crosswalks between the different occupational classification systems and the Post Apartheid Labour Market Survey (PALMS) dataset to estimate green task intensity in the South African labour market. They find that 5.5% (strict) and 32% (broad) of jobs in South Africa are green. A limitation of this methodology is that all occupations in a 4-digit occupation code are given the same green task intensity. This may not accurately reflect the diversity of green tasks performed by the individual occupations within the 4-digit occupation code. For example, *mining and metallurgical technicians* is a 4-digit occupation identified as having positive strict green task intensity by Mosomi and Cunningham (2024). However, mining technicians, specifically in coal mining, are more likely to perform tasks that are directly negative for the environment than metallurgical technicians. One measure of green intensity for both occupations cannot capture this diversity in the tasks performed by each more granular occupation.

In a report prepared by the Industrial Development Corporation (IDC), the Development Bank of South Africa (DBSA) and Trade and Industry Policy Strategies (TIPS), Maia et al. (2011) estimate that 462 567 net formal jobs could be created because of the greening of the economy. Rutovitz (2010) explores the job creation potential of the energy sector under three scenarios: the Energy Revolution case, which envisions a low-carbon future for energy; the IEA Reference case, which was derived from the International Energy Agency (IEA)'s energy projection for Africa; and the Growth without Constraint case, which reflects a future without climate change and no constraints on oil. Rutovitz found that the Energy Revolution case could produce 78 000 net jobs by 2030. As with Maia et al. (2011), no explicit definition of 'green jobs' is put forward by Rutovitz (2010), however, green jobs are identified as those created by the greening of the energy sector. This implies the direction of interest to be the creation of new jobs because of the greening of the energy sector.

2.2 Bottom-up methodology

In this paper, we identify green occupations as per O*NET's lists of green occupations. Several steps are required in the application of the O*NET green occupation codes to South African data, as the occupation classification systems are not the same, and the data needs to be converted from the 6-digit to the 4-digit level.

In brief, this involved the following steps:

1) We matched the O*NET green occupations, as per the three lists described above, to the 6-digit South African Organising Framework of Occupations (OFO) classification system, via a crosswalk we developed.
2) We aggregated the 6-digit OFO occupation classifications to the 4-digit level, resulting in an 'occupational greenness' measure, which is the proportion of 6-digit green occupations at the 4-digit level.
3) We crosswalked the 4-digit OFO classifications to the 4-digit South African Standard Classification of Occupations (SASCO) codes so they can be identified in the survey data.
4) We calculated the number of workers in green transition occupations by applying the 'occupational greenness' measure to household survey employment data.

Occupations Classification Systems are systems of codes allocated to different occupations. Occupations are defined by the International Labour Organisation as "a set of jobs whose main tasks and duties are characterized by a high degree of similarity." This is in comparison to a job which they define as "a set of tasks and duties performed, or meant to be performed, by one person, including for an employer or in self-employment." (*International Standard Classification of Occupations (ISCO)*, 2024). Historically, two different systems for categorisation of occupations were introduced in South Africa, as detailed in Table 1.[5] The Organising Framework for Occupations (OFO) is developed and maintained by the Department of Higher Education and Training, while the South African Standard Classification of Occupations (SASCO) is created and maintained by Statistics South Africa.

[5] The Department of Public Service and Administration released *The Public Service Occupational Classification System: Occupational Dictionary* in 2024 (Department of Public Service and Administration, 2024). The dictionary seeks to improve how occupations in the public sector are categorised and defined. The Centre for Researching Education and Labour (2022) gives a comprehensive overview of the two systems and their rationale. Future refinements to our methodology will include any relevant revisions from this recent classification system update.

Table 1 Occupational classification systems in South Africa

Occupation classification system	Description
Organising Framework of Occupations (OFO)	A South African occupation classification system created by the Department of Higher Education and Training (DHET), the latest version being 2021. This classification system is based on the International Labour Organisation's occupation classification system, the International Standard Classification of Occupations (ISCO). The OFO is based on the 2008 version of the ISCO, which is the latest version. South African labour market data does not use this system to identify occupations (Department of Higher Education and Training (DHET), 2012).
South African Standard Classification of Occupations (SASCO)	A South African occupation classification system created by Statistics South Africa and used in household survey data. The 2003 version of this system is used to identify occupations in labour market data, for example the Quarterly Labour Force Survey and the Census. The SASCO 2003 version is based on the 1988 version of the ISCO (Statistics South Africa, 2012a).

The OFO system, based on the International Standard Classification of Occupations (ISCO), goes down to the 6-digit classification level, which is comparable to the 8-digit level of the O*NET green occupations, albeit somewhat less granular. This allows for a near one-to-one match between these classification systems. The OFO, however, is not used in South African labour market data to identify occupations, which instead rely on the SASCO classification system. Thus, any quantitative research using the bottom-up approach needs to be able to identify green occupations in terms of the SASCO system. To the best of our knowledge this conversion did not exist, thus we developed the method outlined in Table 2 below.

Table 2 Steps in estimating green transition employment in South Africa

	Steps	Worked Example
1	Crosswalk or match the 8-digit O*NET green occupations classifications to the 6-digit OFO system. Matching was done manually, with some straight matches and other less straightforward matches. The descriptions of the occupations, their location within their respective classification systems, and the alternative occupation titles provided by both classification systems, were used to match the O*NET codes with the OFO codes. More information can be found in Appendix A.	*Bus Drivers, Transit and Intercity,* code 53-3021.00 is identified as a Green Increased Demand Occupation by O*NET. This can be matched to *Bus Driver,* code 733101, in the OFO.
2	Calculate an 'occupational greenness' measure, which is the proportion of the 6-digit OFO green occupations in the 4-digit OFO occupations.	*733101 Bus Driver* is part of the *7331 Bus and Tram Drivers* minor group OFO occupation code. This minor group occupation code has three 6-digit occupation codes in total, including *7331 Bus and Tram Drivers.* Therefore, the proportion of green occupations assigned to *7331 Bus and Tram Drivers* is 0.333 (1/3). It is assumed that employment is uniformly distributed among the 6-digit occupations.
3	Match 4-digit OFO occupation codes to 4-digit SASCO codes using the crosswalk developed by DHET.	The DHET crosswalk matches *7331 Bus and Tram Drivers* OFO occupation code to *8323 Bus and Tram Drivers* 4-digit SASCO occupation code. We can conclude that the proportion of green occupations in SASCO 4-digit occupation code *8323 Bus and Tram Drivers* is 0.333. *This is the **greenness measure** of that occupation, which is expressed as a proportion.*
4	Multiply the greenness measure of the 4-digit SASCO code by the number of workers in that occupation to	If there are 23 000 workers employed in the *8323 Bus and Tram Drivers* SASCO occupation code, we estimate

	estimate the number of workers in green transition occupations within that occupation code.	that there 6 900 (23 000 x 0.333) green transition workers within that occupation code.

This general methodology for identifying and quantifying employment in green transition occupations in the South African context is flexible and can be applied to several different bottom-up definitions, including those based on Granata and Posadas (2024)'s green terms dictionary, or the O*NET green tasks. The choice of how 'green jobs' are defined is guided by the research question, data availability, and context.

2.3 Caveats

This methodology does have some important caveats to take note of:

- *Outdated occupation classification systems*:
  Occupations in South African labour market data are identified using SASCO 2003, which was developed in 2003 based on the ISCO 1988. This means that newer occupations that have emerged more recently cannot be captured in labour market data. Moreover, occupations are identified at a 4-digit level which means that each individual code represents many occupations. It is thus necessary to assume that employment is equally distributed across all the 6-digit occupations aggregated under the 4-digit codes, as further disaggregated employment data is not available. While this assumption is made by many other authors in occupation related research,[6] it does reduce the accuracy of the final employment estimates.

- *Use of the O*NET green occupations and green tasks lists:*
  These were developed in 2010 and for the United States labour market. This means that newer occupations, as well as those only relevant in the South African context, will not be captured. There is also a risk that the O*NET lists identify occupations that do not exist within the South African context. However, matching the O*NET green occupations to the OFO occupation codes should help to lessen the likelihood of an occupation not existing in the South African context.

- *An occupation's greenness will be consistent across industries and geographies:*
  This will be true irrespective of the green occupation definition used. For example, a *logistics manager* in mining in Mpumalanga will have the same 'greenness measure' as a *logistics manager* in agriculture in the Western Cape as their occupation codes are the same despite being employed in different industries. There may be differences in skill level or even specific job tasks in different geographies, or within different industries, which cannot be accounted for. This limitation of the bottom-up methodology highlights the usefulness of combining the approach with the top-down approach to identifying brown industries, as is detailed in Section 4.

These limitations mean that the greenness measure is a fairly static one- it changes only when either the original green occupation or green task lists change, or when the occupational classification systems changes (i.e. either SASCO or OFO). In terms of the definitions of green occupations used in this paper, the O*NET green occupation lists have not changed since 2010 and there does not seem to be any indication that future changes are planned. The occupation classification systems are where change is more likely to take place at least in terms of the OFO system. This is typically updated annually, however the latest version is from 2021. On the other hand, SASCO 2003 has been used to define occupations in labour market data for quite some time, and there is no indication that this will change in the future.

