SEPTEMBER 2025
No 373

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The Impact of the Green Transition on Jobs in South Africa

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Abstract
One of the key issues in policy discussions over addressing climate concerns the ways in which countries need to and can balance the combating of climate change with job creation and economic development. South Africa's transition to a low-carbon economy is essential and urgent, as one of the largest carbon emitters among low and middle-income countries and a country with a heavy reliance on coal-based energy production. From the outset, an essential principle guiding this transition has been to ensure that it is just and equitable for all South Africans. However, it has been hard to give effect to this in practice; one important example being that achieving this requires acknowledging and addressing the potential regional disparities in the effects of the shift to a green economy. In this paper we seek to contribute towards an evidence base to ground such a discussion. We employ a comprehensive framework that combines bottom-up and top-down approaches to estimating 'green jobs' in order to analyse how the transition may affect workers in different geographic areas. To capture the spatial dimension of the transition, we draw on Spatial Tax Panel data using provinces and municipalities as our units of analysis. Given sample size limitations in the accompanying survey data, the specific findings should be treated as illustrative examples of how the framework can be operationalised. Even so, they do highlight the imperative to consider the likelihood of large geographic variation in the impacts of the green transition.

Keywords:
Green transition, employment, occupations, environment, South Africa.

JEL codes:
J21, Q52

Acknowledgements: We thank the attendants to the ACEIR-SALDRU seminar held on the 13th of November 2024 for their valuable input and feedback.

Accepted: July 2025

Résumé
L'une des questions centrales dans les débats politiques sur la lutte contre le changement climatique concerne les moyens par lesquels les pays doivent et peuvent concilier la lutte contre le réchauffement climatique avec la création d'emplois et le développement économique. La transition de l'Afrique du Sud vers une économie à faible intensité de carbone est à la fois essentielle et urgente, car le pays est l'un des plus grands émetteurs de carbone parmi les pays à revenu faible et intermédiaire et repose fortement sur la production d'énergie à base de charbon. Dès le départ, un principe fondamental guidant cette transition a été de veiller à ce qu'elle soit juste et équitable pour l'ensemble des Sud-Africains. Toutefois, il a été difficile de traduire ce principe dans la pratique ; un exemple important étant que sa réalisation suppose de reconnaître et de traiter les disparités régionales potentielles dans les effets du passage à une économie verte. Dans cet article, nous cherchons à contribuer à la constitution d'une base factuelle pour alimenter une telle discussion. Nous mobilisons un cadre analytique complet qui combine des approches ascendantes et descendantes d'estimation des « emplois verts » afin d'analyser la manière dont la transition pourrait affecter les travailleurs dans différentes zones géographiques. Pour saisir la dimension spatiale de la transition, nous nous appuyons sur des données fiscales spatiales (Spatial Tax Panel), en utilisant les provinces et municipalités comme unités d'analyse. Compte tenu des limites d'échantillonnage des données d'enquête qui accompagnent ce travail, les résultats spécifiques doivent être considérés comme des exemples illustratifs de la manière dont ce cadre peut être opérationnalisé. Néanmoins, ils mettent bien en évidence la nécessité de prendre en compte la probabilité de fortes variations géographiques dans les impacts de la transition verte.

Mots clés :
Transition verte, emploi, occupations, environnement, Afrique du Sud.

1. Introduction

The global imperative to address climate change is reshaping labour markets across the world, raising fundamental questions about how countries can balance environmental sustainability with economic development and job creation. The scale of the transformation needed to achieve climate neutrality has often been compared to that entailed by the industrial revolution (Pisani-Ferry and Mahfouz, 2023), which significantly exacerbated inequality and vulnerability for those lacking the skills adaptable to the new economy, despite having significantly expanded opportunities in sectors such as manufacturing. While the transition to a low-carbon economy presents significant opportunities for a truly equitable prosperity path, its impact on employment in low and middle-income countries remains poorly understood and inadequately addressed in policy frameworks. To avoid the negative fallout of the exit from fossil fuels and, therefore, stronger opposition to the transition, it is crucial to understand the intersection of potential employment losses and gains, and climate action.

Moreover, the analysis of the impact of the green transition on jobs is often polarised, with studies either warning of the widespread displacement in traditional sectors or celebrating the promise of 'green jobs'. In this paper, we use a comprehensive framework to analyse the impact of the green transition on jobs in South Africa. South Africa is notable in the African context as it has historically contributed significantly to climate change, while many African countries suffer its effects despite having made minimal contributions.

As one of the largest carbon emitters among low- and middle-income countries, and with an economy heavily reliant on coal for energy production, the shift from a carbon-intensive to a low-carbon economy is crucial to South Africa. The economic risks of not transitioning out of fossil fuels are significant, ranging from the loss of export competitiveness and stranded assets, to reduced access to finance and, of course, energy insecurity, given the ageing coal infrastructure (Huxham, Anwar and Nelson, 2019). The economic risks are compounded by environmental risks such as the escalating climate impact and the loss of biodiversity. In addition, there are social risks, among which are energy poverty, health impacts, and an increase in job losses and inequality due to the decline in existing jobs in the coal value chain, as well as missing out on the new green job opportunities.

A critical element of the green transition is ensuring that the transition will be just and fair for all South Africans. The Presidential Climate Commission's *Framework for a Just Transition in South Africa* puts forward a detailed definition of a just transition (Presidential Climate Commission, 2024).

Some of the key points concern achieving quality of life for all in the context of the transition, ensuring the transition contributes to the goal of decent work for all, putting people at the centre of decision-making, as well as building economic resilience regarding renewable energy systems, natural resources, land use and health. Furthermore, the just transition should be guided by principles of distributive, procedural and restorative justice. The policy framework seeks to put the 'just' element of the transition at the heart of all green transition policies (Presidential Climate Commission, 2024). These concerns have been integrated into the country's roadmap for transitioning to a low-carbon economy, the Just Energy Transition Implementation Plan 2023-2027 (JET-IP), which focuses on the reshaping and investment needs in the energy, green hydrogen and electric vehicles sectors (The Presidency, Republic of South Africa, 2023a).

Another critical element of managing a just transition is addressing the uneven impacts in different parts of the country. In particular, the JET Implementation Plan sets out a Just Transition for Mpumalanga province as a cross-cutting priority area, which aligns with the priority investments outlined in the JET IP. Mpumalanga receives specific attention as it will be the most adversely affected by the green transition, as the province is home to 80% of all the coal-fired power plants, 111 related coal mines, and Sasol's coal-to-liquid industrial complex. Much of the economic activity in the province relies in some way on these heavily polluting economic activities (The Presidency, Republic of South Africa, 2023b, 2023a).

There have been relatively few attempts at quantifying and analysing the impact of the transition away from fossil fuels on the South African labour market. The existing research suffers from the same dualistic approach mentioned earlier, of either focusing on the job losses or potential job gains, without bringing these contradictory elements together. A first strand of literature focuses on the job losses linked to the coal value chain. Studies such as the World Resources Institute (2021) and Makgetla (2021) estimate that around 200 000 workers are at risk. In a more detailed study on the characteristics of individuals and households in the coal economy, Bhorat et al. (2024) estimate that between 76 000 and 108 000 workers in coal mining nationally, and 20 481 workers in the electrical utility industry in Mpumalanga, could be retrenched. On the other hand, the study conducted under the COBENEFITS project by the Institute for Advanced Sustainability Studies, International Energy Transition and the Council for Scientific and Industrial Research (2019) put forward that around 79 000 jobs could be created in the clean energy sector by 2030. This is in line with an older study on the job creation potential of the energy sector by Rutovitz (2010), who suggests that a low-carbon energy scenario could create 78 000 green jobs. Maia et al. (2011) take a broader view and look at the sector-wide greening of the economy, estimating that it has the potential to create more than 462 000 formal jobs. Finally, more recently, Mosomi and Cunningham (2024) estimate that between 5.5% and 32% of jobs in South Africa can be considered to be 'green'.

Our approach makes use of the Green Transition Framework outlined in Davidson et al. (2024), which combines a bottom-up approach to identifying occupations related to the green transition, with a top-down approach to identifying 'brown' industries. The result is a matrix that allows us to look at where on the nexus between employment in green transition occupations and brown industries, workers find themselves. We need to know what workers do (i.e. their occupation) as well as where they do it (i.e. what industry they are in) to fully assess what the nature of the disruption to jobs might be as a result of the green transition.

In our application of the Green Transition Framework, we utilise the Spatial Tax Panel data to understand the spatial dimensions of the transition's potential effect, with provinces and municipalities as our unit of analysis. This level of analysis, coupled with the nuance of the three different O*NET green jobs classifications, can better inform the development of targeted, place-based policies which can be tailored to the specific needs of municipalities, based on their predominant industries and the occupations that may face disruption due to the transition. While the findings for each municipality should be treated as suggestive, due to sample size constraints which are exacerbated in smaller municipalities, the results clearly illustrate the potential for wide spatial variation in the intensity of impacts and of potential benefits of the green transition.

Finally, it needs to be noted that the vocabulary around the green transition is complex and, often, the nuances of the different concepts reflect differences in academic and policy fields, in lobbying and power groups, or simply in time and space contexts.[1] The "green transition" appears to us as being the broadest term as it encompasses all shifts toward environmental sustainability and it is also the term used in the Paris Agreement (UNFCCC, 2015). The Paris Agreement is integral to South African policy as the stated goal of South Africa's Just Energy Transition Implementation Plan is to achieve the country's Nationally Determined Contribution (The Presidency, Republic of South Africa, 2023b, 2023a).

The rest of the paper is structured as follows: Section 2 details the bottom-up and top-down methodologies for estimating green jobs, and introduces the analytical matrix along with how it is applied in this paper. Section 3 discusses findings, these being the national, provincial, metropolitan municipal, and local municipal impacts of the green

[1] See Wang and Lo (2021) and Stark, Gale and Murphy-Gregory (2023) for reviews of the concept of just transition and its different variants.

transition using the matrix. Section 4 concludes with a discussion.

2. Applying the Green Transition Framework

Davidson et al. (2024) propose an analytical Green Transition Framework for examining the effects of the green transition on the labour market, utilising both bottom-up and top-down approaches. In this section, we briefly outline the various methodologies employed to arrive at the bottom-up (2.1) and top-down (2.2) measures for green occupations and emissions respectively, as well as the Green Transition Framework used for analysis (2.3).

2.1. The bottom-up approach

Bottom-up approaches to estimating green employment encompass methodologies that produce estimates based on a worker's occupation, irrespective of the industry in which they are employed. The work of the Occupational Information Network (O*NET)'s Green Economy Program, of the United States Department of Labor, which identifies green occupations within the O*NET system, serves as a foundation of much of the research in the bottom-up literature. Dierdorff et al. (2009) pioneered the identification of these occupations, and developed three categories of green occupations:

1. *Green Increased Demand Occupations (GID):* These are existing occupations that 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 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 public transport as people reduce their use of private vehicles. Thus, bus drivers may be in greater demand, but they 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 are architects. The construction of buildings must switch to more environmentally friendly models as we move to a greener economy, and architects will likely need to learn new skills or knowledge to implement greener models.

3. *Green New and Emerging 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" (O*NET, 2025). This occupation would likely not exist if not for the need to transition to a greener economy.

(Davidson et al., 2024)

The bottom-up approach has produced two primary methods for estimating green employment. The first uses definitions of green occupations based on the effect of a green transition on occupations. This literature defines green occupations as those that appear in the three green occupational categories defined by the O*NET Green Economy Program (Bowen, Kuralbayeva and Tipoe, 2018; Bowen and Handcke, 2019; Valero *et al.*, 2021). Dierdorff et al (2011) refer to this as the 'occupational greening' approach. The second method uses definitions of green occupations based on the impact of the work carried out in an occupation on the environment. Typically, this involves estimating green task intensity, which quantifies the degree to which a worker performs green tasks (Vona, 2019; Elliott *et al.*, 2021; Bluedorn *et al.*, 2022; OECD, 2023; Granata and Posadas, 2024; Mosomi and Cunningham, 2024).

The occupational greening approach is generally utilised in research focusing on the employment effects of the green transition. The three definitions of a green occupation allow researchers to delineate employment effects in a more nuanced manner, as they provide three potential effects of the green transition on an individual's labour market outcomes. We follow Davidson et al. (2024) in their occupational greening approach to estimating '*green transition occupations*'. The authors apply several steps to estimate employment in these occupations in South Africa.

Two different occupation categorisation systems are used in the South African context. The Organising Framework for Occupations (OFO) is developed and maintained by the Department of Higher Education and Training (Department of Higher Education and Training (DHET), 2012). The OFO contains detailed occupation codes at the 6-digit level, which are comparable to the O*NET green transition occupation codes. The second is the South African Standard Classification of Occupations (SASCO), which was developed, and is maintained, by Statistics South Africa. The SASCO 2003 version is based on the 1988 version of the ISCO, and is the version of this system used to identify occupations in Statistics South Africa survey data, such as the Quarterly Labour Force Survey and the Census (Statistics South Africa, 2012).

Green transition occupations within the O*NET classification system are best aligned with codes within the OFO system. However, it cannot be used to identify occupations in Statistics South Africa's labour market data. Such identification required the development of a new methodology to apply the O*NET green transition occupation codes to South African labour market data. The approach relies on an existing crosswalk between the OFO and the SASCO created by DHET, as well as a new O*NET to OFO crosswalk developed by the authors (Vandeweyer and Verhagen, 2022; Davidson *et al.*, 2024).

