Investigating The Net Employment Impacts of Renewable Energy In South Africa

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Through job creation, quality public services and better working conditions, people, communities and countries can lift themselves out of poverty, improve livelihoods, engage in local development and live together in peace. This happens only when work is decent – environmentally sound and productive – provides fair wages, and is underpinned by rights.

Sharan Burrow

Preface

Completing this project and finishing this master's degree has been an incredible journey and I have many people to thank for making this experience as special as it was. First and foremost, I would like to thank my supervisors Dr. Enno Schröder and Prof. Jill Slinger for their incredible mentorship and guidance throughout this project. I am grateful to the Institute for Economic Justice for providing me with the data necessary to successfully complete this project. Specifically, I would like to thank Dr. Basani Baloyi for facilitating the the stakeholder engagements and her guidance on the nuances of the topic.

Without the friends I made in the last two years during the EPA programme and the support of my partner, Abbie, I doubt that I would have completed this degree and enjoyed the process as much as I did. Thank you. Finally, I extend my gratitude to my amazing parents, Glenda and Nigel, for their endless support and encouragement throughout this master's experience and always believing in me. Thank you Mom and Dad for proof reading this dissertation and giving me advice along the way. I am exceptionally grateful to have been afforded such an excellent education at this distinguished institution.

Ashok Willis
Delft, August 2021

Summary

This dissertation aims to contribute towards the research on just transitions by providing insight into the extent of the employment impacts caused by a potential energy transition in South Africa. South Africa is in the process of transforming its electricity mix. The majority of electricity is currently sourced from coal-fired power plants. The transition may be towards an electricity mix that includes more renewable sources of electricity generation, particularly from wind and solar technologies. The degree to which this transition will create and displace jobs is presently unclear. Furthermore, the extent to which these new jobs will be demanded locally or abroad and the implications that this transition will have on decent work is uncertain.

The main research question posed at the outset of this dissertation was: **What are the possible net employment effects of South Africa's transition from coal to wind and solar forms of electricity generation?** A quantitative method was employed to address this question: an Input-Output Analysis. The I-JEDI input-output model was used, updated with more recent data for South Africa that has more industrial detail. Additionally, a coal displacement vector was created to calculate the jobs displaced due to lack of demand for coal-fired power plants. Hence, the net employment effects were calculated. This quantitative method was supplemented with findings from a series of semi-structured interviews and a workshop with union members to ground the results in some of the realities of South Africa's socio-political landscape. Two exploratory scenarios were created that were simulated in the model, each with their own narrative about South Africa's future electricity prospects: Integrated Resource Plan (IRP) 2019 scenario and the Ambitious Solar and Wind (ASW) scenario. The IRP 2019 scenario was aligned with the recent government plans to transform the electricity mix. The ASW scenario included higher levels of local manufacturing of solar and wind technologies than currently employed.

The results of this research are exploratory, aiming to provide insight into the boundary of what is possible. The main findings suggest that solar and wind may employ significantly more people than currently employed in the coal-fired power plant supply chain considering both operations and maintenance (O&M) and construction activities. O&M jobs numbers for coal-fired power plants are larger than wind and solar under the IRP 2019 scenario but are comparable for the ASW scenario. While the results from the model showed promising prospects for employment, it was revealed through the stakeholder interactions and literature that there are several challenges to achieving a just energy transition. In particular, there is the challenge of garnering the support of labour unions and ensuring decent work. It was found that the overall skill levels in terms of education for the different sources of electricity were similar, but there are many other skill considerations required for people to change vocation from the old jobs in coal to new jobs in solar and wind.

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Acronyms

Acronyms used in this dissertation

Word	Acronym
Ambitious Solar and Wind	ASW
Computational General Equilibirum Model	CGE
Congress of South African Trade Unions	COSATU
Gigawatt hour	GWh
Independent Power Producer	IPP
Input-output analysis	IOA
Input-output transaction table	IOTT
Institute for Economic Justice	IEJ
Integrated Resource Plan	IRP
International Jobs and Economic Development Impacts	I-JEDI
International Labour Organisation	ILO
Megawatt	MW
Megawatt hour	MWh
National Union of Metalworkers South Africa	NUMS
National Union of Mineworkers	NUM
Operations and Maintenance	O&M
Photovoltaic	PV
Quantec Standard Industrial Classification	QSIC
Renewable Energy Independent Power Producers Procurement Programme	REI4P
South African Renewable Energy Masterplan	SAREM
United Stated Dollar	USD
Technical Vocational Education Programmes Education Training Programmes	TVEP