[6] See for example (Consoli *et al.*, 2016; OECD, 2017; Vona *et al.*, 2018; Rutzer, Niggli and Weder, 2020; Elliott *et al.*, 2021; Bluedorn *et al.*, 2022b)

2.4 Estimates of Green Transition Employment in South Africa

In this next section we provide estimates of "green transition" employment. By this we mean employment that is associated with, and may be affected by, the green transition. The three O*NET green employment definitions provide the additional clarification on the nature of the impact. In estimating green transition employment, we use data from the 2018 and 2019 Labour Market Dynamics dataset. This is pooled data from all four Quarterly Labour Force Surveys, produced annually by Statistics South Africa. Each year, Statistics South Africa (Statistics South Africa, 2018, 2019).[7]

Table 3 shows the number of workers in occupations affected by the green transition as identified using the three O*NET definitions, and employment in each category, as a percentage of total employment. Green Increased Demand (GID) represents the highest proportion of total employment at 4.6%. This indicates that 4.6% of workers are employed in occupations that are expected to see an increase in demand due to the green transition. Workers in these occupations are employed in occupations that can support green activities. Green New and Emerging (GNE) represent the smallest proportion of workers, with only 1% of workers employed in occupations created entirely due to the needs of the green economy. This low proportion is supported by the findings of Amis et al. (2018) that South Africa has not made significant progress toward a greener economy. Green Enhanced Skill (GES) occupations are those that are expected to see a change in their task content and worker requirements because of the green transition, with 3.5% of workers employed in these occupations. In total, approximately 8.7% of all workers are employed in green transition occupations.

Valero et al. (2021) found a similar share of GID employment in the United Kingdom. However, they found much higher shares of GNE (5%) and GES (7%) employment. The GNE share found here is similar to that found for the United States by Bowen et al. (2018) however, the United States has much higher shares of the other two categories. Bowen and Hancke (2019) found estimates for the European Union that are much higher than those found here or in either study mentioned above. They found 22.5%, 20% and 17.4% shares for GID, GES and GNE, respectively. These higher shares are likely the result of a more generous approach to mapping O*NET green occupation codes onto the ISCO-08 codes (Bowen, Kuralbayeva and Tipoe, 2018; Bowen and Handcke, 2019; Valero *et al.*, 2021).

Although they use a different bottom-up methodology, Mosomi and Cunningham (2024) find that 5.5% of South Africa's workers are employed in occupations linked to the environment (strict green). This is comparable to the figure found here for GID. GID occupations involve work that is relevant to the green economy and thus, can be understood to be positively linked to the environment.

Table 3 Green Transition Employment Table

	Green Transition Employment	Proportion of Total Employment
Green Increased Demand (GID)	765 436	4.6%
Green New and Emerging (GNE)	160 241	1.0%
Green Enhanced Skill (GES)	580 471	3.5%
Total green transition employment (adjusted)[8]	1 449 370	8.7%
Total Employment	16 590 171	100%

Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019)

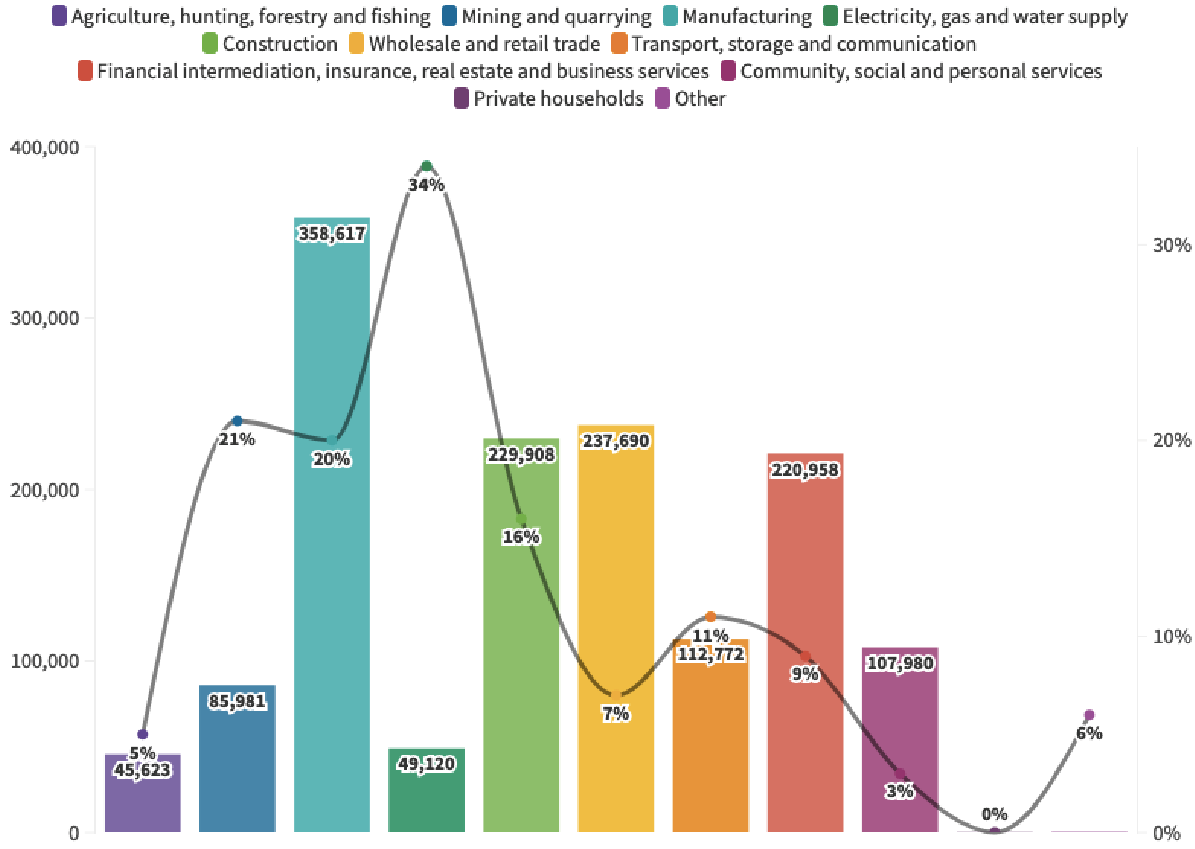
Figure 1 shows employment in green transition occupations for each major industrial sector. The bars represent the number of workers in these occupations, and the line represents the percentage of those employed in the industrial sector who are in those occupations. Manufacturing employs the most workers

[7] Weights are divided by two and applied to estimates to produce weighted estimates.

[8] The employment in the three categories of green transition employment cannot simply be added together to calculate *total* green transition employment, as some of the 4-digit occupations appear in more than one of the lists. Adding the three categories together would result in double counting, and some adjustment is required to prevent this.

in green transition occupations (360 000 workers), which is consistent with the findings of Valero et al. (2021) and Bowen and Hancke (2019). This is followed by the Construction; Wholesale and Retail Trade; and Financial intermediation, insurance, real estate and business services industries. Each industrial sector employs nearly 250 000 workers in green transition occupations. The electricity, gas and water supply industrial sector has the highest concentration of workers employed in green transition occupations, which is again in line with the findings of Valero et al. (2021). South Africa generates 85% of all its electricity through the burning of coal (Hughes *et al.*, 2021). Thus, the electricity, gas and water supply industrial sector is the most heavily polluting sector. It contributes 57% to total CO_2 emissions and has the highest estimated CO_2 per worker. The green transition is expected to necessitate the largest job losses in this industrial sector, given its outsized contribution to carbon emissions. However, Figure 1 shows that 34% of workers in this industrial sector work in green occupations and thus may be less at risk, or better able to transition to alternative jobs.

Figure 1 Green Transition Employment by Industry



Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019)

Table 4 and Table 5 disaggregate workers in green transition employment by race and by gender respectively. Green Increased Demand employment has a similar racial make-up to the broader labour market. However, the Green New and Emerging and Green Enhanced Skill categories have higher percentages of white people working in those categories. Valero et al. (2021) found that Green New and Emerging and Green Enhanced Skill occupations tend to be better remunerated. Taken together, this suggests that, unless carefully managed, the green transition may entrench existing racial inequalities in the labour market.

Table 4 Green transition employment by race

	Green Increased Demand	Green New and Emerging	Green Enhanced Skill	Total Green after adjustment	Total Employed Population
African/Black	72%	54%	68%	69%	75%
Coloured	11%	9%	9%	10%	10%
Indian/Asian	3%	6%	4%	4%	3%
White	13%	31%	20%	17%	12%

Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019)

More men than women work in green transition occupations. The Green Increased Demand category has the highest proportion of men at 88%, which is consistent with the findings of Valero et al. (2021). Workers in these occupations are more likely to be somewhat protected from the consequences of the transition in that they would be expected to either keep their jobs or be able to find new jobs. This indicates that the green transition might also exacerbate existing gender inequalities.

Table 5 Green transition employment by sex

	Green Increased Demand	Green New and Emerging	Green Enhanced Skill	Total Green after adjustment	Total Employed Population
Male	88%	77%	81%	84%	56%
Female	12%	23%	19%	16%	44%

Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019)

Following this approach, we can begin to build a profile of workers that will likely be affected by the green transition, and in what way, based on their occupation. In the next section we build on this by considering the brownness of the industry in which a worker is employed.