The required steps are detailed in Table 2:

Table 2: Steps in estimating green transition employment in South Africa
Source: Davidson et al. (2024)

	Steps	Worked Example
1	Crosswalk or match the 8-digit O*NET green transition 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.	*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 occupations matched to green transition occupations in the 4-digit OFO occupation groups.	*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 transition 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 transition 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 estimate the number of workers in green transition occupations, within that occupation code.	If, for instance, in the employment data chosen, there are 23 000 workers employed in the *8323 Bus and Tram Drivers* SASCO occupation code, we estimate 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 the green task intensity bottom-up approach. The choice of how 'green' jobs are defined is guided by the research question, data availability, and context.

This methodology involves several limitations including the use of an occupational classification system that is not the most recent one and reliance on international green occupation data. South African labour market data utilises SASCO 2003, which is unlikely to be able to identify newer occupations, and requires the assumption that employment is uniform within the 4-digit occupation codes. Moreover, the green transition occupations were developed based on information from the United States in 2010 and as such, it may not fully capture the relevant roles that exist locally.

In this application of the approach to estimating green transition jobs, both Labour Market Dynamics and Spatial Tax Panel (STP) data are used. The two datasets are linked across their industrial and spatial information to leverage the occupation information from the Labour Market Dynamics data and the spatial granularity provided by the STP. The Labour Market Dynamics dataset is pooled data from all four Quarterly Labour Force Surveys, produced annually by Statistics South Africa. We use pooled data from 2018 and 2019. This timeframe was chosen as it reflects a pre-Covid period. To make the data comparable with the STP, we limit the sample to formal sector workers only, as defined by Statistics South Africa in the dataset (Statistics South Africa, 2018, 2019).[2]

The STP is a dataset derived from de-identified administrative Pay-As-You-Earn (PAYE) tax records (Nell and Visagie, 2024). The data is prepared at the National Treasuries' Secure Data Facility, where it is aggregated spatially for public release. The STP provides granular longitudinal estimates for employment and establishments for the formal tax-paying economy at a municipal level and below that includes additional information such as industries, at a 5-digit level using Statistics South Africa's Standard Industrial Classification 7th edition (SIC7) (Nell and Visagie, 2024). We use data from the 2019 Tax Year which is for the period between March 2018 and February 2019. Employment is calculated in the STP as Full-Time Equivalent (FTE) employees, which weights employees based on the period they work within a tax year. For example, if an employee works for 6 months of the 12-month tax year, they would be calculated as 0.5 FTE employees. A novel approach to address head office effects in the STP was developed after assessing the results and identifying anomalies.[3] The STP data presents an opportunity to identify, design and monitor interventions at worker, establishment or firm levels over time.

[2] Weights are divided by two and applied to estimates to produce weighted estimates.
[3] See Appendix A for more information.

The greenness measures are applied to the Labour Market Dynamics data, following which employment in the three green transition occupation categories is calculated per Statistics South Africa's SIC 5th edition[4] (SIC5) 3-digit industry for metropolitan municipalities and all non-metropolitan municipalities per province combined (Statistics South Africa, 1993). Unfortunately, the Labour Market Dynamics data is limited in that it only provides disaggregated data for metropolitan municipalities and provinces (all non-metropolitan municipalities combined). In order to calculate employment in the green transition occupations at a local municipal level for the whole country, we supplement the spatial information from the Labour Market Dynamics with comprehensive administrative employment records from the STP.[5] This approach uses the spatial distribution of employment in the STP to distribute estimated employment in the green transition occupations derived from the Labour Market Dynamics data, matched by industry. The steps are described in Table 3 below.

Table 3: Steps in disaggregating green transition employment to all municipalities

	Steps	**Worked Example**
1	Using the Labour Market Dynamics data, aggregate employment numbers for each green transition occupation definition per 3-digit SIC 5th edition industry code and province and metropolitan municipality. Estimate the share of workers in each 3-digit SIC 5th edition industry code and province and metropolitan municipality that are employed in green transition occupations.	In Johannesburg there are 503 Green Enhanced Skills jobs relative to a total of 8 555 jobs in the *Production, collection and distribution of electricity industry* (code 411). This results in 5.88% of workers in this industry in Johannesburg are employed in Green Enhanced Skills occupations.
2	Using the STP dataset, crosswalk or match the SIC 5th edition 3-digit industry codes to the SIC 7th edition 5-digit industry codes. Matching was completed using a crosswalk developed by Statistics South Africa matching the 7th and 5th edition SIC industry codes, with some gaps filled in manually in cases where they were missing.	*Production, collection and distribution of electricity*, code 411 (5th edition SIC) matches *Generation of Electricity*, code 35101 (7th edition SIC) in the STP.
3	Using the new SIC 5th edition 3-digit industry codes in the STP referred to above, sum the number of FTE employees working in each municipality and 3-digit SIC 5th edition industry code to prepare data to be merged with the Labour Market Dynamics data.	In Johannesburg the *Production, collection and distribution of electricity industry* (code 411 in 5th Edition SIC) has 9 633 FTE employees, which is the sum of all matching 7th Edition SIC 5-digit codes which includes codes: • 35101 (*Generation of Electricity*) – 7319 FTE employees,

[4] The Statistics South Africa SIC 5th edition classification refers to the 5th edition of the Standard Industrial Classification
of all Economic Activities (SIC) created by Statistics South Africa. We also refer to SIC7, which is the updated 7th edition of the same classification system. We also use Statistics South Africa's official conversion table between SIC 5th edition and SIC 7th edition when converting between the two for matching the STP and QLFS data.

[5] The Labour Market Dynamics data was restricted to only include formal sector employees to better align with the STP. However, it is important to note that various informal sector jobs would still affect the greenness of a specific sector or place but would not be accounted for in this analysis.

		• 35102 (*Distribution of Purchased Electric Energy Only*) – 2 136 FTE employees, • 35103 (*Generation and/or Distribution for own use*) – 178 FTE employees.
4	The shares of green transition employment derived from the Labour Market Dynamics data can then be merged onto the STP. The Labour Market Dynamics data does not provide data for non-metropolitan municipalities. For this reason, estimates are calculated slightly differently for metropolitan and non-metropolitan municipalities. Metropolitan municipalities: Multiply the share of green transition workers in an industry and metropolitan municipality, as calculated in the above step, by the number of FTE employees in the corresponding industry and metropolitan municipality from the STP data to determine the number of FTE green transition employees per industry and metropolitan municipality. Non-Metropolitan municipalities Multiply the share of green transition workers in an industry and province, as calculated in the above step, by the number of FTE employees in the corresponding industry and non-metro municipality from the STP data to determine the number of green transition FTE employees per industry and non-metropolitan municipality. It should be noted that all non-metro municipalities within the same province would have the same share of green transition FTE employees per industry, however, municipalities would have higher or lower green transition FTE employees based on the number of FTE employees per industry in each municipality.	Metropolitan municipalities: In the *Production, collection and distribution of electricity sector* (code 411) in Johannesburg, the 9 633 FTE employees identified in the STP are multiplied by the 5.88% share of Green Enhanced Skills to determine that there are 566 Green Enhanced Skills FTE employees. Non-Metropolitan municipalities: In the *Production, collection and distribution of electricity sector* (code 411) in eMalahleni (in Mpumalanga), the 5 453 FTE employees identified in the STP are multiplied by the 32.83% share of Green Enhanced Skills in Mpumalanga to determine that there are 1 790 Green Enhanced Skills FTE employees in eMalahleni. While in the same industry in Thaba Chweu (also in Mpumlanga), the 53 FTE employees identified in the STP are multiplied by the 32.83% share of Green Enhanced Skills in Mpumalanga to determine that there are 17 Green Enhanced Skills FTE employees in Thaba Chweu.
5	Aggregate the number of FTE employees in green transition occupations in a municipality to determine the total number of FTE employees in green transition occupations in the municipality.	In Johannesburg the 566 Green Enhanced Skills FTE employees in the *Production, collection and distribution of electricity sector* (code 411) are added to the Green Enhanced Skills FTE employees calculated from the other industries in Johannesburg (65 712) to calculate the total number of Green Enhanced Skills FTE employees in Johannesburg (66 278). This is divided by the total FTE employees in Johannesburg (1 851 256) to calculate the percentage of Green Enhanced Skills FTE employees in Johannesburg – 3.58%.

2.2. The top-down approach

The top-down approach provides an environmental profile of employment based on industry. Typically, this involves identifying an industry as 'green' or 'brown' based on its consumption and 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 (Becker and Shadbegian, 2009; Elliott and Lindley, 2017; Thomas, 2022; International Renewable Energy Agency and International Labour Organisation, 2023; Eurostat, 2024).

Numerous methodologies have been developed to identify "brown" jobs, or jobs that harm the environment, with the added assumption that any job that is not "brown" is "green" (Vandeplas *et al.*, 2022; OECD, 2023). Recent literature, however, appears to be moving away from the simplistic binary classification of jobs as either "green" or "brown" in the context of environmental sustainability. Instead, researchers are adopting a more nuanced approach that places industries and occupations on a continuous spectrum from greenest to brownest. This new perspective acknowledges the complexity of environmental impacts across different sectors, allows for the possibility of jobs becoming greener over time, and enables more flexible policy approaches to promote sustainability across the entire economy (See Bohnenberger, 2022 and references within). While researchers have been defining this spectrum from different data availability and end use contexts, this paper draws on Bluedorn et al. (2022) and Vandeplas et al. (2022) in defining the green-brown spectrum based on two metrics. The first is pollution intensity, defined as the proportion of total carbon emissions produced by the industry. Intuitively, this is a measure of how damaging the industry is in relation to the rest of the economy. The second metric of interest is emissions intensity, defined as an industry's emissions per worker. Conceptually, this measures the environmental impact of economic activities, particularly in labour-intensive industries, highlighting how efficiently a sector is managing its emissions relative to its workforce.

The history of methods to estimate carbon emissions at an industry level can be traced to early attempts to quantify the costs of climate change. Although some of the assumptions underlying his work have been questioned, Nordhaus is understood to have pioneered this literature by introducing the concept of integrated assessment models (IAMs) (Nordhaus, 1977, 1991, 2019; Hayden, 2021; Masini, 2021). IAMs combine economic and climate systems, allowing for the disaggregation of emissions by sector, which is essential for identifying major contributors to greenhouse gases and developing targeted mitigation strategies. While Nordhaus's work laid the foundation, the field has evolved significantly, with modern IAMs incorporating more sophisticated representations of energy systems and sector-specific technological change, improving the accuracy of sectoral emissions estimates.

The publication of the Stern Review proved to be another key moment in the history of this literature by arguing that the costs of inaction on climate change would be significantly higher than the costs of mitigation (Stern, Common and Barbier, 1994; Stern and Great Britain, 2007). This review led to increased interest in methodologies to estimate carbon emissions at the industry level. Most methodologies to estimate carbon emissions veer towards an energy use accounting framework (IEA, 2021). However, these methodologies are only able to capture the energy use component of carbon emissions neglecting significant sources of carbon emissions. More recent methodologies assess carbon emissions within the consumption and production processes of an economy (Miller and Blair, 2022).

This paper follows these more recent methodologies by utilising EXIOBASE 3 Tables as they include South Africa in their data collection processes as of 2018 (Merciai and Schmidt, 2018; Stadler *et al*., 2018).[6] These tables are derived from a variant of established Input-Output Analysis models: the Multi-Region Input-Output (MRIO) Materials Flows analysis. Input-Output (IO) tables are a quantitative economic tool representing the interconnections between industries within a national economy or different regional economies. The flows of goods and services within an economy are analysed using this tool, illustrating how one industry's output is another industry's input. The Leontief Production approach can then be employed on MRIO tables to estimate the aggregate demand and aggregate supply of a region (Leontief, 1970; Miller and Blair, 2022). More recently, environmental factors (such as estimates of carbon emissions) have been included as production and consumption process inputs within IO tables due to advances in data collection. Therefore, in addition to estimates of aggregate demand and supply, industry carbon emissions can be estimated from the IO tables (UNEP IRP, Australian National Science Agency, and Commonwealth Scientific and Industrial Research Organisation, 2024).

This paper estimates emissions intensity based on industry-level carbon emissions estimates from EXIOBASE 3. Emissions intensity is calculated by dividing the total carbon emissions of the industry by the number of workers employed in that industry and represents the sectoral efficiency in terms of carbon emissions. As this is a per capita measure, more meaningful comparisons can be made between industries with vastly different sized labour forces. Moreover, growth rates in such measures can more accurately capture the progress made by an economy to reduce emissions.

First, emissions intensity per industry is calculated at the national level. Once this is complete, the STP municipal SIC7 5-digit FTE employee data can be combined with the emissions intensity per industry (at a 2-digit level) to derive the estimated total emissions per industry per municipality by multiplying the emissions per FTE employee by the number of FTE employees within that industry and municipality. Total emissions per municipality can

[6] See Davidson et al (2024) for a more detailed review of this literature and the methodology used to derive the EXIOBASE 3 Tables.

thus be calculated after aggregating industry emissions per municipality. Benchmarking of the emissions was conducted against the Emissions Database for Global Atmospheric Research (EDGAR) CO_2 emissions data (Crippa *et al.*, 2024) with a relatively high Pearson's correlation coefficient of 0.6. Lastly, the emissions intensity for each municipality can be calculated by dividing the total estimated emissions by the total FTE employees per municipality.