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Introduction

The world is facing two major crises (García-García, Carpintero, & Buendía, 2020). Firstly, ecological collapse due to human behaviour and the subsequent change of our climate (Rockström et al., 2009). It is widely understood that to mitigate our impact on the environment and our effect on the global carbon cycle, we need to change our fossil fuel dependence by decarbonising our energy supply globally. This is the essence of an energy transition - the transition from "dirty" sources of energy to clean energy generated from renewable sources such as the sun (Smil, 2016). Secondly, the world is plagued with a socio-economic crisis with widespread poverty, inequality, and discrimination around the world (Poschen, 2017). There is a threat that the necessary intervention to mitigate the first crisis - the energy transition, will exacerbate the second. The reason is that an energy transition implies structural change as transitioning from fossil fuels to clean sources of energy leads to social disruption, specifically job losses. Introducing renewables into the energy mix will be highly disruptive to the labour market. This is because the new energy portfolio would require a different set of resources and skills to what is currently in operation (International Labour Organisation, 2019). Clearly, an energy transition is a complex "grand challenge" with no perfect solution, as there is a dilemma as to how to decarbonise the global energy supply without causing social disruption in the process. Therefore there is a need for a "just energy transition".

1.1. Need for a "just energy transition"

It is in this dilemma that the energy transition poses that the term "just energy transition" is developed. In this concept, justice and equity are incorporated into the decarbonisation of the global energy supply (Gambhir, Green, & Pearson, 2018). Therefore, an energy transition must uplift the socio-economic conditions of a population (developmental welfarism), while moving towards a more environmentally sustainable energy system (Swilling, Musango, & Wakeford, 2016). A key component of the developmental welfare aspect of the just energy transition concerns adequate employment.

Employment in a Just Energy Transition

According to Poschen (2017) from the International Labour Organisation (ILO), one of the main contributors to the concept of the “just transition”, the energy transition would increase the demand and investment toward green sectors and subsequent removal of resources from non-green activities. This would both create and destroy direct jobs. Furthermore, through the supply chains and income variations, indirect jobs would be affected. The challenges in the job transition would result from unexpected job losses, location, absence of nearby alternatives, short comings of political programmes and the mismatch in skill level between people who work within the current energy system and a new green energy system (International Labour Organisation, 2018). According to this ILO framework, job quality, employee skills and gender equality must also be considered. A series of engagements with key stakeholders in the just energy transition in South Africa was conducted -see Appendix A. Five out of ten stakeholders said that one of the most important aspects of the just transition concerned the nature and quality of employment. Other concerns included women affected by the transition, ownership of new electricity plants, and ensuring equal access to and security of supply of electricity.

Decent Work

The concept of decent work was developed by the International Labour Organisation as "opportunities for men and women to obtain decent and productive work in conditions of freedom, equity, security and human dignity" (International Labour Organisation, 1999). Decent work, therefore sees employment in broad terms of contributing people’s livelihoods and as a means to help achieve sustainable development goals such as eradicating extreme poverty and hunger, among other goals (International Labour Organization, 2018a). Decent work is considered to have four interdependent pillars including: "employment, rights at work, social protection and social dialogue" Bell and Newitt (2010, p.15). Therefore, a just energy transition may be aligned with the concept of "decent work" if it is able to create decent employment by incorporating the aspects of these four pillars.

1.2. Challenges for a Just Energy Transition in South Africa

The challenge in South Africa for a just energy transition is particularly large for at least the following reasons: current dependence on coal, conflicting views of multiple actors, and socio-economic factors. These will be outlined below.

1.2.1. Current Dependence on Coal

Over 95% of South Africa’s electricity is generated by a vertically integrated state-owned enterprise (SOE), namely, Eskom (Jaglin & Dubresson, 2016). Approximately 86% of this energy comes from coal (Statistics South Africa, 2018).

The current energy system employs approximately 90 000 people in the coal mining sector, (Minerals Council South Africa, 2020), and Eskom employs approximately 47 000 people (Eskom, 2020). South Africa is also the fifth largest coal exporter in the world

(Eberhard, 2011). This means that the industry employs more people than those necessary to supply domestic power plants, making the challenge particularly large. If South Africa moves away from coal, the threat of increasing unemployment due to a collapsing coal fired energy system is daunting. The fate of the people currently employed by the coal mining industry is uncertain once the source of their livelihood is replaced.