3 The Top-down Approach: Estimating the Pollution Intensity of Industrial Sectors

The top-down approach provides an environmental profile of employment based on industry. Typically, this has involved identifying an industry as green based on output or production processes. Green employment is then estimated by characterising all workers employed in those industries as being involved in green employment, regardless of their occupation. Identifying industries involved in the production of renewable energy as green is a common method (Thomas, 2022; International Renewable Energy Agency and International Labour Organisation, 2023). Another commonly used definition is producers of environmental goods and services (Becker and Shadbegian, 2009; Elliott and Lindley, 2017; Eurostat, 2024). One limitation here is that producers may also manufacture goods that are not green, and there is often not sufficient data to distinguish the non-green goods. This can also make the methodology difficult to compare across countries that classify secondary goods differently, or which may not be able to separate them (OECD, 2023). These methodologies are difficult to apply to the South African context due to the lack of relevant data for South Africa.

However, another strand of the literature involves using the top-down approach to identify 'brown' jobs, or jobs that harm the environment. Most often these methodologies do not provide a binary definition for brown industries, but rather place the industry on a spectrum from green to brown. There are various ways this can be done: emissions intensity measures the carbon emissions per worker for each industry, while pollution intensity considers the proportion of total carbon emissions contributed by each industry. Both identify 'brown' industries as those with higher intensity (Bluedorn *et al.*, 2022b; Vandeplas *et al.*, 2022). This section of the paper focuses on estimating these measures for South Africa.

3.1 Environmental Costs and Carbon Emissions

The costs associated with climate change have been part of economic literature for a few decades, most notably pioneered by Nordhaus, who introduced the concept of integrated assessment models (IAMs) (Nordhaus, 1977, 1991, 2019). These models typically assess the costs of climate change by evaluating the damage functions related to temperature increases and their effects on economic output. Initial estimates suggested that moderate warming might have some economic benefits, particularly in colder regions, but that overall, the long-term impacts would be negative (Nordhaus, 2019). Nordhaus' work, however, has proven controversial. Debates on his assumptions (e.g., climate change will be a gradual and linear process, lack of impact on certain sectors, not accounting for potential disruptive events); ethical concerns, particularly on discounting potential disproportionate impacts on vulnerable populations; and even his conclusions on "economically optimal" levels of warming, have fuelled a generation of research (Hayden, 2021; Masini, 2021).

A pivotal moment in the literature was the publication of the Stern Review, which argued that the costs of inaction on climate change would be significantly higher than the costs of mitigation. It estimated that without action, climate change could reduce global GDP by up to 20 per cent by the end of the century, while the cost of reducing greenhouse gas emissions to avoid the worst impacts would be around 1 per cent of global GDP per year (Stern, Common and Barbier, 1994; Stern and Great Britain, 2007).

In part buoyed by the Stern Review, and as part of ongoing efforts of the Intergovernmental Panel on Climate Change (IPCC), there has been increasing emphasis on understanding how to enforce transitions in economic processes and as a result accelerate mitigatory impacts on the expected costs of climate change on global GDP (IPCC, 1992, 1995, 2003, 2007, 2014, 2023). This effort has led to an increasing interest in methods to estimate carbon emissions at the sectoral level of an economy, with the underlying assumption that targeted interventions at the sectoral level can have scalar effects on mitigatory impacts at the country (GDP) level, which in turn will bear positive effects at the global scale. Prevalent methods to estimate carbon emissions at the sectoral level have a relatively nascent methodological history, most veering towards an energy use accounting framework—that is, estimating sectoral energy use, and calculating emissions as a share from the energy-mix of energy production at the aggregate level (IEA, 2021). South Africa has also been producing a report on their carbon emissions using a similar approach (Department of Environmental Affairs, 2014).

However, using an energy use accounting framework (EAF) paints an incomplete picture of sectoral level carbon emissions. The IPCC has been attempting to expand the scope of how carbon emissions can be estimated at the regional level, and how these should be interpreted. The most notable departure from EAF-type methods is to acknowledge that energy use is only one component of carbon emissions that can emanate from production and consumption processes in a sector. For example, agriculture can have a miniscule energy use footprint at the national scale, but depending on the type of agriculture, there can be massive net impacts on carbon emissions (consider dairy and livestock agriculture—bovine stock, in particular, has been shown to generate a significant proportion of greenhouse gas emissions at the country scale). To account for such nuances, recent research on the methodologies to assess carbon emissions, and their (true) social costs within the consumption and production processes of an economy, has resulted in a series of methodological innovations that combine modern data generation and processing tools with older techniques like Input-Output (IO) Analysis and computable general equilibrium models (Miller and Blair, 2022).

3.2 Sectoral Carbon Emissions from Global Input-Output Tables

In our approach to estimating carbon emissions at the sector level of an economy, we use a variant of established Input-Output Analysis models: the Multi-Region Input-Output (MRIO) Materials Flows analysis. In brief, Input-Output (IO) tables are a quantitative economic technique that represents the inter-dependencies between different sectors of a national economy or different regional economies. They are used to analyse the flow of goods and services within an economy, showing how the output of one industry is an input to another industry, and using the Leontief Production Function approach, they allow for the estimation of aggregate demand and aggregate supply of a region (Leontief, 1970; Miller and Blair, 2022).

Recent innovations in data collection have allowed for the incorporation of environmental factors as inputs for production and consumption processes within the IO tables, thereby as a corollary to the estimates of aggregate demand and aggregate supply, one is also able to estimate the emissions generated by each sector considered in the IO tables being used (UNEP IRP, Australian National Science Agency, and Commonwealth Scientific and Industrial Research Organisation, 2024).

A limitation of this analysis has been that not all countries of the world are accounted for in MRIO tables. The focus has usually been OECD countries, and only over the last few years have non-OECD countries (starting with G20 economies such as China, India and Brazil) begun being included in the tables. Usually, non-OECD countries are clubbed together as regions, and South Africa has till recently featured in the sub-Saharan Africa region in most global tables. Only over the last five years have individual African countries begun featuring in global MRIO tables. The MRIO tables we use in our analysis – EXIOBASE 3 Tables – have included South Africa in their data collection processes since their last estimation round (i.e., 2018).(Merciai and Schmidt, 2018; Stadler *et al.*, 2018)

3.3 South African Data and Extracts of Sectoral Carbon Emissions

For the extraction of sectoral carbon emissions for the South African economy, we conduct the following calculations. At every time period, MRIO tables (in our case, EXIOBASE 3 tables) describe the global inter-industrial sector material flows within and across countries for *k* countries with a transaction matrix *Z*:

$$Z = \begin{pmatrix} Z_{1,1} & Z_{1,2} & \cdots & Z_{1,k} \\ Z_{2,1} & Z_{2,2} & \cdots & Z_{2,k} \\ \vdots & \vdots & \ddots & \vdots \\ Z_{k,1} & Z_{k,2} & \cdots & Z_{k,k} \end{pmatrix}$$

Each submatrix on the main diagonal $Z_{i,\,i}$ represents the domestic interactions for each industry *n*. The off-diagonal matrices $Z_{i,\,j}$ describe the trade from region *i* to region *j* (with *i, j* = 1, 2...*k*) for each industrial sector. This allows for the definition of a global demand *Y*:

$$Y = \begin{pmatrix} Y_{1,1} & Y_{1,2} & \cdots & Y_{1,k} \\ Y_{2,1} & Y_{2,2} & \cdots & Y_{2,k} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{k,1} & Y_{k,2} & \cdots & Y_{k,k} \end{pmatrix}$$

Final demand satisfied by domestic production is represented by the main diagonal $Y_{i,\,i}$ and direct import to final demand from region *i* to country *j* by $Y_{i,j}$. Again, like the transaction matrix, there are *k* industrial sectors being considered.

The global economy is then represented as *x*, where *x* is the total output for the regions considered, and *e* represents the summation vector:

$$x = Ze + Ye$$

Following the environmental cost model of IO analysis (Leontief, 1970), we extract a matrix *C*, where, $C_{i,k}$ represents the net carbon emissions from the global output function *x*, *i* represents the region, and *k* represents the industrial sectors. From this matrix C, we extract the column vector where *i* represents South Africa.

A further complication that arises at this juncture relates to the classification systems in use. EXIOBASE 3 (and other MRIO tables) define industrial sectors using the International System of Industrial Classification, version 4 ('International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 4', 2008). South African data systems, particularly those related to the labour market (e.g., Quarterly Labour Force Survey), use their own native industrial classification system (Central Statistics Service, 1993; Statistics South Africa, 2012b). In our analysis, we use the most aggregate level of the industrial classification system from EXIOBASE 3 (i.e., ISIC v4), as this allows for a one-to-one correspondence mapping to the South African system of industrial classification.

3.4 Estimating Pollution Intensity

In our analysis, we construct a pollution intensity metric for South Africa using the sectoral carbon emissions shown. We define pollution intensity as the share of carbon emissions of each industrial sector in relation to the total emissions across all sectors. This allows us to compare which sector contributes how much to the total carbon emissions across all economic processes in the South African economy.

For the year 2018-19, Figure 2 shows the pollution intensity of industrial sectors (i.e., share of carbon emissions contributed by each industrial sector) based on the Standard Classification of Industry (SIC) alongside total employment in those sectors. The bars represent employment in each industrial sector and the line represents the share of CO_2 contributed by each industrial sector.