2.3. The Green Transition Framework

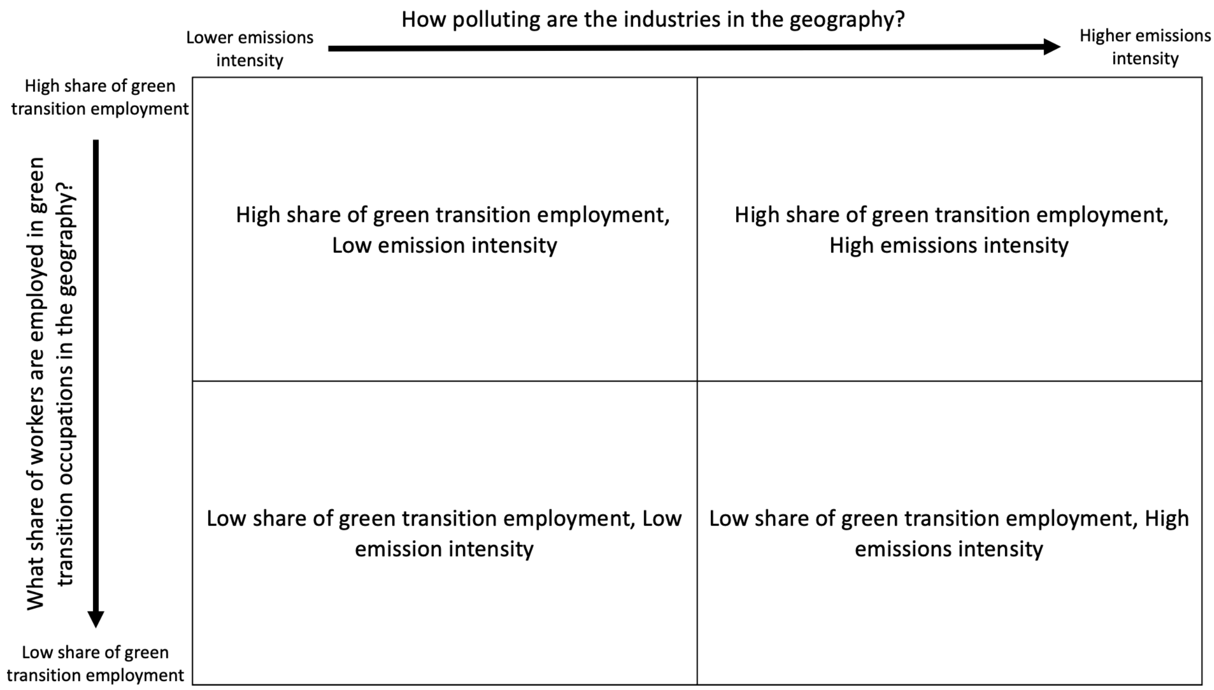
In investigating labour market transitions resulting from the green transition, it is important to consider the occupation in which a worker is employed (and the green nature of that occupation) alongside the emissions that may result from their work. This paper applies the theoretical Green Transition Framework developed by Davidson et al. (2024) to profile geographies with regard to the impact the green transition will have on them. This application makes use of the bottom-up and top-down measures discussed in the above section to better understand the impact of the green transition on provinces and municipalities, thereby gathering a greater understanding of the impact on the people who live and work in these areas.

The Green Transition Framework is presented and analysed in the form of a matrix in which information on green occupations is represented along the vertical axis (bottom-up approach), while the horizontal axis delineates a measure of the polluting nature of industries (top-down approach). By bringing these two dimensions together, we can better assess the extent to which different profiles of workers may be affected by the green transition.

Local context will greatly impact these labour transitions: one aspect here is space or geography with respect to local economies (for instance, coal mining in Mpumalanga), and another is intertemporal local economy sectoral shifts. As a result, this paper considers the geographic distribution of green transition workers, and the brownness of the industries in which they work. We utilise the flexibility of the Green Transition Framework by representing geographic areas (municipality and province) as our unit of analysis. This allows for the profiling of geographies that may benefit from specific types of interventions to support the green transition in South Africa. Moreover, as our central focus is the employment effects of the green transition, this paper uses the proportion of green transition employment on the vertical axis, and the emissions intensity estimated from the top-down approach, along the horizontal axis. Figure 1 specifies the framework matrix for this application.

Figure 1: Understanding the effects of the green transition on the local labour markets

Source: Adapted from Davidson et al. (2024)



In this application of the framework, geographies found in the top right quadrant have high emission intensity as well as a high share of green transition jobs. These would be the highest priority areas considering the high risk of job losses and high potential to shift. Depending on the green transition occupation definition used, this may indicate existing potential (in the case of GID), or a need for training and development to support the transition (GES), or changes already underway (GNE). Each definition will suggest slightly different policy recommendations. Geographies found in the top left quadrant have low emission intensity, and high green transition job shares. These are not necessarily geographies that are at risk of losing jobs due to the green transition, however, they are geographies where green transition job growth can potentially be spearheaded by encouraging further greening of the economy, particularly in cases where these account for a large number of workers, such that interventions would benefit more individuals. Depending on the definition of green transition occupation, different opportunities would be available to support this growth.

The bottom right quadrant contains geographies with high emission intensity and low green job shares. These are geographies that are potentially at higher risk of losing jobs, with no clear greening opportunities. It is important to understand which geographies are located in this quadrant, so that mitigation strategies can be developed. Geographies in the bottom left quadrant are low priority due to potentially having a low risk of transition related job losses and low shares of green transition employment.

2.4. Limitations

An inherent limitation of the study is the potential for measurement error in combining detailed cross-tabulations of occupation, industry and geography, which inevitably leads to small sample sizes and greater sampling variability. This paper makes use of the Quarterly Labour Force Survey (QLFS), a household-based sample survey that gathers labour market data for individuals aged 15 and over in South Africa, which uses a Master Sample derived from the 2011 Census to ensure national, provincial, and metropolitan municipal representativity. There are tens of thousands of potential permutations of industry by occupation categories[7], with most estimates based on fewer than 25 observations[8] per category at the metropolitan municipal and provincial levels. At the national level, only 0.8% of industry-occupation combinations exceed this threshold.[9] It would be ideal to test these results against those derived from other sources of data, however recent worker level occupational information is not available at the municipal level.

In addition, the analysis is limited to workers in the formal sector. The Spatial Tax Panel data covers only formal sector employment, and the application of the O*NET classification system is not suited to the measurement of informal green transition occupations. Given that the green transition will inevitably affect informal employment, this remains an important avenue for future research.

Finally, we do not consider any impact on wage levels or the quality of employment from a green transition. For instance, workers in the coal value chain are bound to earn higher-than-average salaries due to tighter labour market regulations facing these industries. In addition, this paper does not attempt to answer whether the demand for new green jobs will stay ahead or fall behind the total number of jobs lost in heavily polluting industries. This is because it is extremely difficult to predict how workforce demand might change in practice, bearing in mind that the green transition is expected to mutually create and destroy jobs at different intensities, both within and between occupations and industries at the same time.

Considering these limitations, the empirical findings should be treated as suggestive rather than conclusive. They provide an illustrative example of how the Green Transition Framework can be spatialised at the sub-national level.

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[7] There are 448 4-digit occupation codes and 158 3-digit industry codes.

[8] This benchmark is based on the work conducted by Labour Market Intelligence (2022) on the provincial Lists of Occupations in High Demand. Further details can be found in Appendix B.

[9] Appendix B contains further detail on this limitation.

3. Findings

In this section, we analyse the impact of the green transition on jobs at the national level, , provincial and metropolitan municipal levels, and local municipal levels. Four measures are used: emissions intensity (top-down approach) and three green transition occupation categories. Carbon emissions per worker (emissions intensity) are derived from EXIOBASE 3 industry-based carbon emissions data, as discussed in section 2.2. This appears on the horizontal axis of all matrices. The share of jobs in green transition occupations is derived from the bottom-up approach and appears on the vertical axis of all the matrices. As discussed in section 2.1, there are three definitions of green transition occupations: i) Green Increased Demand (GID) ii) Green Enhanced Skills (GES) iii) Green New and Emerging Occupations (GNE).

As noted above, limitations associated with small sample sizes raise concerns regarding potential bias. Consequently, the results below are presented for illustrative purposes to demonstrate how the Green Transition Framework can be spatialised.

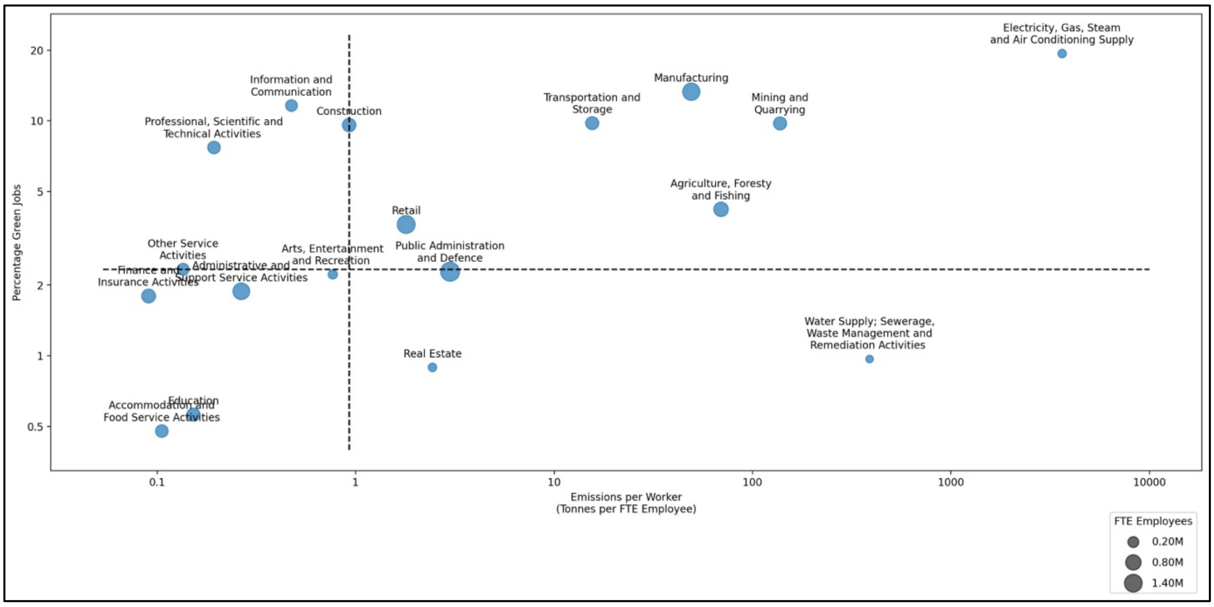
3.1. Impacts of the green transition at the national level

Figures 2, 3 and 4 present the results of applying the framework at a national level per 1-digit industry classification.[10] A clear finding is that workers in Electricity, Gas, Steam and Air Conditioning Supply are at the extremes of the green transition (top right quadrant). This makes sense in that energy production and distribution are binding constraints in the just transition. We estimate that this industry alone accounts for 57% of total emissions, while total employment is small (see Table C1 in the appendix). This means that emissions per worker within Electricity, Gas, Steam and Air Conditioning Supply are exponentially higher (notice the log scale on the horizontal axis) than most other industries – close to ten times greater than the second most heavily polluting industry, Water Supply; Sewerage, Waste Management and Remediation Activities, and more than 1 400 times greater than a middle-ranked industry like Wholesale and Retail Trade. Therefore, reducing emissions per worker is almost impossible without transforming how South Africa produces its energy. Other industries cannot be compared with the same yardstick.

[10] Indicators which are combined in the framework matrix are reported in Tables C1 and C2 of the appendix.

Figure 2: Green Increased Demand jobs and emissions per worker by SIC7 1-digit sector

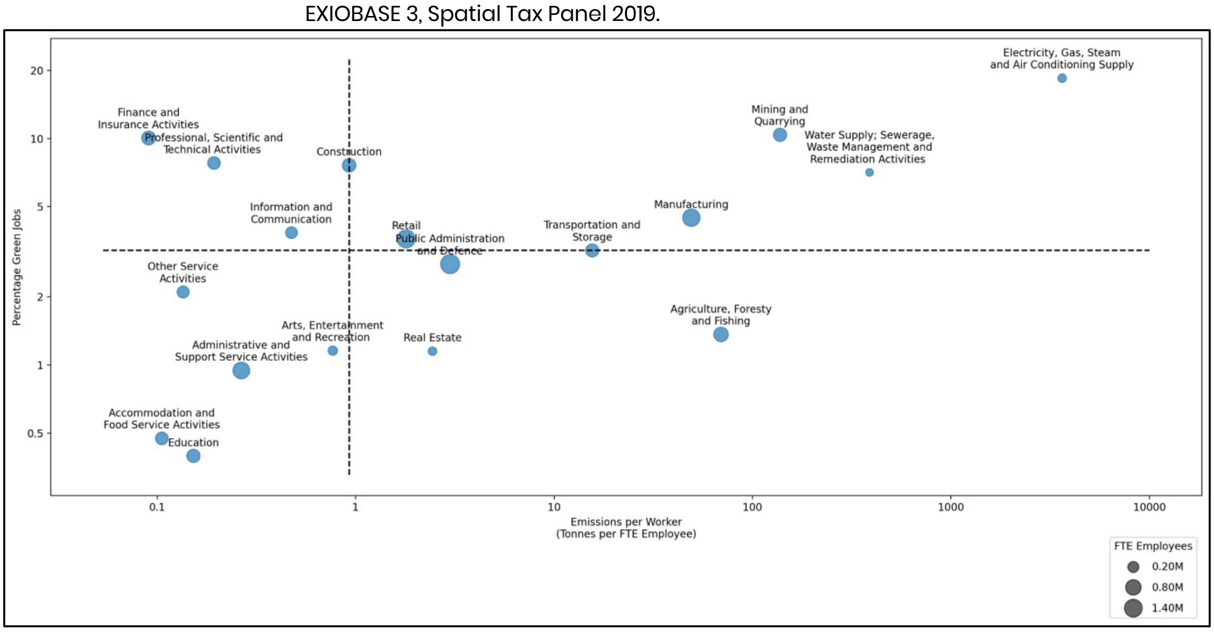
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