1.2.2. Conflicting views in a multi-actor system

A part of the challenge in South Africa stems from the conflicting opinions pervading over an energy transition in a multi-actor arena. Labour unions have rejected the notion of small scale private sector renewable energy companies entering the grid without a "Just Transition Plan" due to the potential social disruption caused by a collapsing coal mining and coal-supplied energy industry (Khumalo, 2018). Conversely, there are small-scale private renewables companies who are competing for a spot on the grid. Eskom, would be reluctant to loose their entire market share and decommission all their power plants. Furthermore, the government's position is not unanimous as some within government support the transition while others do not.

1.2.3. Socio-economic factors

In the first quarter of 2021, South Africa's unemployment rate peaked at 32.6% (Reuters, 2021). The South African context is unique, with a specific political history that has shaped the coal mining sector, whereby Black people were banned from many skilled jobs until the fall of apartheid in 1990. Black families were prevented from permanently settling in mining towns. This has left most mining towns with high levels of poverty, unemployment, bad housing and infrastructure, illiteracy, and many documented and undocumented single migrant labourers (Cronje & Chenga, 2009). Therefore South Africa has a particular socio-economic situation, whereby the country is desperate to increase the employment rate, but those who depend on coal cannot easily transition to other livelihoods.

1.3. Opportunity for an Energy Transition in South Africa

Despite these challenges, there are also significant opportunities for a just energy transition in South Africa. These opportunities arise from the country's vast wind and solar availability, the dramatic cost decline in solar photo-voltaic (PV) and onshore wind generation technologies, and the pressure to reform the current energy system from an environmental and economic perspective (Bischof-Niemz & Creamer, 2018). South Africa has some of the best solar and wind availability worldwide. Technological improvements in these generation technologies has made them much cheaper to deploy. This makes small-scale wind and solar power plants an attractive option to the private sector, potentially creating many jobs. Finally, the current energy system has failed. Eskom has been unable to meet demand in the last decade. Rolling power cuts are ubiquitous in South Africa as the company tries to reduce the load (du Venage, 2020). Eskom had a gross debt of R454bn (€25bn) in 2020 (Bloomberg, 2020). Additionally, the country is the 14 largest greenhouse gas emitter worldwide (McSweeney & Timperley, 2020). Therefore, there is pressure to reform the system from both an economic and environmental perspective.

Recognising this, the government plans to introduce renewable energy into the country's electricity generation portfolio with the Integrated Resource Plan (IRP) 2019. The plan includes targets for 2030 of at least 32% of the country's installed power capacity coming from renewable energy (Department of Mineral Resources and Energy, 2019). This plan allows for previously excluded small-scale private companies producing renewable energy, particularly solar and wind, to enter the grid. However, the IRP 2019 has put limits on their development until a "Just Transition Plan" is released. While renewable energy will create job opportunities, the number and nature of employment is uncertain. As of June 2021, the Presidency has lifted the threshold for companies producing without a license to 100MW, making the adoption of solar and wind even more enticing (Kuhudzai, 2021).

Owing to the focus of the policy on solar and wind as well as the overwhelming geographical and economic reasons for South Africa to adopt these technologies, this dissertation will limits scope limited to utility-scale solar and onshore wind renewable energy technologies. These two technologies are referred to as "solar" and "wind" for the sake of brevity for the remainder of this dissertation. Other forms of renewable energy such as hydro and geothermal are excluded from this analysis.

1.4. Research Questions

This dissertation investigates the employment impacts of an energy transition in a country where there is large potential for solar and wind sources of energy, but that also has a job-rich coal industry on which many people are dependent. Consequently, the main research question is:

What are the possible net employment effects of South Africa's transition from coal to wind and solar forms of electricity generation?

To be clear, wind in the above question refers to onshore wind owing to the relative market maturity compared to offshore wind. Similarly, solar refers to utility-scale solar PV electricity plants owing to the large scale roll-out considered for this analysis. The net employment effects are the differences in the number of jobs gained by the introduction of solar and wind and the jobs lost to coal dissolution. This research investigates the period 2019-2030 to align the analysis with with the IRP 2019 that has targets for 2030. Moreover, the period up to 2030 has been considered sufficiently short term by notable authors who have investigated similar research questions for different case studies such as Pollin, Garrett-Peltier, Heintz, and Hendricks (2014). The authors argue that investigating too far into the future results in more uncertainty due technological change -see Section 3.6.3. The following three sub-questions were developed to make this estimation:

1. How does the lack of demand for local coal-fired electricity production and coal exports influence employment in South Africa?