The Electricity, gas and water supply industrial sector, has a pollution intensity of 0.57, implying that it contributes the most to total national carbon emissions at just above 57% of total emissions. This observation aligns with studies such as Hughes et al. (2021), which inform us that 85% of electricity in South Africa was produced through coal power plants in 2021. Given that the production and consumption processes of this industrial sector are strongly aligned with coal-based power production, the pollution intensity of 0.57 makes sense. Employment in this sector is by far the lowest across all the industrial sectors at only 143 000 workers[9]. The green transition will undoubtedly have the largest negative effects on the electricity sector in South Africa given its outsized contribution to carbon emissions. However, it is important to note that these workers' occupations are also important for determining how they will be affected by the green transition.

Figure 1 shows that the highest concentration of workers in green transition occupations can be found in the Electricity, gas and water supply industrial sector at 34%. As discussed in Section 2.4, most of the effects indicated by the green occupation categories are positive. This suggests that not all workers in this industrial sector will be equally negatively impacted by the green transition. Policy concerning the just economic transition must support the most vulnerable workers, and identifying these vulnerable workers is a key first step.

As a comparison to the electricity generation sector, most other sectors contribute to carbon emissions indirectly. Consider the agriculture, hunting, forestry and fishing sector at 0.094 (i.e., 9.4% of total CO_2

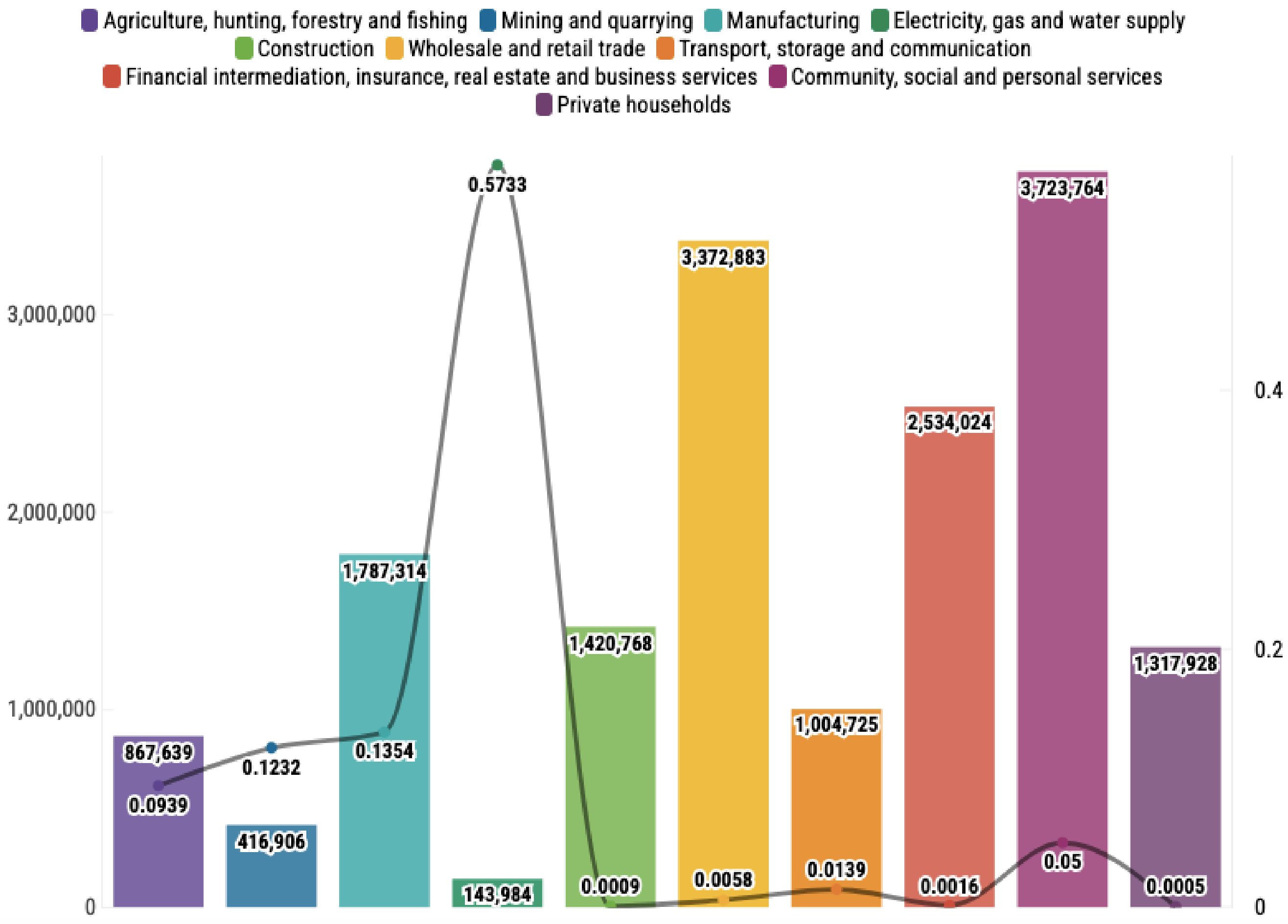
[9] As an order of magnitude, Makgetla et al. (2019) estimate that in the coal value chain (mostly comprised of coal mining, power generation and petrochemical production) the number of workers at risk was of around 120 000.

emissions), and Mining and quarrying sector at 0.12 (12%) – these are other sectors that are part of the transition narrative and highly linked to carbon emissions narratives at the national scale. The emissions footprint of agriculture in South Africa, for example, is most likely driven by methane production given its established tradition of livestock farming, and the fact that one tonne of methane is equivalent to 28-36 tonnes of carbon dioxide equivalent (IEA 2021).

Mining and quarrying in South Africa, on the other hand, is strongly linked to the upstream electricity generation supply chain – producing more than 220 tonnes of coal per year, the sector contributes to the carbon footprint quite significantly even though they might not be producing carbon emissions directly. On the other end of the electricity supply chain, as the largest consumers of coal-powered electricity, the manufacturing sector contributes strongly to the total carbon footprint, ranking itself as the second highest contributor to total carbon emissions (Wakeford, Hasson and Black, 2016).

Some of the largest employers are the sectors with the lowest pollution intensity: the community, social and personal services sector (employing 3.7 million workers), wholesale and retail trade (employing 3.4 million workers), and the financial intermediation, insurance, real estate and business services sector (employing 2.5 million workers), together contribute a total of 6% of total CO_2 emissions while employing more than 30% of the total workforce.

Figure 2 Pollution intensity and employment by industrial sector, 2018-2019



Source: Own calculations using data from EXIOBASE 3 and Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019)

A final note on pollution intensity one should consider is that this is a time-sensitive metric. As it is extracted from global MRIO tables, our time intervals and horizons are only constrained by the data source. In its current iteration, the data source we use, i.e., EXIOBASE 3, can allow for annual estimations of sectoral carbon emissions from 1995 till 2022. Pollution intensity is also a locally contextual measure as it presents a relative picture of how different sectors in a selected economy are performing vis-à-vis carbon emissions. This makes it strongly linked with national economic development strategies. For example, with electricity production witnessing a strong transition away from coal-based power generation in South Africa, it is conceivable that pollution intensity of the electricity, gas, and water supply sector will witness a strong decline in more recent time periods.