Figure 3: Green Enhanced Skills jobs and emissions per worker by SIC7 1-digit sector

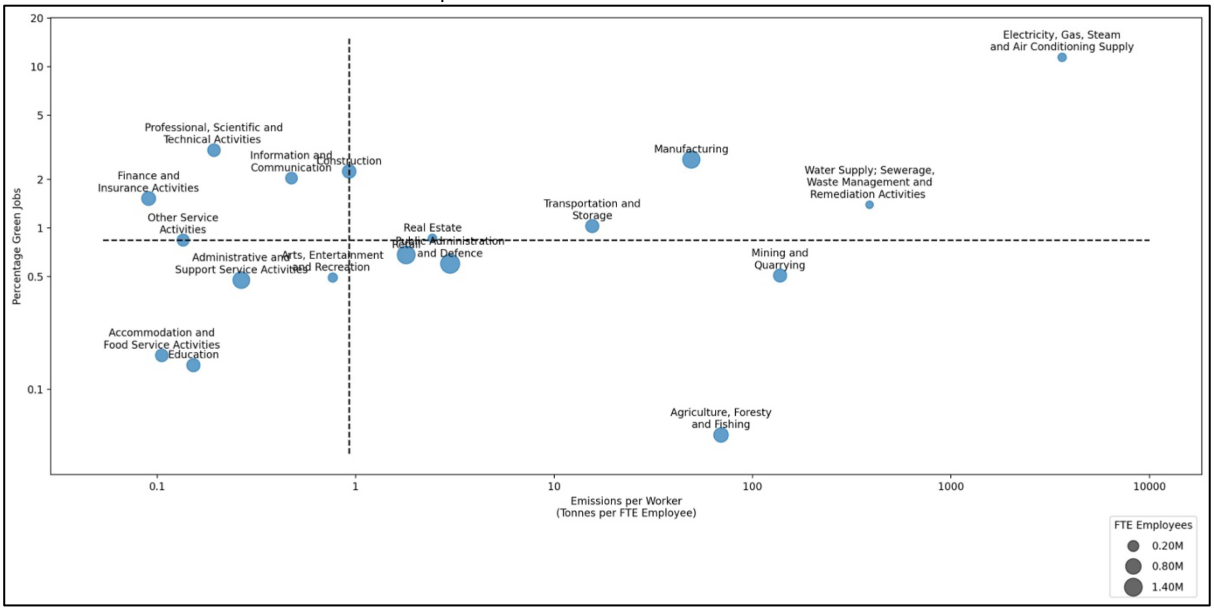
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

Figure 4: Green New and Emerging jobs and emissions per worker by SIC7 1-digit sector

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

At the same time, it is important to note that the energy sector is also responsible for creating many opportunities in green transition occupations. In fact, Electricity, Gas, Steam and Air Conditioning Supply is ranked highest in the share of green transition employment, when using any of the three definitions. In the Electricity, Gas, Steam and Air Conditioning Supply industry, 18.9% of workers are in GID occupations, 10.7% are in GNE occupations, and 17.3% are in GES occupations (see Table C2 in the appendix). In other words, the green transition will disrupt energy-related workers more than any other industry, but the same workers tend to be in occupations where new green skills can also be created or where workers already have skills needed to support the green economy. The application of the Green Transition Framework allows us to bring these more nuanced understandings to the fore.

Mining and Quarrying, Manufacturing, and Transportation and Storage industries are each noteworthy as industries contributing heavily toward pollution (quadrants on the right). Each has above-average emissions per worker compared to the rest of the economy. However, Mining and Quarrying has nearly three times the intensity of emissions per worker compared with Manufacturing, while Manufacturing has more than three times the emissions intensity compared with Transportation and Storage. Mining and Quarrying, and Manufacturing contribute similar levels to total emissions (roughly 13% each) because Manufacturing has a larger total number of workers (approximately 1 270 000) compared with Mining and Quarrying (approximately 420 000).

The framework suggests that each of these industries is at greater risk of job losses from a green transition. Yet, workers in these industries also appear to be potentially better placed to transition to other jobs in the green economy. The share of workers with skills already compatible with a green economy (GID) is roughly 13% for all three industries, which is well above average. In addition, there is scope for retraining of activities in occupations to become green economy relevant (GES), as approximately 10% of the workforce in Mining and Quarrying is employed in GES occupations.

Agriculture, Forestry and Fishing stands out as an industry with higher levels of environmental risk and with less room for mitigation, at least in terms of our framework (bottom right quadrant). Agriculture can cause pollution, for example through the release of methane gas in the farming of livestock or from nitrous oxide in the application of fertiliser in crop production. Farming also tends to cover large areas leading to higher transport costs which raise emissions. The level of emissions per worker for Agriculture, Forestry and Fishing is lower than in Mining and Quarrying but higher than in Manufacturing. The difference is that agricultural workers appear to have a limited share of occupations which are green ready (less than 5% in GID) with not much scope for retraining (less than 1.5% in GES).[11] That said there might be opportunities for green transition conservation activities in rural areas, such as afforestation or the rehabilitation of subtropical thickets, forests, and woodlands, which could mitigate as carbon sinks (see Winkler and Black, 2024).

In addition, industries which have a more promising transition path, because emissions per worker are relatively low and green transition job shares appear relatively high (left hand quadrants), are identified. Such a situation characterises workers in Professional, Scientific and Technical Activities; Information and Communications as well as Financial and Insurance Activities. These industries may be least negatively affected by a green transition, although some occupational task-level retraining may be required.

In summary, the application of the Green Transition Framework at the national level highlights the interplay between emissions intensity and apparent workforce opportunities in the green transition. Industries like Electricity, Gas, Steam and Air Conditioning Supply

[11] The literature provides a mixed picture of the share of green transition jobs in the agriculture, forestry and fishing industry. In the United States, Bowen et al (2018) find that 5% of employment in agriculture forestry and fishing is in GID occupations in the United States, 6% in GES occupations and 0.1% in GNE. According to Bacerra and Piñeros-Ruíz (2024), Colombia sees 14% of GID occupation employment in agriculture, forestry and fishing, 1% in GNE and 2% in GES. Bowen and Handcke (2019) find, in the European Union, that 18% of employment in agriculture, forestry and fishing is in GID occupations, 8% in GES and 8% in GNE. Many factors may contribute to the differences between these results including labour market structure (e.g. in Colombia, agriculture accounts for 19% of total employment and only 5% in South Africa (Statistics South Africa, 2018, 2019; World Bank Open Data, 2025)) and the occupation classification system utilised (e.g. in the United States, the authors can identify green transition occupations in their labour market data at the 8-digit level which is the level that they defined at whereas, our paper is only able to identify occupations at the 4-digit level). This may also be indicative of the existing structure of agriculture in South Africa from an occupational and emissions perspective and the differences that may exist between these and other countries. Further research would be needed to understand the differences.

dominate emissions per worker but also seem to employ many workers who may transition to work in the green economy more easily across all definitions, while Mining and Quarrying and Manufacturing face high emission intensities yet present above-average need for retraining. Conversely, Agriculture, Forestry and Fishing shows limited green economy relevant occupations and retraining potential. Industries like Professional, Scientific and Technical Activities and Information and Communications potentially have a more promising transition path. Understanding the complexities is crucial in navigating the green transition from the perspective of the workforce and how these may influence the local level transition.

3.2. Impacts of the green transition at the local municipal level

An important dimension of the green transition is the uneven geographical spread of energy generation and other types of economic activities, which will inevitably impose a greater burden on different localities and regions. The industry-level results, outlined in the section above, can mask large spatial heterogeneity. This section explores the potential for this spatial heterogeneity at the local municipal level to better understand the potential employment effects of the transition.

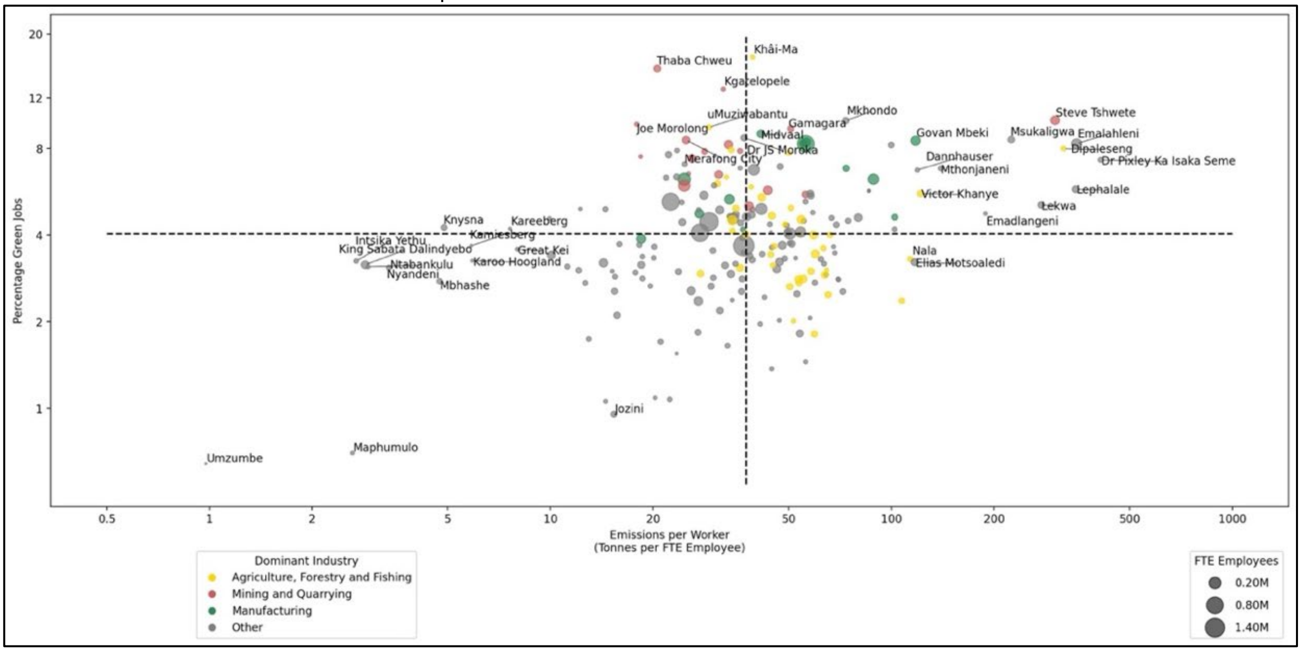
Figures 5, 6 and 7 present the results at a local municipal level.[12] We resize the bubbles (representing municipalities) according to the size of the workforce and colour according to the dominant industry. The dominant industry is the industry employing the largest proportion of the workforce in the municipality.

Local municipalities will face a different set of constraints and possibilities in navigating the green transition, depending on their role in the economy. This has the potential to amplify spatial inequalities. Emissions per worker are highest in the following ten municipalities (quadrants on the right): Dr Pixley Ka Isaka Seme (MP), Emalahleni (MP), Lephalale (LIM), Dipaleseng (MP), Steve Tshwete (MP), Lekwa (MP), Msukaligwa (MP), Emadlangeni (KZN), Mthonjaneni (KZN) and Victor Khanye (MP). The intensity of emissions per worker is as much as nine times higher in Emalahleni and three times higher in Victor Khanye compared with the municipal median level. It is noteworthy that seven of the top ten most intense emitters are municipalities from Mpumalanga where coal mining and coal-fired power plants are concentrated.

[12] A map showing the geographical spread of each of the indicators used in the framework is also presented in figures C1-C4 of the appendix.