2. How does the increased demand for solar and wind energy influence employment in South Africa?

As the main research question aims to provide insight into what may happen to employment in the future, the third sub question was developed:

3. Which scenarios should be considered when evaluating the employment effects of renewable energy by 2030?

Owing to the conflicting views in the multi-actor arena for the just energy transition, the method used incorporated findings from engagements with key stakeholders in the energy transition space in South Africa. The final outcome of this dissertation is policy implications for the South African government for an employment-centred energy transition. Hence, the following two sub-questions were developed.

4. How do actors in the South Africa's energy arena perceive the need for creating employment in South Africa's energy transition?

5. What policy advice can be provided for an employment-centred energy transition in South Africa?

The contribution that this dissertation attempts is two-fold. Firstly, this dissertation aims to add to the quantitative assessment of the employment effects of renewable energy in South Africa. The method used for this quantitative assessment is an input-output analysis, using an updated version of the I-JEDI model developed by (Keyser, Flores-Espino, Uriarte, & Cox, 2016) — see Section 3.3. Few studies have attempted this calculation. What is proposed is an alternative and possibly improved method with more relevant data to what has been done before — see Section 2.3.3. Secondly, this dissertation aims to contribute to the policy discourse for a job-rich and sustainable energy system in South Africa, based on the quantitative results supported by findings from stakeholder engagements.

1.5. Chapter Summary

This chapter is summarised as follows:

1. There is a need for a just transition, whereby justice and equity is incorporated into the decarbonisation of the global energy supply.

2. An important pillar to the justice and equity component is employment.

3. The challenge for a just transition in South Africa arises from: i) the country's current dependence on coal, ii) the deeply conflicting views in a multi-actor system, and iii) socio-economic factors.

4. The opportunity for a just energy transition in South Africa arises from the country's ample solar and wind availability as well as recent government policies to incorporate more renewable energy into the electricity mix.

5. The main research question for this dissertation is: **What are the possible net employment effects of South Africa's transition from coal to wind and solar forms of electricity generation?**

1.6. Document Structure

This dissertation is structured as follows: Chapter 2 reviews the relevant literature on employment in a just energy transition in South Africa and investigates the appropriate methods to address the main research question. Chapter 3 describes the method followed to answer the main research question and describes the data used. Chapter 4 presents and discusses the results of the dissertation. Chapter 5 concludes the dissertation by discussing the contribution of this research, addressing the main research question, presenting the limitations of the approach, implications for policy and recommendations for future work. Supplementary sections can be found in the appendix. Appendix A provides an summary of the interviews and stakeholder engagements. Appendix B provides more detail into the modelling process. Appendix C provides some additional results of the analysis.

Throughout this dissertation, findings from a series of stakeholder engagements described in Section 3.1 were used to inform decisions in the literature review and methods chapters. Similarly, findings from these interviews were used in interpretation of results and recommendations.

2

Literature Review and the South African Context

This chapter has two purposes. The first is to present a summary of the current state of knowledge on employment in a just energy transition in South Africa. Secondly, this chapter reviews the methods used to study the net effects upon employment of renewable energy to make appropriate methodological choices for this dissertation.

To find peer-reviewed scientific literature in journals on the current state of knowledge of employment in a just energy transition in South Africa, key words such as "renewable energy", "jobs", "employment", "South Africa" and "just transition" were searched on *Google Scholar*. To find independent research reports, the Trade and Industrial Policy South Africa (TIPS)[1] Just Transition Portal was also searched. The portal has a collection of most research reports of just transitions in South Africa performed by independent research organisations from 2011 to 2020. Furthermore, through engagements with key stakeholders in the energy transition space (see Appendix A) — relevant research reports were recommended and reviewed. These stakeholder engagements were facilitated by the Institute for Economic Justice [2]. Where possible, quotations from these stakeholder engagements were used to supplement the data gathered from the literature. Fourteen relevant articles were found that discuss the topic specifically in the South African context. Four were in peer reviewed journals, nine were other articles written by independent research organisations and one was a book.

The literature review concerning methods for modelling the net employment effects of renewable energy was also performed by searching key words, such as "modelling", "renewable energy", "employment", "energy transition" and "net employment effects" on *Google Scholar*. It became clear that certain authors were well-known and cited on

[1] https://www.tips.org.za/just-transition
[2] https://www.iej.org.za/

the topic such as Garrett-Peltier (2017); Pollin, Epstein, Heintz, and Ndikumana (2009); Pollin et al. (2014). These studies have consequently been cited many times on the topic and the literature that they refer to has also been traced. Other literature was found to fill certain knowledge gaps as the literature review proceeded and methodological decisions were made. In total, 66 scientific articles and reports were reviewed in the methodological literature review. Therefore, a grand total of 80 published sources were reviewed.