3.5 Estimating Emissions Intensity of Workers Across Sectors

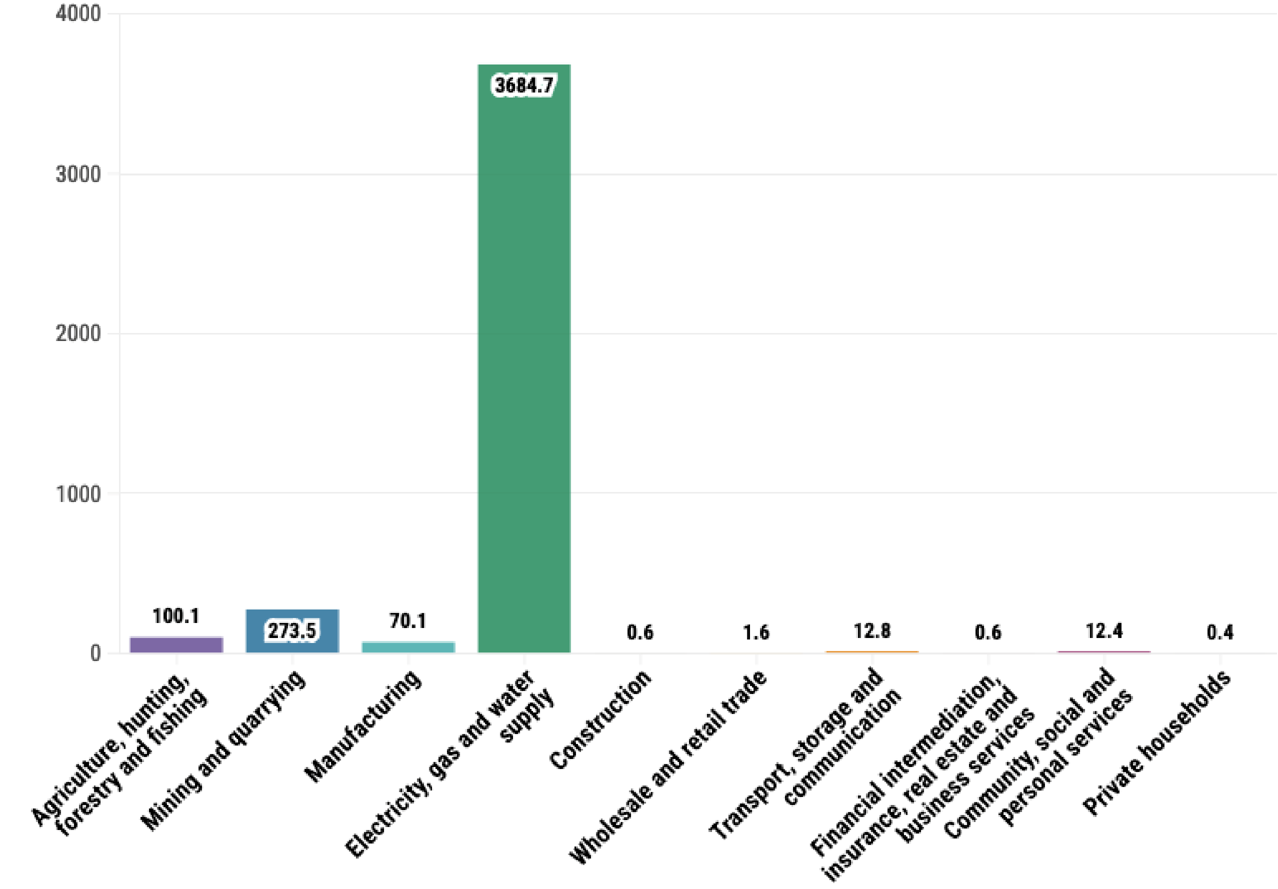
Emissions intensity is a per capita measure of sectoral carbon emissions. Such a measure allows one to conduct more meaningful comparisons between sectors and regions with different labour force sizes, by expressing sectoral carbon emissions on a per-worker basis. Further, growth rates of per capita measures such as emissions intensity can provide a more accurate picture of progress in reduction of carbon emissions within an economy than total carbon emissions, especially in regions and sectors which are in a state of flux in terms of labour market participation. Producing lesser carbon emissions and employing fewer workers might have different implications at the worker (per capita) level than producing more carbon emissions and employing many workers. In particular, this emerges as a critical metric because in transitioning away from fossil fuels and activating various net-zero trajectories, the Nationally Determined Contributions (NDCs) imply a structural change of the economy and an inflexion of the industrial development policy which will lead to favouring some sectors over others. This could have policy implications, similar to the economic growth narratives: if sectoral carbon emissions are growing at a faster rate than the rate of growth of workforce employed in the same sector, net effect on aggregate green transition narrative will be negative.

3.5.1 Estimates of Emissions Intensity in South Africa

For this measure, we begin with the total sectoral carbon emissions in tonnes for a given year (see Figure 2 for 2018-19). We include the total workers in the same sectors for the selected year and calculate emissions intensity for a given year as the carbon emissions for a sector divided by the number of workers for that sector.

Figure 3 shows the emissions intensity (i.e. carbon emissions per worker) in each major industrial sector based on the Standard Classification of Industry (SIC). As discussed above, this reflects how much carbon emissions can be attributed to a worker. As with pollution intensity, the Electricity, gas and water supply industrial sector has the highest emissions intensity. It is far above the national emissions intensity (56 tonnes per worker). The other industries with emissions intensity above the national figure are Agriculture, hunting, forestry and fishing; Mining and quarrying; and Manufacturing.

Figure 3 Emission intensity by industry, 2018-2019



Source: Own calculations using data from Labour Dynamics Survey 2018-2019 and EXIOBASE 3.

Much like pollution intensity, emissions intensity is also a time sensitive metric, as it relies on data sources that are produced at frequent intervals. For sectoral carbon emissions, we rely on EXIOBASE 3, and for our labour market data, the Labour Dynamics Survey 2018-19 – both are produced at an annual frequency. Reading sectoral pollution intensity and emissions intensity together allows us to build a better comparative framework for understanding the economic transitions of a country.

4 Assessing the Potential Labour Market effects of Greening

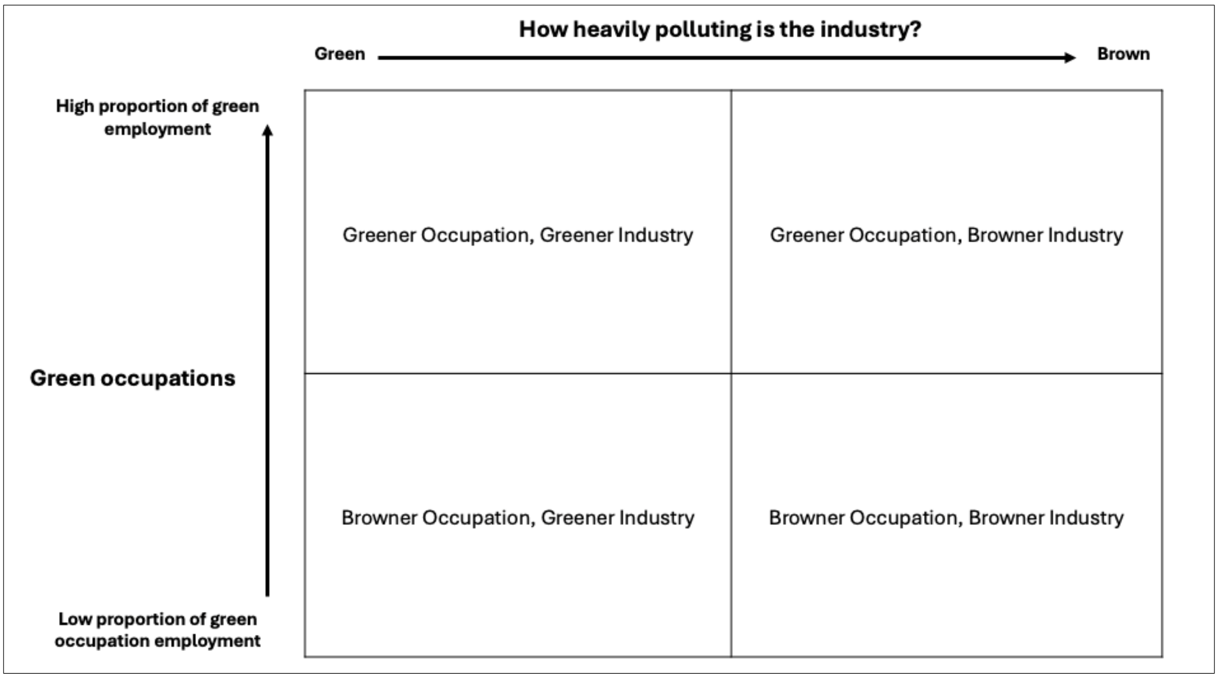
4.1 The Framework

In this section we combine the bottom-up and top-down approaches, and develop a general framework, in the form of a matrix, which seeks to bring together occupation and industry level information to answer labour market questions about the green transition. Here we build on the work of Bluedorn et al. (2022), Vona et al. (2018) and Valero et al. (2021) to explore whether those working in 'green occupations' are working in 'green' or 'brown' industries.

The transition will, and has, brought about many changes to the labour market. The occupation in which workers are employed, and the industry where they carry out their work, are both important parts of answering labour market questions about the green transition. Considering only occupation, or only industry, seemingly only tells one side of the story. While a worker may work in an occupation deemed to be 'positively' green using the bottom-up approach, for example in the Green Increased Demand category, it also matters whether they are employed in a polluting industry or a greener industry, as identified in the top-down approach. Both what a worker does, and the industry in which they do it, matter when looking at labour market transitions in the context of a green transition. Thus, the combined approach allows us to provide a more holistic and nuanced framework for analysing and contextualising the potential employment effects of the green transition.

The left axis of the matrix in Figure 4 is a spectrum reflecting the information on green occupations. The top spectrum refers to the polluting nature of the industry, from green to brown. The matrix is flexible in that the choice of definition for green occupation, green and brown industries and the exact form of the spectrum will depend on the aims and context of the questions being investigated.

Figure 4 Framework for understanding the effects of the green transition on the labour market[10]



The first advantage of this framework is that it identifies workers at the individual level based on both where they work and what work they do. Then it aggregates these individual level profiles to reflect the national or regional picture. This allows for building profiles of workers, which can provide important information for contextually relevant policy development, as this policy would consider the individual level changes required, rather than the broad aggregate changes.[11] The second advantage of this framework is that it does not prescribe a particular way of defining each of the elements of the framework. This allows for flexibility in the use of the framework which allows it to be reflective of the realities of the context being explored.

[10] The generic matrix presented may appear to be continuous, however the example in Figure 5 will show that each axis is categorical

[11] Valero et al. (2021) calculated a figure similar to our proposed matrix for the United Kingdom. However, they use only the aggregate green transition employment rather than the individual green occupation categories. We look at each category individually as they each have different policy implications. The figure referred to here is Figure 4.2 in the paper.