Figure 5: Green Increased Demand employment shares and emissions per worker by local municipality

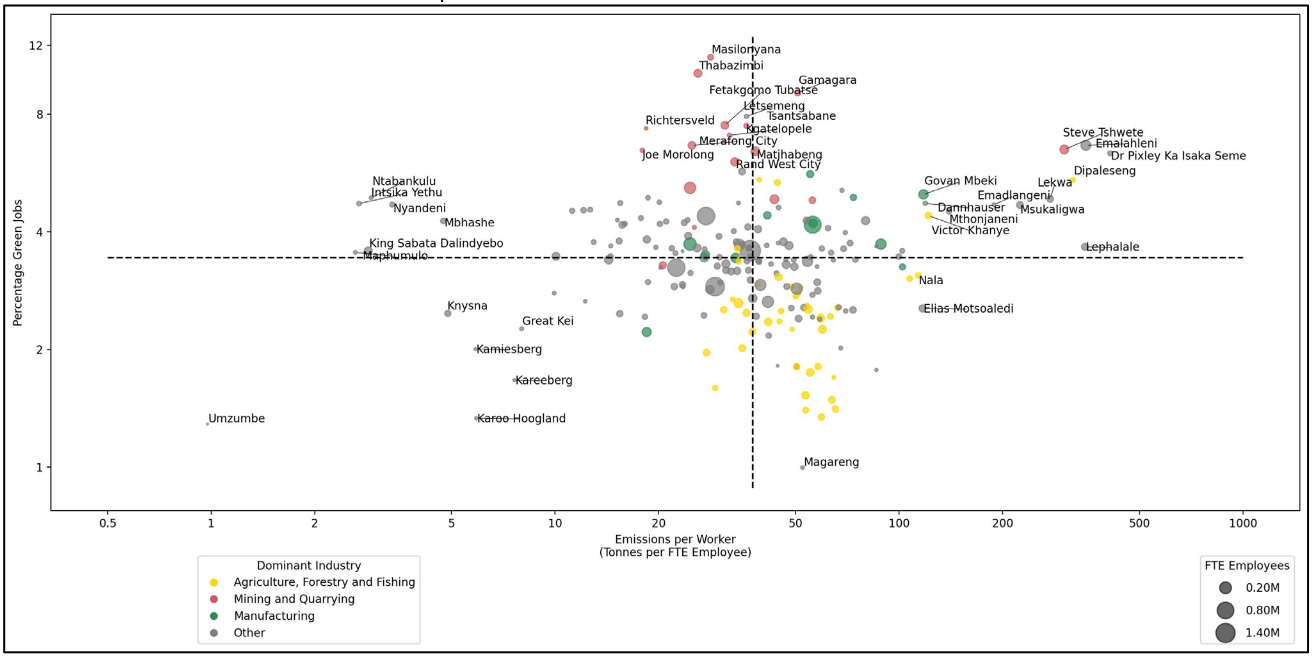
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values

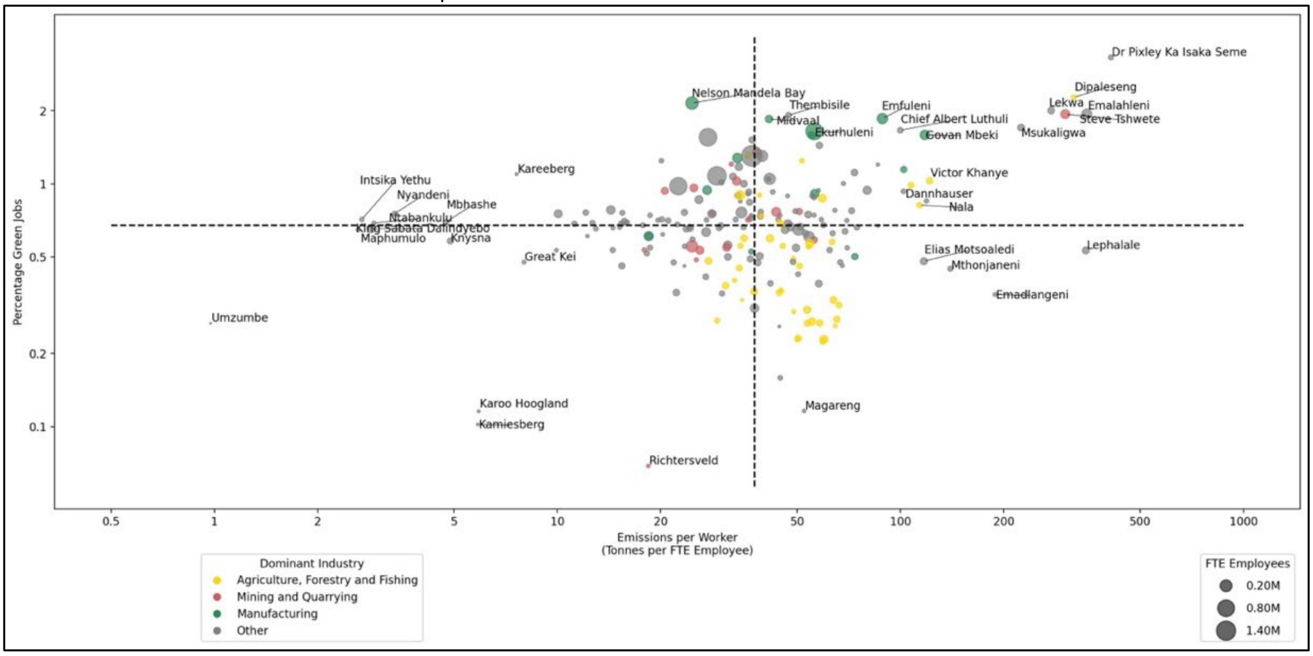
Figure 6: Green Enhanced Skills employment shares and emissions per worker by local municipality

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values

Figure 7: Green New and Emerging employment shares and emissions per worker by local municipality
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

High levels of emissions per worker are closely related to coal-based energy production (see also Figure C5 in the appendix). For instance, the Majuba power station is located in Dr Pixley Ka Isaka Seme; Duvha, Kendal, Kriel and Matla power stations are located in Emalahleni; Medupi and Matimba power stations are located in Lephalale; Komati, Arnot and Hendrina power stations are located in Steve Tshwete; Grootvlei power station is located in Dipaleseng; Tutuka power station is located in Lekwa; Cambden power station is located in Msukaligwa; and Kusile power station is located in Victor Khanye. The exceptions are Mthonjaneni and Emadlangeni in KwaZulu-Natal which are agriculture/mining economies.

Coal power generation usually coincides with upstream mining of coal, although some of these municipalities are involved in other minerals extraction. Another factor driving up emissions per worker is the small size of the formal workforce outside of power generation and mining. For example, Dr Pixley Ka Isaka Seme, Emadlangeni, Mthonjaneni and Dipaleseng all have a total formal workforce of fewer than 8 000 full-time equivalent employees, as reported in the STP. Even though this major industry employs a small number of workers, these places have little else to fall back on beyond their minerals-energy production.

On a more positive note, the top ten municipalities with high emissions per worker also seem to rank favourably in terms of their share of green transition employment (quadrants on top). Between 5% and 10% of workers in these municipalities are estimated to be employed in GID or GES occupations. In other words, there are activities which these workers may already be able to perform, or otherwise could perform with some level of retraining, which are compatible with a green sustainable economy. A significant challenge, however, is that the locations of growth in the green economy may not occur where these workers are living. It is also not clear whether the magnitude of increased demand for green transition occupations would match the level of decreased demand when moving away from brown industries. Moreover, even if workers in brown industries can be re-deployed to green economy activities, the negative shock of reduced demand from brown industries could devastate those businesses in the area sustained by their proximity to those industries.

Another important insight from the figures is that several rural municipalities have higher than average emissions related to their role in agricultural production. To be clear, this is not nearly as extreme as for coal-driven economies, but these municipalities also seem to rank poorly in terms of green transition employment (bottom right quadrant). Agriculture, Forestry and Fishing workers may find it difficult to readily shift into work requiring green-compatible tasks and activities. That said, these workers may not face such high levels of disruption as food products are essential even during a green transition. However, workers employed in different industries may be at greater risk of job loss. This highlights the potentially heightened vulnerability of those municipalities at risk of job losses due to their reliance on heavily polluting industries as well as low percentages of workers with skills relevant to the green economy. It is also important to note that many of these municipalities are outside Mpumalanga, where much of the current just transition policy is focused.

Interestingly, municipalities with a large Mining and Quarrying sector are spread along the spectrum of emissions per worker (both left and right quadrants). Mining economies with below average emissions include Rustenberg, Merafong City, Thabazimbi and Fetakgomo Tubatse. These positive examples tend to be larger settlements where there is scope for diversification beyond mining even if into locally traded goods and services. In fact, South African mining towns on the platinum belt may benefit from the green transition because of the strategic importance of platinum in the production of catalytic converters and green hydrogen. The connection between mining and coal power production greatly elevates emissions such as in the case of Steve Tshwete municipality.

The framework can also be used to identify municipalities that appear to rank favourably in terms of readiness for a green transition and have low emissions per worker (left hand quadrants). The top ten lowest emitters identified in the data include Umzumbe (KZN), Maphumulo (KZN), Intsika Yethu (EC), King Sabata Dalindyebo (EC), Ntabankulu (EC), Nyandeni (EC), Mbhashe (EC), Knysna (WC), Kamiesberg (NC) and Karoo Hoogland (NC). Most of these examples are a result of very small formal economies which mostly supply government-related services with fewer than 5 000 full-time equivalent employees, as reported in the STP. However, a few are also actively involved in green energy supply with small hydro-electric power plants located in Intsika Yethu, King Sabata Dalindyebo and

Nyandeni. In addition, King Sabata Dalindyebo and Kynsna are relatively large economies featuring some measure of tourism. Interestingly, these ten lowest emitting municipalities do not seem to show above-average shares of green transition employment reflecting small absolute numbers of green transition occupation workers.

3.3. Impacts of the green transition at the provincial and metropolitan municipal level

This section explores how the green transition might impact provinces and metropolitan municipalities. For brevity, we report and discuss only one definition of green transition occupations, Green Enhanced Skill (GES) occupations, alongside emissions per worker. The figures for Green Increased Demand (GID) and Green New and Emerging (GNE) occupations are provided in Appendix C and point in the same direction as the GES results.

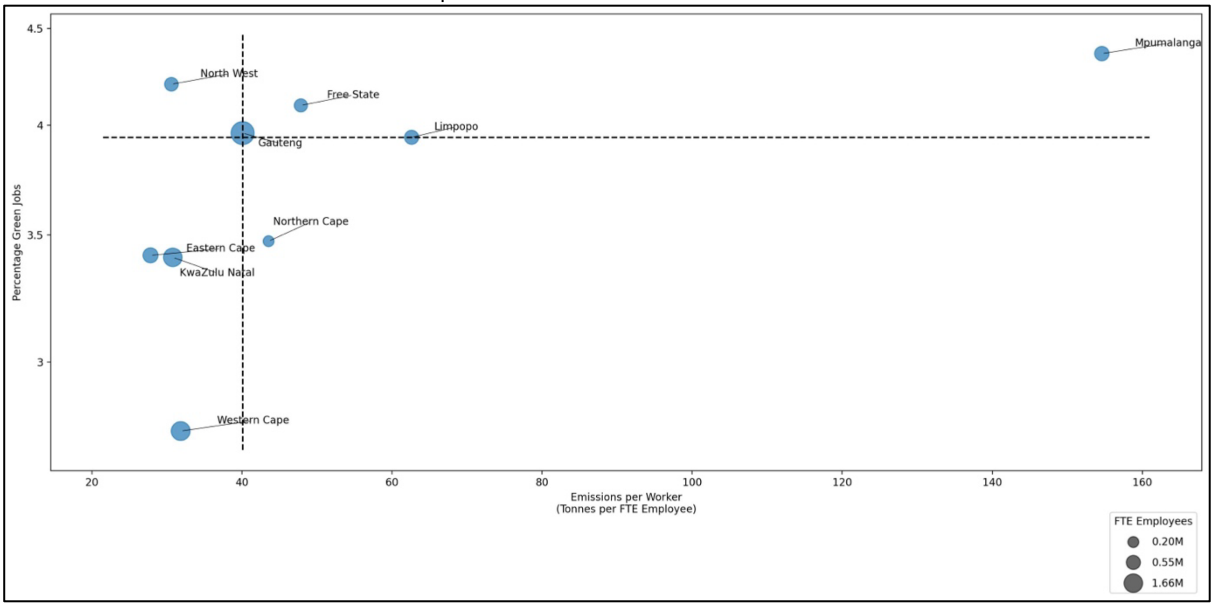
Figure 9 applies the framework to the level of provinces. It is immediately striking how much higher Mpumalanga scores in terms of emissions per worker compared to other provinces. We estimate that Mpumalanga produces more than three and a half times the median level of emissions per worker, 40 tonnes per FTE employee. Gauteng emits the median level of emissions per worker. Limpopo is next in line at one and a half times the median level. In contrast, the Western Cape, KwaZulu-Natal, North West and the Eastern Cape have more favourable emissions levels than other provinces. While these differences are not as extreme as at the local municipal level, the distribution is skewed considerably by Mpumalanga. This makes sense as Mpumalanga is responsible for the bulk of coal-based power production which is also evidenced in the analysis of local municipalities.

When combined with the estimated need for upskilling, as the GES employment shares reflect, Mpumalanga is located in the top right quadrant. This is followed closely by the North West province (top left quadrant), although the North West does not face the same pressures in terms of the intensity of emissions. It is interesting that the Western Cape and, to a lesser extent, KwaZulu-Natal and the Eastern Cape feature as low emitters but with lower-than-average relative shares of GES employment.

What is not apparent in this application of the framework is the role of workforce size in influencing the absolute size of emissions or workers in green transition occupations. This is because emissions and employment in green transition occupations have been converted into relative measures (against the size of the workforce) in order to make meaningful comparisons. While this is intentional, it is important to understand that Gauteng is responsible for 35% of total carbon emissions which is higher than Mpumalanga at 21%. Similarly, as many as 42% of all modelled employment in occupations identified for green retraining (GES) is located in Gauteng, followed by 15% in KwaZulu-Natal. The largest provinces will always be important in contributing to total levels, even if relative levels of emissions per worker or the share of employment in green transition occupations are not particularly high.