2.1. Employment in a Just Energy Transition in South Africa

There is an increasing body of literature that addresses employment in the “just energy transition” in South Africa. These sources have been summarised in Table 2.1. This table presents an outline of the current knowledge around employment in just transitions in South Africa as of 2021. The reviewed literature for South Africa includes journal articles as well as documents produced by independent research and advocacy organisations.

The outcome of the literature review of employment in a just transition in South Africa shows that there are few-peer reviewed scientific journal articles that address the topic. There is an increasing body of research, which has been conducted by independent research groups and organisations. All the studies of the publication type "Research report" in Table 2.1 are of this nature. There is a dearth of research that uses modelling as a research method. Only three modelling studies were found that use modelling as their primary methodology, while the other studies were primarily qualitative based on literature and stakeholder engagements. One non-modelling study quantified the employment impacts of solar technologies using survey-based analytical methods. While there are three studies that use modelling as their primary methodology, they were all based on the same model - e-SAGE, which is a computational general equilibrium model. These models will be reviewed in more depth in Section 2.3.3. Prior to this, it is first necessary to understand the need for modelling employment in the first place.

Table 2.1: Literature review of employment for just energy transitions in South Africa. Source: Author.

Literature	Method	Publication type	Findings
(Swilling et al., 2016)	Literature review	Journal	Unlikely just transition. But rapid emergence of renewable energy and cooperation of key actors may provide optimisitic outcomes.
(L. Baker, Newell, & Phillips, 2014)	Multi-level perspective	Journal	Greater attention is required for the political economy of just transitions.
(Death, 2014)	Discourse analysis	Journal	Critique of "green growth" in transitions in South Africa.
(Halsey et al., 2019)	Desktop research & stakeholder engagement	Research report	An energy transition could lead to more employment if managed correctly.
(Burton, Marquard, & McCall, 2019)	Desktop research	Research report	Suggests worker transfer programmes to manage inevitable job losses from coal in a just energy transition.
(Tyler & Steyn, 2018)	Desktop research & stakeholder engagement	Research report	Coal absorbs many unskilled workers. Some studies show positive net employment effects of a just energy transition, others negative.
(Naudé & Rivett-Carnac, 2018)	Desktop Research	Policy brief	Job opportunities arise from repurposing old mines for pumped storage, manufacturing and construction for renewable energy activities.
(Halsey, 2018)	Desktop research	Research Report	There is a knowledge gap around comparable job numbers from different energy generation sectors.
(Bischof-Niemz & Creamer, 2018)	Primary research	Book	Renewable energy can lead to a more industrial economy and jobs gains.
(R. Fourie, North, Carter-Brown, & Spencer, 2021)	Survey based analytical	Research Report	Solar PV market will play a significant role in employment over the next 9 years across all scenarios.
(Khobai et al., 2020)	Statistical analysis	Journal	Short term increase in employment. Statisically insiginificant increase long-term.
(Hartley, Burton, et al., 2019)	CGE modelling	Research report	Net positive employment effects of renewables.
(Hartley, Merven, Arndt, & Ireland, 2019)	CGE modelling	Research report	Net positive employment effects of renewables.
(Burton, Caetano, & McCall, 2018)	CGE modelling	Research report	Net positive employment effects of renewables.

2

2.2. The Need for Modelling Employment in the “Just Transition”

There have been various methods used to assess employment within a just transition in South Africa. Most of the studies reviewed have been qualitative and their results found that that there is a lot of uncertainty on the question of labour. Khobai et al. (2020) investigated the short-term and long-term effects upon employment as a result of renewable energy introduction into South Africa for the period 1996–2014 using an auto-regressive distributed lag model. The method employed here, uses historical data for a statistical analysis, providing insight into correlation of renewable energy introduction and unemployment rates. However, this study cannot answer questions of causation. For example: "what if renewable energy were to replace coal?" is not possible with this sort of model. The study therefore does not consider what may happen if renewable energy replaces a significant proportion of South Africa's current energy generation by 2030 to be consistent with the latest policy developments in the the IRP 2019 (Department of Mineral Resources and Energy, 2019). Additionally, the correlation of these variables does not provide a detailed breakdown of jobs at the sectoral level. This was also identified as a knowledge gap by Halsey (2018) which stated that there is a knowledge gap concerning comparable jobs per sector for different types of electricity generation.