4.2 Example Analyses using the Framework for South Africa

This section outlines some examples of ways in which the analytical framework can be formulated, based on the definitions, data and research questions at hand. As outlined, this paper uses specific definitions or measures of green occupations and how polluting an industry is. Once these user-defined elements of the framework have been determined, the next step is to decide how to represent the analytical framework such that it can answer the research question. There are two main factors defining how the framework is put together. The first is the figures used in each part of the framework. These could simply be the numbers or proportions of workers. The second is the choice of the level of detail. This will depend in part on the choice of definition or measure of green occupation and polluting nature of industries, as well as how detailed the data being used is.

Example 1

Table 6 shows the number of workers employed in GES occupations by emission intensity of the industry they are employed in. This example only shows workers in GES occupations. The left axis shows the GES occupations in three categories: those 4-digit SASCO occupations that are entirely GES occupations, those 4-digit SASCO occupation codes with a proportion of GES occupations between 50% and 60% and those with a percentage of GES occupations less than 30%. The emissions intensity of the industry is presented on the top axis as those industries with emission intensity below the national level and those above the national level. This shows that significantly more workers in GES occupations across all three GES occupation categories are working in greener industries, represented here as those with below the national CO_2 tonnes per worker figure. This may indicate that the majority of workers in GES occupations may not need a significant intervention as they are not working in the most polluting industries. However, further exploration of which individual 4-digit GES occupations are represented in greener industry categories is needed to better understand the context.

Table 6 Number of workers by Green Enhanced Skill occupation category and emission intensity

	Below national emissions intensity	Above national emissions intensity
100% GES occupations	124 914	25 106
Between 50% and 60% GES occupations	88 047	64 390
Below 30% GES occupations	207 654	69 988

Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019) and EXIOBASE3

Example 2

Table 7 shows the percentage of workers in green and brown industries, respectively, by GID occupations. Green and brown industry is measured here as those below and above the national average CO_2 per worker. This table includes all workers in the economy. The left axis shows the GID occupations in three categories: those 4-digit SASCO occupations that are entirely GID occupations, those 4-digit SASCO occupation codes with a proportion of GID occupations of 50%, those with a percentage of GID occupations less than 30% and those 4-digit occupations which do not contain any GID occupations. This table reflects the concentration of GID and non-GID employment in brown versus green industries. There is a higher proportion of those in brown industries working in GID occupations. 7% of all those working in industries with above the national CO_2 per worker are employed in wholly GID occupations, compared to only 2% in greener industries. This indicates that there is a relatively higher concentration of workers in GID occupations working in heavily polluting industries. This suggests that 7% of workers in industries where job losses are expected due to the green transition do jobs which could support the green economy. As such, this suggests that not all workers in these vulnerable industries will face the same degree of vulnerability to the green transition.

Table 7 Percentage of workers by Green Increased Demand occupation and Emissions Intensity

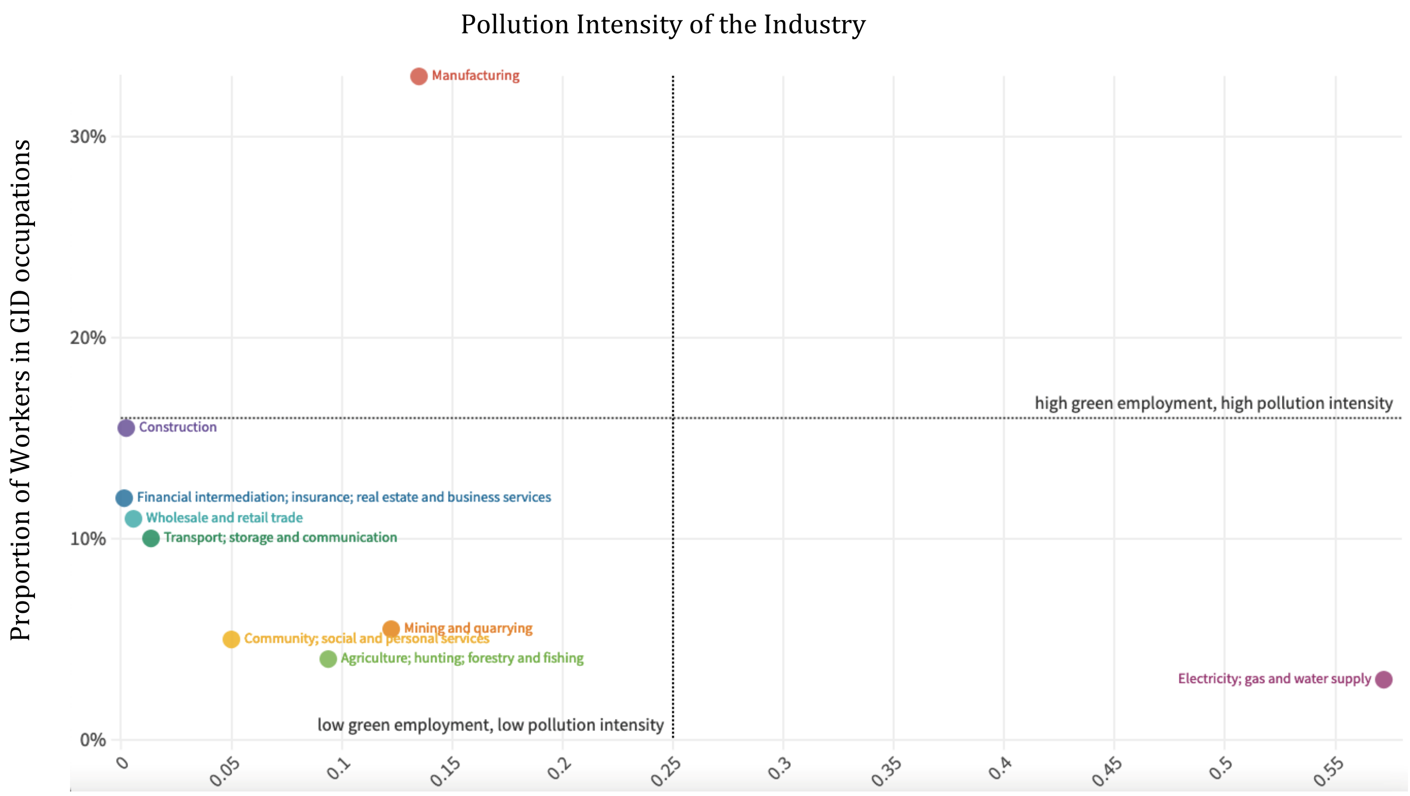
	Below national emissions intensity	Above national emissions intensity
100% GID occupations	2%	7%
50% GID occupations	1%	2%
Below 30% GID occupations	1%	2%
Non-GID occupations	91%	80%

Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019)

Example 3

Figure 5 shows the proportion of workers in GID occupations and the pollution intensity of 1-digit industrial sectors. The industrial sectors with higher pollution intensity employ a lower proportion of workers in GID occupations, apart from the manufacturing sector. The manufacturing sector employs the largest proportion of workers in GID occupations, and has the second highest pollution intensity (0.14). Some of the low proportions of workers in GID occupations in the electricity, gas and water supply; mining and quarrying; and agriculture, hunting, forestry and fishing industrial sectors may be explained by the fact that these industrial sectors employ very few of all the workers in the labour market. They employ 1%, 3% and 5%, respectively, of all workers. There is a low proportion of workers in GID occupations in the community, social, and personal services industrial sector, despite the sector employing a significant proportion of all workers. The majority of GID occupations are technical or practical in nature, which are less relevant to that industrial sector.

Figure 5 Proportion of Workers in Green Increased Demand Occupations by Pollution Intensity of Industries



Source: Own calculations using data from Labour Dynamics Survey 2018-2019 (Statistics South Africa, 2018, 2019) and EXIOBASE3.

5 Next Steps and Concluding Remarks

In South Africa, the questions on greenness of the economy are centred on electricity and energy generation processes. The implications of transitioning towards a green economy are strongly linked to the impacts both upstream and downstream of the energy generation supply chain. Both carbon footprints of industries, as well as workers with the necessary skills as determined by their occupation, are directly linked to the high carbon footprint of electricity generation. Combining these measures as proposed by the framework we present gets us closer to identifying workers who may be at greater risk, or on the other hand better placed to withstand the risks associated with the green transition.

The methodology outlined in this paper utilises both a bottom-up and a top-down approach to identify the greenness of both the occupation of a worker and the industry in which they are employed. The lists of green occupations developed by O*NET are used to identify green employment in the bottom-up approach, and pollution and emissions intensity measures form the basis of the top-down approach. Considering these approaches together, as outlined in the framework suggested, allows for an individual-level work profile of what they do and where they do it to be developed. This will facilitate the identification of workers and communities that are likely to be impacted by the Just Energy Transition. Considering the imperative for the transition to be just and fair, this approach has the potential to assist in the development of targeted policy and intervention strategies, as well as track the impact that the transition is having on the labour market over time.