Figure 9: Green Enhanced Skills employment shares and emissions per worker by province

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

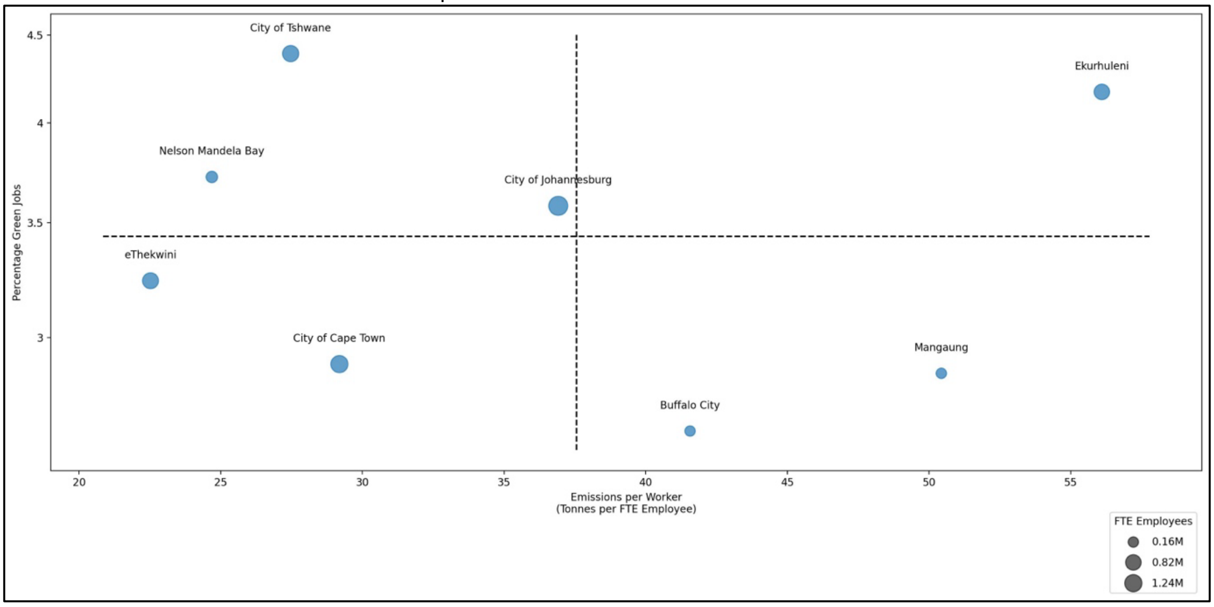


Notes: Dashed lines indicate median values. See figures C6 and C7 in the appendix for the application of GID and GNE definitions.

This leads to a discussion of the role of metropolitan municipalities in the green transition. The size of the metropolitan municipalities means that they are significant levers for influencing total emissions as well as employing a greater number of workers in green transition occupations. In fact, Johannesburg, Ekurhuleni and Cape Town produce the most absolute volume of CO_2 of all municipalities, together accounting for 33% of total emissions, although not in terms of emissions per worker. The estimated number of workers in green transition occupations is also heavily concentrated in the metropolitan municipalities, with the top ranked metropolitan municipalities, Johannesburg, Tshwane and Cape Town, accounting for 44% of all employment in GES occupations. These absolute concentrations warrant a strategic focus, notwithstanding that the metropolitan municipalities do not stand out in terms of their relative levels (see section above). To be clear, most of the metropolitan municipalities are below average in their intensity of per worker emissions, which aligns with the international literature, but the concentration of workers and industry causes a high volume of pollution. This is not necessarily a problem and could even be an opportunity to lower emissions in cities further because workers are easier to reach. The relative contributions and ranking of metros should also be tested against alternative data sources in light of sampling constraints inherent within our data.

Figure 10: Green Enhanced Skills employment shares and emissions per worker by metropolitan municipalities

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values. See figures C8 and C9 in the appendix for the application of GID and GNE definitions.

It is important to emphasise that we should not treat all metropolitan municipalities the same. Moving back to the framework, ranking metros according to the relative size of their workforce reveals some important distinctions (see Figure 10). The relative level of emissions varies significantly across the metropolitan municipalities, with Johannesburg situated in the middle, Ekurhuleni at one and a half times the Johannesburg level, and eThekwini at about half the Johannesburg level. This means that Ekurhuleni produces two and a half times the emissions per worker compared with eThekwini, when looking at either end of the spectrum. Heavier emissions per worker in Ekurhuleni are understandable in light of its focus on heavy industry and airport logistics. But this focus may have led to higher shares of workers in green transition occupations in Ekurhuleni as these occupations are dominated by the types of technical and physical skills required in those industries. We estimate that about 4% of workers in Ekurhuleni are in occupations which could be retrained in readiness for a green transition (GES). There is less variation in the share of workers in green transition occupations which falls between 2 and 4% in all metropolitan municipalities.

In summary, the distinctive character of the local economy of each metropolitan municipality implies that the local workforce will face different risks, as well as opportunities, in navigating the green transition. These are noticeable, particularly in terms of emissions per worker. In practice, further research and consultation are required to appreciate the options and steps to reduce emissions while mitigating employment losses.

4. Discussion and conclusions

The transition to a greener economy is expected to lead to fundamental shifts in employment patterns. As economies move towards more sustainable practices, significant changes in job structures and industries are expected to take place, creating both challenges and opportunities for businesses and workers. It is therefore essential to understand both the magnitude and direction of these employment shifts to effectively plan and prepare for the transition, notwithstanding limitations in the application of the available data. A better understanding of how various industries will be impacted would allow policymakers, businesses, and employees to plan and mitigate potential negative outcomes. While this study does not provide a robust estimation of the net impact of the green transition on overall employment or its equity implications based on employee characteristics, we provide a potential methodology for analysing the transition's localised effects to provide more granular insights into the potential economic consequences.

In this paper, we utilise Davidson et al.'s (2024) Green Transition Framework which proposes combining top-down and bottom-up approaches to estimating green or brown employment. This balanced approach helps us to assess the scope of the transition's impact on employment in a more nuanced manner. This paper uses O*NET's definitions of green transition occupations and CO_2 per worker (emissions intensity). The green transition occupations provide three potential effects of the green transition on a worker based on their occupation, which can be analysed alongside the potential effect based on the industry a worker is employed.

In South Africa, as in many other countries grappling with the coal exit, the Just Transition is expected to have highly localised effects. Given the regional variations in industry concentration, a spatialised analysis of the impact of the green transition is necessary to understand how different areas may be affected. In this paper, we apply data from the Spatial Tax Panel to operationalise the Green Transition Framework. This allows us to analyse the share of workers in green transition occupations and emissions intensity of industries, respectively, per geographic area (municipalities and provinces), to understand the potential implications of the green transition on these geographies.

Given that South Africa's energy mix is predominantly coal-based, we find that the Electricity, Gas, Steam and Air Conditioning Supply industry has the highest intensity of CO_2 emissions per worker. However, the workers in this industry may benefit from employment opportunities in an emerging green economy. The Mining and Quarrying, and Manufacturing industries see relatively high emissions intensity, while also employing a high share of workers who would have relevant skills for the green economy with some additional training (GES occupations). These findings suggest that while the green transition may lead to job losses in these relatively high-emitting industries, the workers employed in them may have skills potentially relevant to the green economy, allowing them to more easily take up roles in a greener economy. The Agriculture, Forestry and Fishing industry is responsible for relatively higher emissions intensity, however the industry appears to employ relatively small shares of green transition occupation workers. The Professional, Scientific and Technical Activities, and Information and Communications industries may have a brighter transition path as they have lower emissions intensities and high estimated shares of employment in green transition occupations. This may suggest that these industries are less at risk of job losses as a result of the green transition and employ workers with green economy relevant skills.

Examining the localisation of the transition's impact, we find – not surprisingly – that the Mpumalanga province and its municipalities are among the highest emitters in the country. Seven out of the ten municipalities with the highest emissions are in Mpumalanga. However, the estimated task composition of jobs in the province may mean the workers hold substantial potential for moving into employment in the green economy. Although there is a risk that green economy opportunities may not fully materialise, it is important to note that Mpumalanga municipalities hold the greatest shares of workers with the potential to take up green economy opportunities. These areas have the highest concentration of workers in high-emitting industries and seem to have the most substantial potential for transition to green jobs.

However, more concerning findings of our analysis pertain to municipalities where employment is vulnerable to the green transition and where the potential for workers to leverage green economy growth seems limited. While efforts are underway to diversify the economy, support local governments in anticipating changes, and the implementation of skilling programs, these initiatives are largely concentrated in Mpumalanga municipalities, leaving other vulnerable areas at risk of being overlooked. The Just Transition efforts in South Africa, particularly those related to the energy sector, are heavily concentrated in Mpumalanga. A notable example of this focus is the "just" dimension outlined in the Just Energy Transition (JET) Implementation Plan, which is almost exclusively directed at Mpumalanga. Our findings suggest the need to reevaluate the geographic scope and focus of efforts that are aimed at preparing the labour force for the transition. Many of the municipalities in the bottom right quadrant (i.e. those with low estimated shares of green transition employment and high shares of employment in emissions intense industries) face high levels of deprivation, with more than 50% of the population living in income poverty and an average official unemployment rate of 27% (Statistics South Africa, 2015). This suggests that failure to broaden this scope may increase spatial inequality as well as exacerbate socio-economic disparities, particularly given that municipalities within the coal belt are not among the most impoverished in the country.

Municipalities have also been identified with low emissions where there are high estimated concentrations of green transition employment, whether existing, emerging or requiring support. These municipalities may be important for localising national industrial strategies and identifying where there may be opportunities for the development of new more localised industrial policies that can encourage green job development, creating specialist value chains around existing potential. The platinum and hydrogen value chains stand out along the platinum mining belt.

We should, however, note several key limitations to the analysis presented. Firstly, the results should be interpreted as an illustrative example of how the Green Transition Framework can be spatialised to sub-national levels. We have flagged small sample bias concerns in the survey data that have to be used. In addition, the analysis only captures the formal sector because this is the coverage of the tax data that is used. Ideally, the ranking of highest and lowest emitters alongside green transition employment should be tested with other sources of data to establish that these results are not due to small samples and measurement error. More recent worker level occupational information at the municipal level for South Africa is required to test these results. Then, the analysis is static in the sense that it does not capture elements that may have important implications for green economy labour market transitions, such as wage, job quality and employment demand changes. It is possible to undertake such dynamic modelling. But such exercises require confidence in the base data for them to be reliable.

Limitations aside, our analysis points to important questions that should be asked around current transition policy. It highlights both industries most at risk of disruption and potential new opportunities. To capitalise on this potential, substantial efforts will be required in terms of upskilling and reskilling the workforce, but the question of who should take responsibility for investing in these skills development initiatives currently remains unresolved. The JET-IP recommends the establishment of a Skills Development Zone focused on renewable energy in Mpumalanga, which aligns with our analysis and suggests a promising way forward. However, our analysis highlights questions around the prudence of too large a focus on one geographic region in the absence of a national framing. This may leave many other vulnerable groups around the country to weather the potential negative impact of the green transition without equally needed assistance and, potentially, narrows the consideration of new employment opportunities across the country.

This is not to deny that, while the green transition may present substantial opportunities for job creation in South Africa, targeted, inclusive, and region-specific policies are essential. These policies must be designed to mitigate the risks associated with the green transition but should also aim to maximise the benefits, ensuring that vulnerable areas and industries are adequately supported to make the shift toward a greener economy.

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Appendix A: Head Office Effect improvement to Spatial Tax Panel

One limitation of the Spatial Tax Panel is the presence of the 'head office' effect for some firms that may report all their employees' place of work at a head office. This has always been difficult to both identify and quantify. A new approach has been developed that uses the home address of each employee per establishment to quantify what percentage of employees are living in a different municipality or more than a municipality away from where they work. After conducting detailed analysis assessing both sectoral trends (particularly where there is dominance of a few firms) and those of the largest establishments, a simplified rule-based system to reallocate employees that suffer from 'head office' effects was developed. The simplified system reallocates employees at establishments with more than 1 000 FTE jobs if at least 50% of employees work more than a municipality away from where they live. Establishments with more than 50 FTE jobs (but fewer than 1 000) are reallocated if at least 75% of employees work more than a municipality away.

We estimate that 12.8% of all FTE employees suffer from the 'head office' effect in the STP and we reallocate these employees to their home address municipalities. While not perfect, this is a better approximation of the spatial distribution of formal employment and is essential in modelling the job impacts related to a green transition.

Appendix B: Small Sample Bias Concerns

The Quarterly Labour Force Survey (QLFS) is a household-based sample survey that aims to collect data on the labour market activity of people 15 years and over in South Africa. Since 2015, all Statistics South Africa household sample surveys employ the 2013 Master Sample based on the 2011 Census to create a household sample representative at the national, provincial and metropolitan municipality levels. The Master Sample includes 3 324 primary sampling units (PSU) that produce an expected sample of approximately 33 000 dwelling units. The Master Sample is divided into four 'rotation groups' designed to have the same distribution patterns as the sample as a whole. Each rotation group is numbered one to four which corresponds to the quarters of the year in which the sample will be rotated for that group.

The bottom-up approach detailed in section 2.1. relies on provincial and metropolitan municipal estimates of green transition employment, derived from QLFS data. However, the reliability of these estimates is constrained by small sample sizes. Disaggregation by both 3-digit industry and 4-digit occupation, as well as by geographic area, produces small samples. As shown in Table B1, almost all employment estimates by both industry and occupation in each geographic area are based on sample sizes smaller than 25 observations. The benchmark of 25 observations is based on the work of the *Labour Market Intelligence Programme of the Department of Higher Education and Training* (DHET) to identify *Occupations in High Demand* at the provincial level. As part of their process to establish a list of the Provincial Occupations in High Demand, they use occupation data from the QLFS to estimate measures of employment pressure for 3-digit occupations. They remove all 3-digit occupations with fewer than 25 observations (Labour Market Intelligence, 2022).

Table B1: Overview of sample sizes of employment estimates by 3-digit industry and 4-digit occupation

	Percentage of sample sizes under 25 observations	Percentage of sample sizes that are zero
Province		
Eastern Cape	99.91%	97.60%
Free State	99.92%	98.18%
Gauteng	99.09%	93.48%
Mpumalanga	99.26%	98.02%
Western Cape	99.84%	96.17%
North West	99.92%	98.32%
Limpopo	99.42%	98.25%
Kwa-Zulu Natal	99.83%	96.68%
Metropolitan municipality		
Cape Town	99.89%	96.88%
Ekurhuleni	99.92%	96.69%
eThekwini	99.91%	97.71%

Johannesburg	99.88%	96.75%
Nelson Mandela	99.99%	98.69%
Tshwane	99.93%	97.23%
Buffalo City	99.99%	99.13%
Mangaung	99.98%	99.05%

Note: the denominator here represents the number of industry-occupation combinations available in the data i.e. there are 387 4-digit occupations and 157 3-digit industries in the pooled 2018 2019 QLFS data.