Ward, Sharma, and Searight (2020) found that socio-economic and climate modelling for national planning is one of the research gaps that, if filled, would be the most beneficial to the support of just transitions in South Africa. Given the complexity of a just energy transition, the qualitative studies should be supported by quantitative models that can provide an estimation of the net employment effects of introducing more renewable energy into South Africa's electricity mix. Formal models have been used to reduce complexity and identify essential factors and processes through abstraction and experimentation (Köhler et al., 2019).

In the series of engagements with stakeholders (see Appendix A), many believed that there are numerous research gaps regarding the question of labour. They believed that rigorous economic evidence on the sectoral level about the potential jobs gained and lost was missing. For example, an interview was held with representatives of South African labour unions to understand their perspectives on a just energy transition in South Africa. When asked about the biggest research gaps on the topic of the just energy transition, the response was:

> **"A quantification of jobs on the sectoral level, and what skill level will be required to work in each sector."** (Respondent K as interviewed by B. Baloyi (IEJ) and A. Willis, see Appendix. A)

This quantification gap may be filled by models as models can provide insight into economic indicators such as employment under different scenarios in the short, medium, and long term (Kowalski, Stagl, Madlener, & Omann, 2009).

There is clearly uncertainty in the understanding of the South African economy and its responses to exogenous shocks such as the introduction of renewable energy and the simultaneous corresponding lack of demand for coal. This uncertainty can be aided by models that, through their abstraction and simplification of reality, can help decision makers understand the system of interest and make more informed evidence-based decisions (Enserink et al., 2010). Furthermore, models help us explore the future, as we are interested in how the system works and, subsequently, what may happen to the number of jobs created by a transition from coal to solar and wind technologies at a future date.

2.3. Review of Methods to Estimate the Net Employment Effects of Renewable Energy

Mu, Cai, Evans, Wang, and Roland-Holst (2018), conducted a literature review of 26 studies investigating the employment effects of renewable energy policies. The studies used mixed methods: input-output analysis, CGE models, and analytical methods. The value of these methods over other modelling methods used for in the energy transition, is that they are designed to model and calculate macro-economic indicators such as employment (Perman, Ma, McGilvray, & Common, 2003). With the macro-economic data at the core of the calculation they are able to integrate sustainability concerns such as CO2 emissions and demand for renewable energy (Hardt & O'Neill, 2017). This is why these methods are the basis in the literature for most employment estimates due to renewable energy.

Of the twenty-six studies, two of the studies found negative impacts upon employment, one was neutral, five were either positive or negative depending on the scenario, and eighteen were positive. All these countries were in the Northern Hemisphere, with varying sources of renewable energy potential. The heterogeneous results indicate that the effect upon employment of energy transitions is dependent on the country's context and method used for estimation. In some instances, these effects have been quantitatively moderate and thus, it has been argued that green energy policies should be evaluated purely by their impact on CO_2 emissions (Pestel, 2019). Given South Africa's unique context, it cannot be inferred whether renewable energy will be beneficial to employment purely by evaluating the findings of other studies in different countries.

Three potential methods to calculate renewable energy's impact upon employment have been identified by this literature review. To decide which of the three potential methods should be used to make the appropriate calculation, these methods are reviewed briefly below. Each method has its strengths and weaknesses, but an input-output analysis has been chosen as the method for this dissertation.

2.3.1. Input Output Analysis (IOA)

Input-output analysis (IOA) can estimate the economy-wide impact that a change in the final demand for goods and services produced by a sector has on employment (Pollin et al., 2014). IOA can analyse, through change in demand for supply chains, how an exogenous shock can impact the intermediate and final output. Correspondingly, the employment in individual economic sectors can be calculated (Markandya, Arto, González-Eguino, & Román, 2016). An important feature of IOA is that it can track direct, indirect and induced jobs in an economy due to changes in renewable energy (Pollin et al., 2014). Direct jobs refer to those of persons directly working on renewable energy services such as solar panel installation or manufacturing of wind turbines. Indirect jobs refer to industries that supply intermediate goods for renewable energy such as goods that may be needed for wind turbines. Induced effects would be how the spending of money earned by people in direct and indirect employment stimulates the economy and induces jobs in unrelated sectors. The sum of the direct, indirect and induced jobs are the employment gains. Correspondingly, the "employment losses" will be those jobs that are lost from the industry that generates electricity from coal, owing to effects that may be direct, indirect, or induced. The net employment effects will be the difference in the jobs gained by producing energy that relies on solar and wind versus the job losses in the industry that functions upon the generation of electricity from coal.