There are numerous key areas of interest for future work utilising this framework. Trend analysis of the suggested framework would provide a more accurate picture of the green transition's effects, as it would allow us to distinguish between consistent features and once off phenomena. Bowen and Handcke (2019) find that employment in Green Increased Demand occupations in each of the major industrial sectors has not increased, and rather remained stable, or even decreased, over time in the European Union. They trace this stability to the high-quality training provided to many workers in the traditional industrial sectors in which workers gain very industry-specific skills, as well as the investment by employers in specific capital assets. This means that both workers and employers are reluctant to change in such a way that they lose their advantage. This produces a bias toward the status quo in the Green Increased Demand occupation make-up of industries. They find that, instead, employment in Green New and Emerging and Green Enhanced Skill increased, suggesting this was the effect of the green transition for the European Union. However, each economy will have specific factors which influence the effects of the green transition on their labour market.

In the case of South Africa, there is significant variation in the few estimates that have been put forward with regards to the impact of the transition on the labour market. As previously mentioned, Mosomi and Cunningham (2024) estimate that green jobs represent between 5.5% and 32% of jobs in the country. Bhorat et al. (2024) focus on the jobs at risk in the coal mining sector and highlight that coal mining employment only represents 0.5% of total employment. The previous estimations of jobs vulnerable to the just transition have been proposed by Makgetla et al. (2019) and they stress that employment vulnerability might be low at the national level, but very high in the municipalities where coal mining or coal plants are concentrated. This highlights the importance of trend analysis to understand the unique effects found for each economy of the green transition. Using pooled Labour Market Dynamics data, or Quarterly Labour Force data, over the past decade or so can indicate trends in the distribution and density of green employment. Looking ahead, something like this could prove a useful evaluation tool of how the green transition tool is impacting employment.

Pollution intensity and emission intensity for more detailed industrial sectors would allow for more accurate identification of workers vulnerable to the impacts of the green transition. This paper used estimates of pollution and emission intensity of industries at the major group level. This means that many individual industrial sectors are given the same emissions intensity leading to very blunt definitions of green and brown industries. An example of this is that some parts of the renewable energy industry will fall into the electricity, gas and water supply and thus, workers in that industrial sector will be regarded as having the highest emissions and pollution intensity. This individual example is unlikely to affect many workers, as South Africa's renewable energy industry is relatively small, and some parts of that renewable energy industry will fall into other major group industries such as manufacturing. However, it does highlight the need for more detailed industrial sector breakdowns to provide a clearer picture of the profile of workers. Work is underway to calculate and analyse estimates of the framework at more detailed occupation and industrial code levels.

Tables 3 and 4 in section 2.4 of the paper outline some additional results for the demographic profile, in terms of gender and race, of those working in green transition occupations. Further work is needed here to expand on these results to possibly include socioeconomic factors such as income and education.

The framework also raises some important questions around employment opportunity. We identify where workers are located in the matrix, but do we understand why? If at every level of green transition employment, workers are located in browner industries, is this a question of there not being jobs in greener industries? If we build this matrix out over time, do we see clustering in any particular quadrant? Does this differ for different geographic regions? Furthermore, by understanding where workers are located in this matrix, we can proceed to draw comparisons with firm side/output data, such as where are growth sectors located on the green-brown spectrum?

An appealing feature of the framework which extends its usefulness beyond the South African context is that it can work across various definitional systems. Users can select the definition of green jobs, the occupational and other classification systems, and the data that are best suited to their purpose and context, and apply them to the same framework.

References

Amis, A.M. *et al.* (2018) *The Green Economy Barometer 2018*. Cape Town, Pretoria: The African Centre for a Green Economy; Trade and Industrial Policy Strategies.

Becker, R.A. and Shadbegian, R.J. (2009) 'Environmental Products Manufacturing: A Look inside the Green Industry', *The B.E. Journal of Economic Analysis & Policy*, 9(1). Available at: https://doi.org/10.2202/1935-1682.2117.

Bhorat, H. *et al.* (2024) *Just Transition and the Labour Market in South Africa: Measuring Individual and Household Coal Economy Dependence*. Cape Town: Development Policy Research Unit, University of Cape Town.

Bluedorn, J. *et al.* (2022a) 'A Greener Labor Market: Employment, Policies, and Economic Transformation', in *World Economic Outlook, April 2022: War Sets Back the Global Recovery*. Washington DC: International Monetary Fund (World Economic Outlook). Available at: https://doi.org/10.5089/9781616359423.081.

Bluedorn, J. *et al.* (2022b) 'A Greener Labor Market: Employment, Policies, and Economic Transformation', in *World Economic Outlook, April 2022: War Sets Back the Global Recovery*. Washington DC: International Monetary Fund (World Economic Outlook). Available at: https://doi.org/10.5089/9781616359423.081.

Bowen, A. and Handcke, B. (2019) *The social dimensions of 'greening the economy': developing a taxonomy of labour market effects related to the shift toward environmentally sustainable economic activities*. LU: Publications Office. Available at: https://data.europa.eu/doi/10.2767/448791 (Accessed: 8 June 2024).

Bowen, A., Kuralbayeva, K. and Tipoe, E.L. (2018) 'Characterising green employment: The impacts of "greening" on workforce composition', *Energy Economics*, 72, pp. 263–275. Available at: https://doi.org/10.1016/j.eneco.2018.03.015.

Burton, J. *et al.* (2018) *Coal Transitions in South Africa - Understanding the implications of a 2C-compatible coal phase-out plan for South Africa*. IDDRI; Slimate Strategies.

Central Statistics Service (1993) *Standard Industrial Classification of all Economic Activities (SIC) Fifth Edition*. 09-90-02. Pretoria: Central Statistical Service.

Centre for Researching Education & Labour (2022) *Occupation and qualification classification report: A framework to classify occupations and Qualifications in the public service sector*. Public Service Sector Education and Training Authority. Available at: https://pseta.org.za/wp-content/uploads/2024/02/Occupations-and-Qualifications-Classification-Framework-in-the-Public-Service.pdf.

Consoli, D. *et al.* (2016) 'Do green jobs differ from non-green jobs in terms of skills and human capital?', *Research Policy*, 45(5), pp. 1046–1060.

Department of Environmental Affairs (2014) *GHG Inventory for South Africa*. Pretoria: Department of Environmental Affairs, Republic of South Africa.

Department of Higher Education and Training (DHET) (2012) 'GUIDELINES: ORGANISING FRAMEWORK FOR OCCUPATIONS (OFO) 2012'. Pretoria, South Africa: DHET. Available at: https://www.dhet.gov.za/Publications/OFO%20Guideline%20-%202012.pdf (Accessed: 10 June 2024).

Department of Public Service and Administration (2024) *The Public Service Occupational Classification System: Occupational Dictionary*. Available at: https://www.dpsa.gov.za/dpsa2g/documents/hrmd/2023/14_1_1_p_14_11_2023_dictionary.pdf.

Dierdorff, E.C. *et al.* (2009) 'Greening of the World of Work: Implications for O*NET®-SOC and New and Emerging Occupations'.

Dierdorff, E.C. *et al.* (2011) 'Greening of the World of Work: Revisiting Occupational Consequences'.

Elliott, R.J.R. *et al.* (2021) 'Eco-Innovation and Employment: A Task-Based Analysis', *SSRN Electronic Journal* [Preprint]. Available at: https://doi.org/10.2139/ssrn.3767265.

Elliott, R.J.R. and Lindley, J.K. (2017) 'Environmental Jobs and Growth in the United States', *Ecological Economics*, 132, pp. 232–244. Available at: https://doi.org/10.1016/j.ecolecon.2016.09.030.

European Environment Agency (2024) *Extreme weather: floods, droughts and heatwaves*. Available at: https://www.eea.europa.eu/en/topics/in-depth/extreme-weather-floods-droughts-and-heatwaves (Accessed: 10 June 2024).

Eurostat (2024) *Environmental economy – statistics on employment and growth, 2020-21*. Eurostat.

Hayden, F.G. (2021) 'Critique of Concepts about Systems and Time in William Nordhaus's Research about Climate Change', *Journal of Economic Issues*, 55(2), pp. 447–453. Available at: https://doi.org/10.1080/00213624.2021.1909343.

Hughes, A. *et al.* (2021) 'Evolution, Assumptions and Architecture of the South African Energy Systems Model SATIM', *Energy Systems Research Group- Working Paper* [Preprint].

IEA (2021) *Key World Energy Statistics 2021*. Paris: International Energy Agency.

International Renewable Energy Agency and International Labour Organisation (2023) *Renewable energy and jobs: Annual review 2023*. Available at: https://www.irena.org/Publications/2023/Sep/Renewable-energy-and-jobs-Annual-review-2023 (Accessed: 17 July 2024).

International Standard Classification of Occupations (ISCO) (2024) *ILOSTAT*. Available at: https://ilostat.ilo.org/methods/concepts-and-definitions/classification-occupation/ (Accessed: 10 June 2024).

'International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 4' (2008). New York: United Nations.

IPCC (1992) *Climate Change: the 1990 and 1992 IPCC assessments*. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme.

IPCC (1995) *Climate Change 1995: IPCC Second Assessment*. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme.

IPCC (2003) *Climate Change 2001: Synthesis Report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme.

IPCC (2007) *Climate Change 2007: Synthesis Report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme.

IPCC (2014) *Climate Change 2014: Synthesis Report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme.

IPCC (2023) *Climate Change 2023: Synthesis Report*. First. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme. Available at: https://doi.org/10.59327/IPCC/AR6-9789291691647.