At the national level, small sample size limitations persist when disaggregating by industry and occupation. Only 564 industry-occupation groups have sample sizes larger than the 25-observation threshold, accounting for only 0.8% of all possible combinations. The primary factor leading to these small sample sizes is the relatively few observations in the sample compared to a large number of industry-occupation permutations: there are 103 176 individuals[13] in the overall national sample, as well as 158 3-digit industries and 448 4-digit occupations.

This issue presents a challenge for researchers examining disaggregation of employment by detailed industry and occupation codes. While increasing the sample size of the QLFS could offer a solution to reach at least 25 observations per industry-occupation combination at the national level, Statistics South Africa would need to survey 1 769 000 employed individuals. The United States captures this type of data through the *Occupational Employment and Wage Statistics* (OEWS) survey. The OEWS survey gathers data from approximately 1 100 000 establishments, providing comprehensive labour market insights across industries and occupations. Its sample is drawn from state unemployment insurance information and stratified by metropolitan and nonmetropolitan areas, ensuring representativity at these levels (Bureau of Labor Statistics, 2024). Firm level surveys explicitly incorporate industry representation into sample selection, resulting in larger, more reliable datasets that may improve employment estimates. Statistics South Africa does produce employment figures based on data from a firm-level survey, the Quarterly Employment Statistics, however this data lacks the same level of occupational detail found in the QLFS and is only provided as aggregated rather than unit level data. Strengthening its scope could improve labour market analysis and data accuracy.

[13] For the purposes of this paper, it was necessary to restrict the sample to formal sector workers only as the Spatial Tax Panel is restricted to formal workers only. This was done to ensure that the green transition shares calculated using the QLFS could be used to estimate the number of full-time equivalent employees in the Spatial Tax Panel. However, this does not reduce the sample a great deal as 72% of the employed individuals surveyed report working in the formal sector in the pooled 2018 2019 dataset.

Appendix C

Table C1: Emissions, aggregated to 1-digit industry, 2018/19
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

Industry	Total CO2 Emissions (Million Tonnes)	Share of Total Emissions (%)	Total FTE Employment	CO2 Emissions per worker
Electricity, Gas, Steam and Air Conditioning Supply	264.40	57.19	72 814	3 631.10
Water Supply; Sewerage, Waste Management and Remediation Activities	18.37	3.97	47 249	388.90
Mining and Quarrying	57.72	12.49	419 184	137.71
Agriculture, Forestry and Fishing	43.44	9.40	625 863	69.41
Manufacturing	62.44	13.51	1 270 408	49.15
Transportation and Storage	6.42	1.39	412 632	15.57
Public Administration and Defence	5.52	1.19	1 845 285	2.99
Real Estate	0.18	0.04	73 578	2.44
Wholesale and Retail Trade	2.63	0.57	1 465 181	1.80
Construction	0.44	0.10	474 942	0.93
Arts, Entertainment and Recreation	0.08	0.02	104 336	0.77
Information and Communication	0.13	0.03	265 427	0.48
Administrative and Support Service Activities	0.29	0.06	1 101 773	0.27
Professional, Scientific and Technical Activities	0.07	0.01	353 274	0.19
Education	0.06	0.01	425 626	0.15
Other Service Activities	0.04	0.01	289 564	0.14
Accommodation and Food Service Activities	0.04	0.01	359 774	0.11
Financial and Insurance Activities	0.05	0.01	512 583	0.09
Human Health and Social Work Activities	0.00	0.00	323 065	0.00

Table C2: Green transition employment aggregated to 1-digit industries, 2018/19

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

		Green Enhanced Skills jobs		Green Increased Demand jobs		Green New and Emerging jobs	
Industry	**Total FTE Employment**	**% within each industry**	**% of total**	**% within each industry**	**% of total**	**% within each industry**	**% of total**
Electricity, Gas, Steam and Air Conditioning Supply	72 814	17.3	3.2	18.9	2.6	10.7	6.6
Mining and Quarrying	419 184	10.4	11.1	9.7	7.5	0.5	1.9
Financial and Insurance Activities	512 583	9.8	12.9	1.9	1.8	1.5	6.5
Construction	474 942	7.7	9.4	9.6	8.5	2.3	9.1
Water Supply; Sewerage, Waste Management and Remediation Activities	47 249	7.7	0.9	1.0	0.1	1.5	0.6
Professional, Scientific and Technical Activities	353 274	7.6	6.9	7.3	4.8	3.1	9.3
Manufacturing	1 270 408	4.5	14.5	13.5	31.8	2.8	29.7
Information and Communication	265 427	3.9	2.7	11.3	5.6	2.1	4.6
Wholesale and Retail Trade	1 465 181	3.7	13.8	3.5	9.7	0.7	9.0
Transportation and Storage	412 632	3.2	3.4	9.9	7.6	1.1	3.8
Public Administration and Defence	1 845 285	2.7	12.8	2.3	8.0	0.6	9.1
Other Service Activities	289 564	2.2	1.6	2.3	1.2	0.9	2.1
Agriculture, Forestry and Fishing	625 863	1.4	2.2	4.3	5.0	0.1	0.3
Real Estate	73 578	1.2	0.2	0.9	0.1	0.9	0.6
Arts, Entertainment and Recreation	104 336	1.1	0.3	2.0	0.4	0.5	0.5
Administrative and Support Service Activities	1 101 773	1.0	2.8	2.0	4.1	0.5	4.7
Accommodation and Food Service Activities	359 774	0.5	0.5	0.5	0.3	0.2	0.5
Human Health and Social Work Activities	323 065	0.4	0.4	0.7	0.4	0.2	0.5
Education	425 626	0.4	0.5	0.5	0.4	0.2	0.6

Figure C1: Total CO2 emissions and emissions per worker by municipality

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

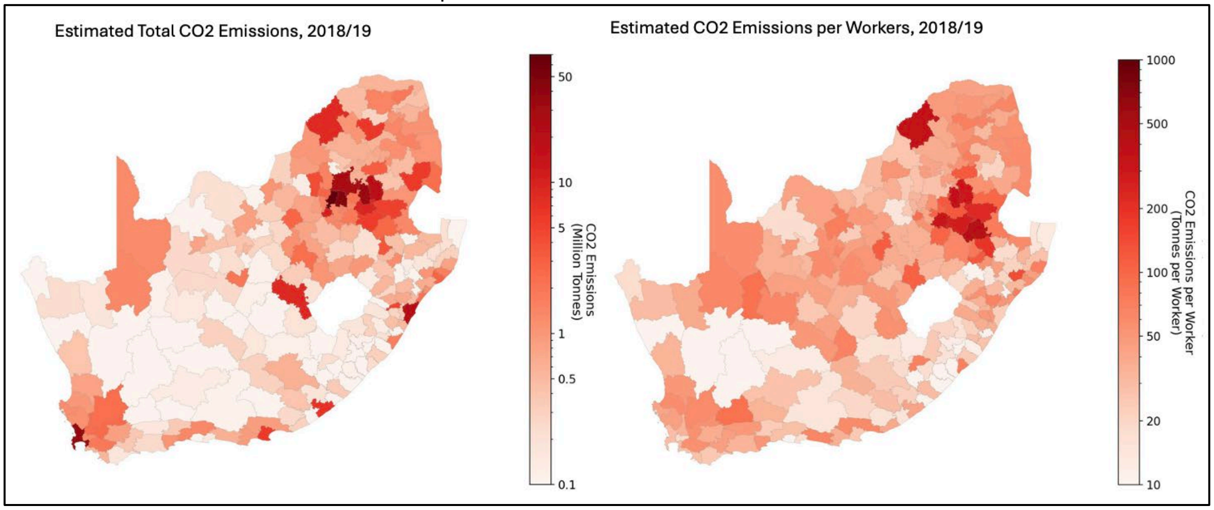


Figure C2: Green Increased Demand employment by municipality

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

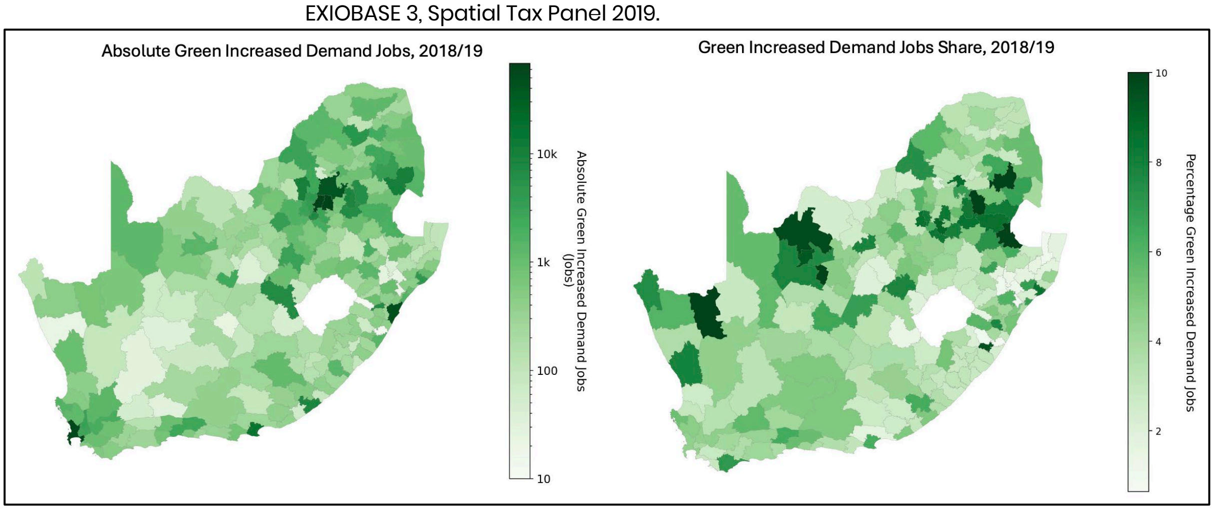


Figure C3: Green Enhanced Skills employment by municipality
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

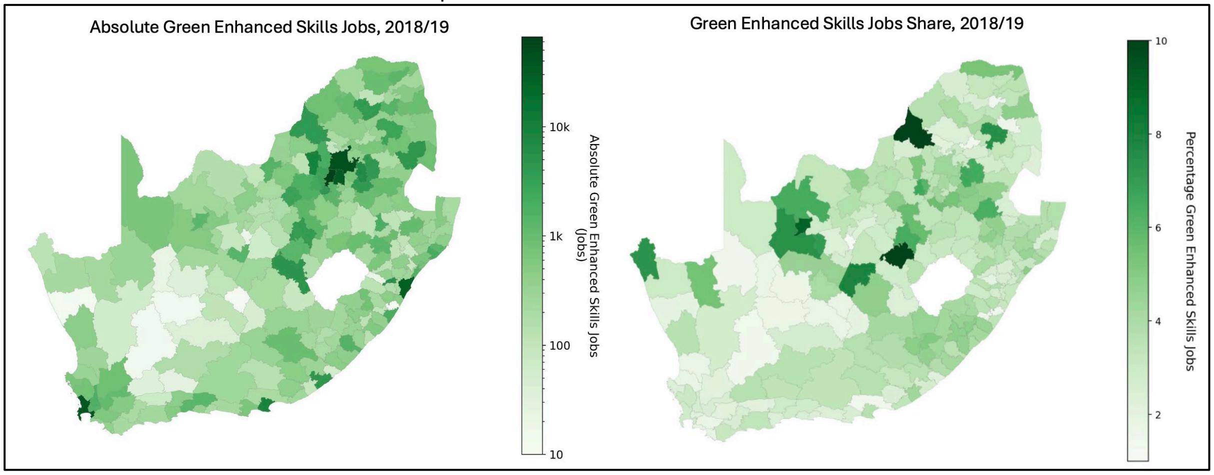


Figure C4: Green New and Emerging employment by municipality
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.