2.3.2. Analytical Methods

Analytical methods tend to be survey-based. These methods are useful as they are able to gather data from key stakeholders and are potentially able to present a clearer idea of what the situation is on the ground. They have been influential in policy reports drawn up by governments or non-governmental organisations. They are also less computationally complex than CGEs or IOA, and have fewer data requirements, making them attractive in poor data situations. They are, however, unable to calculate the induced effects. Ignoring induced effects, especially for induced job losses and may reflect the employment estimates too positively Stavropoulos and Burger (2020).

Existing Survey-Based Analytical Methods

Maia et al. (2011) estimated the direct employment potential of renewable energy in South Africa. Their study, relied on survey-based analytical methods. Consequently, they were able to calculate the direct employment effects only. Similarly, R. Fourie et al. (2021), calculated the direct gross employment effects on jobs of the Solar PV industry across several scenarios. This was based on data from surveys of over 1000 companies. The main drawback of these studies is that they are only able to calculate the direct gross employment effects. Excluding the indirect and induced effects that may be significant when calculating the *net* employment effects (Stavropoulos & Burger, 2020).

Baran, Szpor, and Witajewski-Baltvilks (2020) used analytical methods to investigate the impacts upon labour market of decarbonising the energy industry in a coal producing country, namely, Poland. The study found that coal miners will struggle to find employment in the renewable energy industry and manufacturing sector as a result of both the skills difference in renewable energy services and the wage difference that manufacturing would dictate. Poland has a similar number of coal miners to South Africa—approximately, 80 000. A key difference between Poland and South Africa is that Poland had an unemployment rate of 3% in 2018, while South Africa's was 32.6% in the first quarter of 2021 (Reuters, 2021). Therefore, Poland requires workers to change industry to maintain the employment rate. Conversely, South Africa has the potential to create new jobs for people who were unemployed as well as create jobs for people through skills transfer of coal miners to renewable energy services. This serves as a useful point of departure for analysing the transfer of employment in South Africa, but it is inconclusive vis-à-vis the potential net effect upon employment of renewable energy policies.

2.3.3. Computational General Equilibrium Models (CGE)

CGEs are also able to track the net employment effects of renewable energy as at the core of a CGE is an input-output table (Perman et al., 2003). CGEs are extended input-output models with price dynamics, supply-side constraints, and assumptions about technological change (Pollin et al., 2014). Pollin et al. (2014), one of the leading authors on the topic of the relationship between renewable energy and employment, explains how CGE models are expensive to make, meaning that access to them is often restricted and modeller's assumptions are often unclear and non-transparent. CGEs are also neoclassical in nature and adjust prices so that supply meets demand often assuming full employment. With South Africa's unemployment rate at 32.6% in 2020 this renders this sort of analysis misleading (Reuters, 2021). Similarly, CGEs rely on many modeller assumptions for the relationship between variables. Therefore, the results remain somewhat arbitrary if the assumptions are not clear and the relevant data is missing. For example, an assumption that the economy works at full employment, at all times, makes it difficult to track the effect of green investments on job creation. Storm and Isaacs (2016) extensively highlight the issues of using CGE models particularly in the South African context.

Existing CGE studies for employment in just energy transition in SA

Two recent studies have been found that have attempted to calculate the possible net employment effects of renewable energy in South Africa using CGE models (Hartley, Burton, et al., 2019; Hartley, Merven, et al., 2019). These studies use the SATIMGE. The model combines two dynamic models: a "bottom-up" integrated energy systems model (SATIM) and the National Treasury's eSAGE model (a CGE). Hartley, Burton, et al. (2019) investigated the number of jobs lost in a declining coal sector as well as the jobs gained by renewable energy technologies. The study found that there is likely to be a positive net employment increase as a result of a transition to renewables, with the majority of jobs being those with skills (grade 12 and up). Similarly, the study found that, regardless of a transition to renewable sources of electricity generation, the number of jobs in the coal industry is expected to decline.

Similar to the study above, Hartley, Merven, et al. (2019) also used SATIMGE to estimate the net employment effects of renewable energy in South Africa. The research finds that removing the constraints on renewable energy deployment leads to increases in real GDP and employment under conservative renewable energy costs (and to greater ones under optimistic costs), despite a decline in coal-fired energy and employment in the coal sector.