Leontief, W. (1970) 'Environmental Repercussions and the Economic Structure: An Input-Output Approach', *The Review of Economics and Statistics*, 52(3), pp. 262–271.

Maia, J. *et al.* (2011) *Green Jobs: An Estimate of the Direct Employment Potential of a Greening South African Economy*. Pretoria: Industrial Development Corporation; Development Bank of Southern Africa; Trade and Industrial Policy Strategies.

Makgetla, N. *et al.* (2019) *National Employment Vulnerability Assessment: Analysis of potential climate-change related impacts and vulnerable groups*. Trade and Industrial Policy Strategies. Available at: https://www.tips.org.za/images/National_Employment_Vulnerability_Assessment_Analysis_of_potential_climate-change_related_impacts_and_vulnerable_groups.pdf.

Masini, F. (2021) 'William Nordhaus: A disputable Nobel [Prize]? Externalities, climate change, and governmental action', *The European Journal of the History of Economic Thought*, 28(6), pp. 985–1004. Available at: https://doi.org/10.1080/09672567.2021.1963798.

Merciai, S. and Schmidt, J. (2018) 'Methodology for the Construction of Global Multi-Regional Hybrid Supply and Use Tables for the EXIOBASE v3 Database', *Journal of Industrial Ecology*, 22(3), pp. 516–531. Available at: https://doi.org/10.1111/jiec.12713.

Miller, R.E. and Blair, P.D. (2022) *Input-output analysis: foundations and extensions*. Third edition. Cambridge, United Kingdom New York: Cambridge University Press. Available at: https://doi.org/10.1017/9781108676212.

Mosomi, J. and Cunningham, W. (2024) *Profiling Green Jobs and Workers in South Africa: An occupational tasks approach*. Working Paper. Available at: http://localhost:8080/handle/11090/1038 (Accessed: 1 July 2024).

Nordhaus, W. (2019) 'Climate Change: The Ultimate Challenge for Economics', *The American Economic Review*, 109(6), pp. 1991–2014.

Nordhaus, W.D. (1977) 'Economic Growth and Climate: The Carbon Dioxide Problem', *The American Economic Review*, 67(1), pp. 341–346.

Nordhaus, W.D. (1991) 'To Slow or Not to Slow: The Economics of The Greenhouse Effect', *The Economic Journal*, 101(407), p. 920. Available at: https://doi.org/10.2307/2233864.

OECD (2017) *Getting Skills Right: Skills for Jobs Indicators.* Organisation for Economic Co-operation and Development. Available at: https://www.oecd.org/en/publications/getting-skills-right-skills-for-jobs-indicators_9789264277878-en.html.

OECD (2023) *Job Creation and Local Economic Development 2023: Bridging the Great Green Divide*. OECD (Job Creation and Local Economic Development). Available at: https://doi.org/10.1787/21db61c1-en.

Rutovitz, J. (2010) *Independently reviewed by Thapelo Letete, Energy Research Centre, University of Cape Town*. Johannesburg: Greenpeace Africa.

Rutzer, C., Niggli, M. and Weder, R. (2020) 'Estimating the Green Potential of Occupations: A New Approach Applied to the U.S. Labor Market', *WWZ Basel Working Paper* [Preprint], (2020/03). Available at: https://doi.org/10.5451/UNIBAS-EP76063.

Stadler, K. *et al.* (2018) 'EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables', *Journal of Industrial Ecology*, 22(3), pp. 502–515. Available at: https://doi.org/10.1111/jiec.12715.

Statistics South Africa (2012a) *South African Standard Classification of Occupations (SASCO) 2012*. 09-90–01 (2012). Pretoria: Statistics South Africa. Available at: www.statssa.gov.za.

Statistics South Africa (2012b) *Standard Industrial Classification of all Economic Activities (SIC) Seventh Edition*. 09-90–02. Pretoria: Statistics South Africa.

Statistics South Africa (2018) 'Labour Market Dynamics in South Africa 2018'. DataFirst. Available at: https://doi.org/10.25828/cq37-bn90.

Statistics South Africa (2019) 'Labour Market Dynamics in South Africa 2019'. DataFirst. Available at: https://doi.org/10.25828/KJGZ-YY35.

Stern, D.I., Common, M.S. and Barbier, E.B. (1994) *Econonmic growth and environmental degredation: A critique of the environmental Kuznets Curve*, *Discussion Papers in Environment Economics and Environmental Management*. York. Available at: https://ageconsearch.umn.edu/record/263933/files/york-010.pdf.

Stern, N.H. and Great Britain (eds) (2007) *The economics of climate change: the Stern review*. Cambridge, UK ; New York: Cambridge University Press.

Thomas, G. (2022) *Low carbon and renewable energy economy, UK: 2020*. United Kingdom: Office for National Statistics. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/finalestimates/2020 (Accessed: 17 July 2024).

UNEP IRP, Australian National Science Agency, and Commonwealth Scientific and Industrial Research Organisation (2024) *Technical Annex for Global Material Flows Database - version 4*. Technical Annex. Canberra: Commonwealth Scientific and Industrial Research Organisation.

US Environmental Protection Agency (2024) *Climate Change Indicators: Weather and Climate*. Available at: https://www.epa.gov/climate-indicators/weather-climate (Accessed: 10 June 2024).

Valero, A. *et al.* (2021) *Are 'green' jobs good jobs? How lessons from the experience to-date can inform labour market transitions of the future*. London: Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science.

Vandeplas, A. *et al.* (2022) *The Possible Implications of the Green Transition for the EU Labour Market - European Commission*. Discussion Paper 176. Office of the European Union. Available at: https://economy-finance.ec.europa.eu/publications/possible-implications-green-transition-eu-labour-market_en (Accessed: 1 July 2024).

Vona, F. *et al.* (2018) 'Environmental Regulation and Green Skills: An Empirical Exploration', *Journal of the Association of Environmental and Resource Economists*, 5(4), pp. 713–753. Available at: https://doi.org/10.1086/698859.

Vona, F., Marin, G. and Consoli, D. (2019) 'Measures, Drivers and Effects of Green Employment: Evidence from US Local Labor Markets, 2006-2014', *FEEM Working Papers* [Preprint], (19.2019).

Wakeford, J., Hasson, R. and Black, A. (2016) 'Greening the Manufacturing sector', in *Greening the South African Economy: Scoping the issues, challenges and opportunities*. Juta and Company (Pty) Ltd.

Appendix A: Method for Matching O*NET to OFO occupations

Steps for matching O*NET to OFO

1. Match based on the name of the occupation e.g. civil engineer matched to civil engineer (Green highlight)
2. Match based on specialisation within OFO 6-digit occupation or based on an alternative title for the O*NET occupation (yellow)
3. Match based on description of occupation (purple)
4. Match to closest occupation in OFO but then when applied to labour market data use the industry information to improve match.
   For example: Recycling workers are identified in O*NET list, however the OFO has Rubbish and Recycling workers under the same occupation, and this is also matched to the Garbage Collectors SASCO code. There is an Industry code for Recycling. Therefore, the green share for the Garbage Collector is given only to workers who have that occupation and are in the Recycling industry.

The majority of those matched using method 2, are matched to specialisations and so the specialisations are included in the denominator for the green share to account for the match to specialisation rather than the whole occupation. In some cases, the whole occupation is identified elsewhere within the list as one of the green categories and so the specialisations are not included in the calculation. *Industrial Safety and Health Engineer* is identified as a GID occupation in O*NET and matched to a specialisation under the *Industrial Engineers* OFO 6-digit occupation. Elsewhere on the list of GID occupations, *Industrial Engineer* is also identified as GID. This means that the specialisations are not included in the calculation of the green share as it would be double counting to include both industrial engineer and its specialisation, *Industrial Safety and Health Engineer*.

Lists are matched and calculated separately.

The reasons for matching O*NET to OFO codes are:

1. We can match occupations at the same level. The O*NET green occupations are at the 6-digit level and the OFO includes occupations at this same level. This allows us to match a *Hydrologist* in the O*NET with a *Hydrologist* in the OFO rather than matching a Hydrologist with the whole 4-digit *Geologists & Geophysicists* occupation group.
2. The use of the OFO here allows us to calculate the proportion as we see how many 6-digit occupations are in a 4-digit occupation group. i.e. there are seven 6-digit occupations under the 4-digit *Geologists & Geophysicists* occupation group.

ACEIR – South Africa Node
SALDRU, School of Economics
University of Cape Town
Private Bag X1
Rondebosch, 7701
South Africa

Contact:
Vimal Ranchhod
Tel: +27 21 650 5715
Email:
vimal.ranchhod@uct.ac.za

ACEIR – Ghana Node
ISSER, University of Ghana,
Legon, Accra
Ghana

Contact:
Robert Darko Osei
Email: rdosei@ug.edu.gh

ACEIR – Kenya Node
School of Economics University
of Nairobi
Kenya

Contact:
Damiano Manda
Email: dkmanda@gmail.com

ACEIR
SALDRU, School of Economics
University of Cape Town
Private Bag X1
Rondebosch, 7701
South Africa

Contact:
Murray Leibbrandt
Tel: +27 21 650 5715
Email:
murray.leibbrandt@uct.ac.za;
haajirah.esau@uct.ac.za
www.aceir.org.za