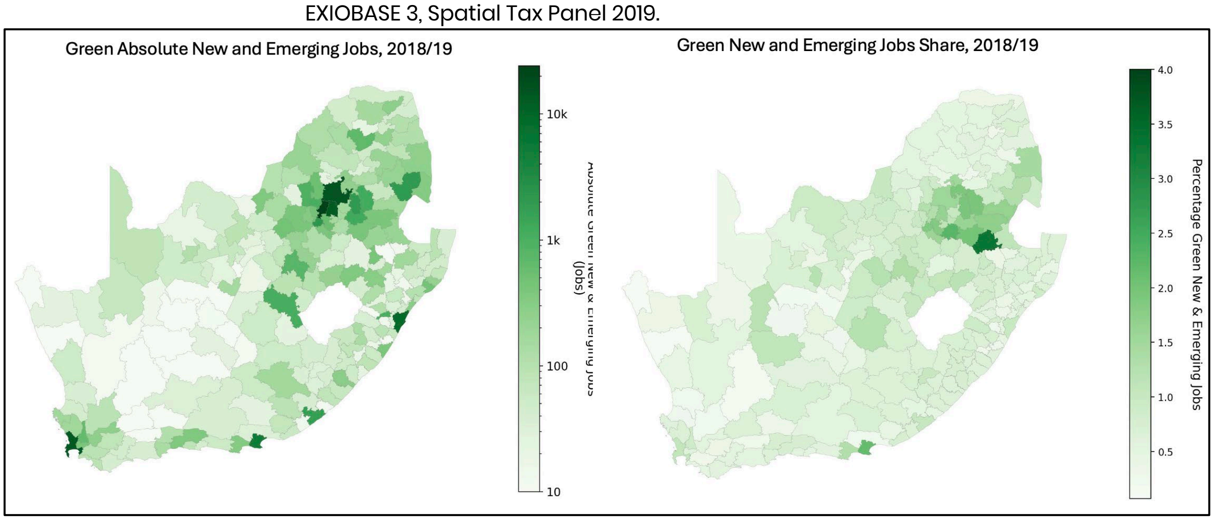
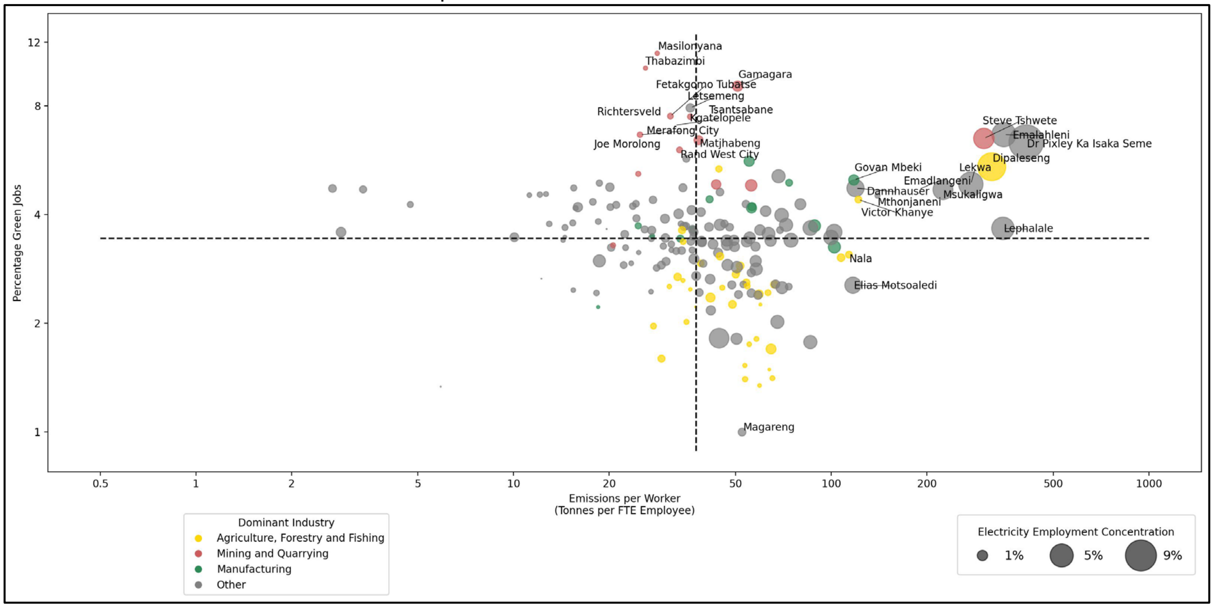


Figure C5: Green Enhanced Skills employment shares and emissions per worker by local municipality

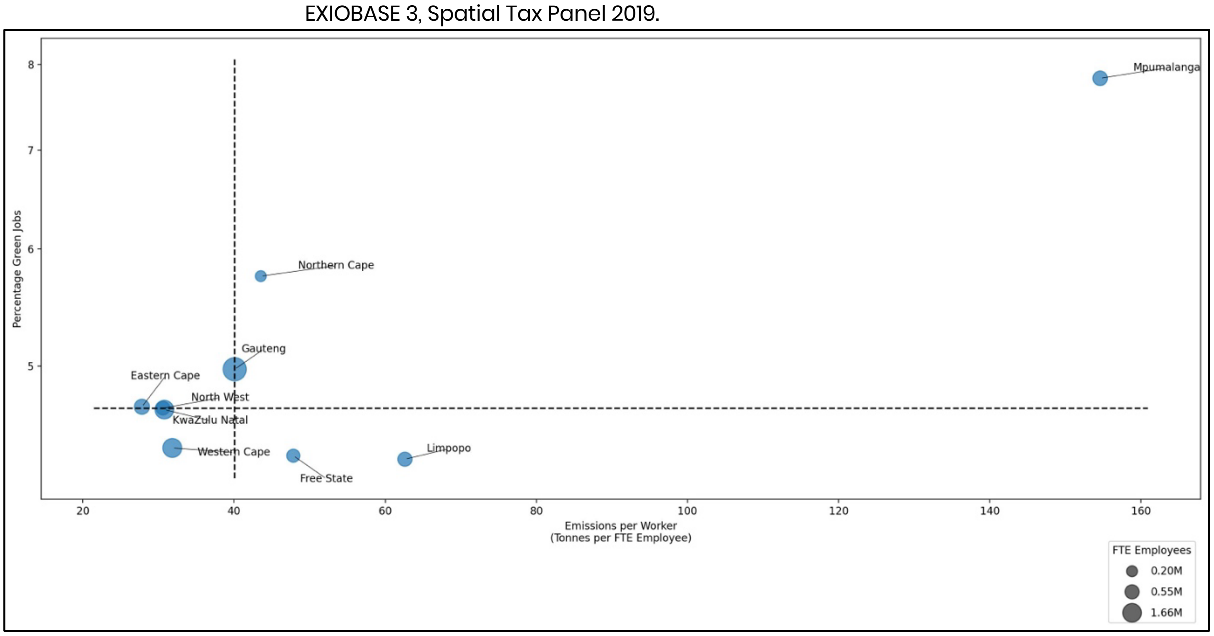
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values. The size of the bubbles represents the concentration of employment in the Electricity, Gas, Steam and Air Conditioning Supply industry.

Figure C6: Green Increased Demand employment shares and emissions per worker by province

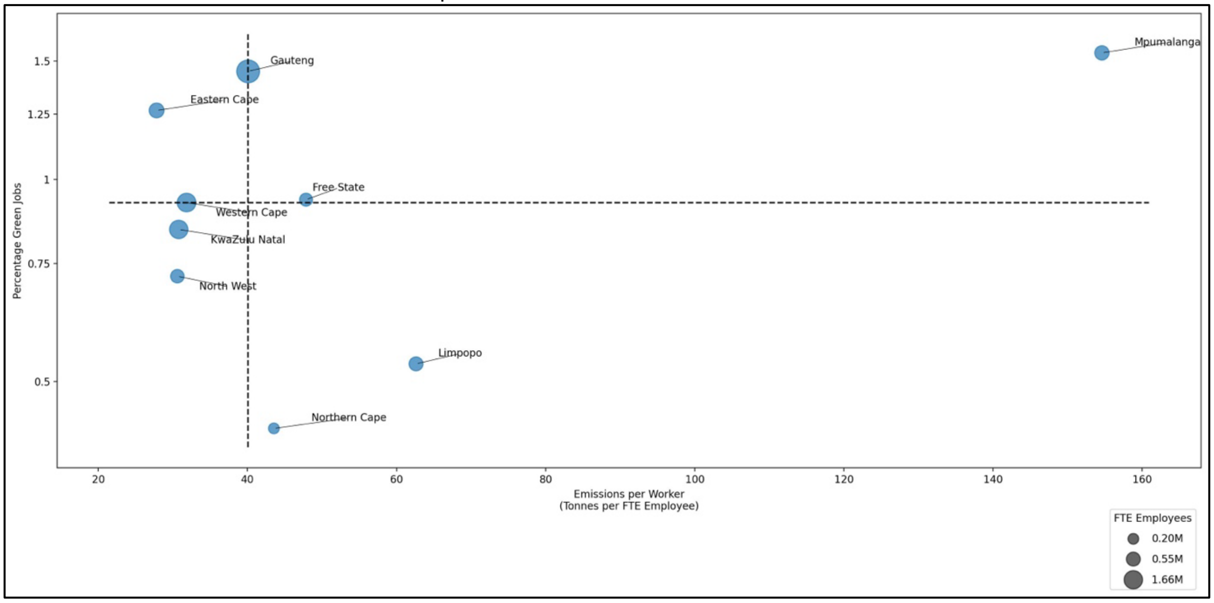
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

Figure C7: Green New and Emerging employment shares and emissions per worker by province

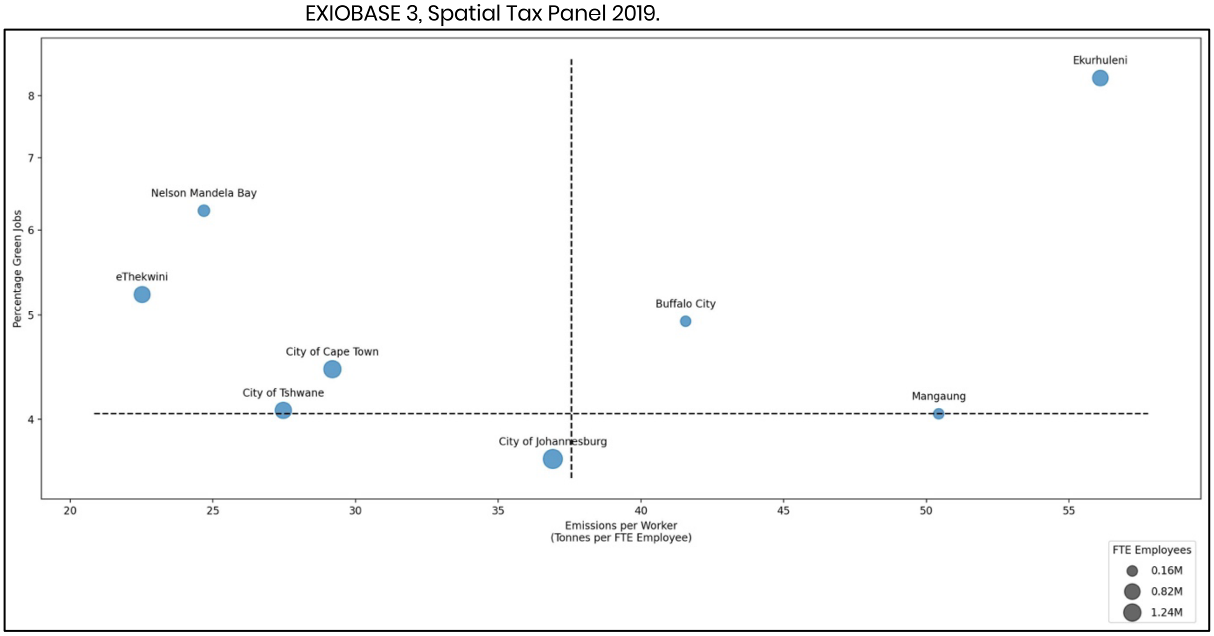
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

Figure C8: Green Increased Demand employment shares and emissions per worker by metropolitan municipality

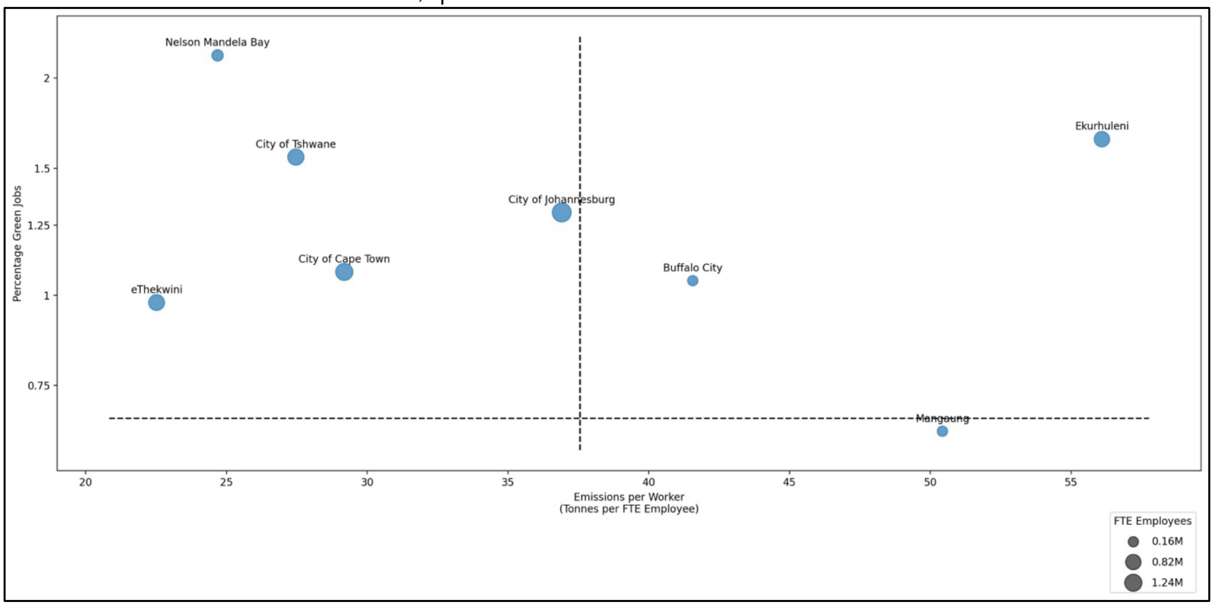
Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

Figure C9: Green New and Emerging employment shares and emissions per worker by metropolitan municipality

Source: Own calculations using Labour Market Dynamics 2018-2019, EXIOBASE 3, Spatial Tax Panel 2019.



Notes: Dashed lines indicate median values.

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Legal deposit 3rd quarter 2025
ISSN 2492 - 2846

Graphic design MeMo, Juliegilles, D. Cazeils
Layout PUB
Printed by the AFD reprography service

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