As pointed out by Pollin et al. (2014), there are hidden modeller assumptions in CGE-based studies. This is also true for these two studies mentioned above. e-Sage uses an input-output table from 2007 as the basis for the model (Merven, 2015). This was not mentioned in the studies. Furthermore, after tracking down the foundations of the e-SAGE model to Thurlow (2004), it was found that the model has a neo-classical closure condition. This condition is that "savings is exogenous and that investment adjusts passively to maintain the savings-investment balance." (Thurlow, 2004, p. 10). How to treat savings and investment is a highly contentious issue in macro-economics. For example, Keynesian economics argues that investment is exogenous and that savings adjusts. Storm and Isaacs (2016, p. 2) argue that CGE's assume that the "economy behaves as neoclassical theory predicts, rather than consciously relating the model to empirical reality (which may not conform to the neoclassical assumptions)". CGE's assume that all markets clear and that the market is perfectly competitive. These assumptions may not be relevant in South Africa's unique context and therefore this conscious relation to empirical reality is imperative to South Africa's unique context. This is due to South Africa's rare social-economic climate such as high unemployment and high inequality etc. Storm and Isaacs (2016) concludes that CGEs are not the only options available for macroeconomic analyses and other options avoid the flaws highlighted. This macroeconomic savings and investment assumption was not clear in these research papers investigating the employment effects of renewable energy. The two above-mentioned studies have an overlap of authors from the Energy Research Centre at the University of Cape Town and they all use the same CGE model. This is not a weakness inherent to the studies, but it does indicate a lack of modelling research on the topic. Greater model diversity that employs different methods and assumptions that yield similar results will increase the validity and credibility of the results for decision makers to trust and use.

Pauw (2007) calculated economy-wide impacts of decarbonising South Africa's electricity supply. The study also uses a CGE model. As of 2021 the study may be considered outdated especially with change in cost of wind and solar technologies in the last decade which have been reflected in South Africa's most recent plans as of 2019 (Department of Mineral Resources and Energy, 2019). The study is useful in that it disaggregates the employment effects into highly skilled, skilled, semi-skilled and unskilled workers. While these three studies have used different methodologies to what have been used in this dissertation, they are thorough and will be useful as a source of comparison.

2.3.4. IOA -An imperfect but important tool

The three most commonly used methods for estimating the employment effects of renewable energy have been reviewed. While all the methods have their strengths and weaknesses, it was decided to use IOA as the primary research method for this dissertation. An overview of the weaknesses and assumptions of the IOA will be presented, followed by an explanation why, despite these assumptions, it was selected as the modelling method of this dissertation.

An input-output analysis has several assumptions that can be considered weaknesses for example: it assumes constant returns to scale, zero production limitations – i.e supply of capital and labour is infinite, output is related to input linearly (no economies of scale) and fixed input-ouput coefficients (Stavropoulos & Burger, 2020). Fixed input-output coefficients mean that the inter-industry transactions are assumed to remain constant. Therefore, the results from IOA analysis would likely be an overestimation of job opportunities; (Caldés, Varela, Santamaría, & Sáez, 2009); providing the boundary for what is possible.

Despite these limitations, this method was selected as the quantitative core of the dissertation. Owing to the capability of an IOA to estimate indirect and induced impacts on top of direct impacts, it will provide useful, albeit imperfect, insights into South Africa's just energy transition employment potential. Additionally, the IOA method is transparent for other researchers, the data requirements can be fulfilled, and there are many case studies that have used this method providing a useful form of validation and comparison. With the knowledge of these assumptions and limitations, we will know the results are to be regarded with caution, focusing on the sectors providing opportunities for employment rather than specific numbers. Moreover, IOA does not make neoclassical assumptions of full employment.

2.4. A closer look at IOA for the employment effects of renewable energy

This section reviews studies that have used IOA to estimate the the employment effects of a switch to renewables from fossil fuels. Based upon these studies, fundamental choices within the input-output analysis were made. The points for decision making are:

1. How to include renewable energy into the input output table.
2. How to use IOA for a forward-looking analysis.

These decisions have had impacts on the modelling choices within this thesis. First, the reviewed studies are compared and summarized in Table 2.2. Thereafter, each of the fundamental points for decision-making are discussed in more detail to justify the decisions made for this research.

2.4.1. Inclusion of renewable energy into the Input-Output Analysis

For the IOA to estimate jobs of an activity, firstly vectors for demand need to be constructed. Based on the demand for a sector, it is possible to calculate how many jobs are needed to supply this demand. The calculation is, however problematic in that that most input-output tables that form the basis of the IOA do not have an explicit renewable energy sector. How and which renewable energy activities should be incorporated into the input-output analysis must be determined (Wiebe, 2018). Accordingly, this new sector for renewable energy needs to be included within this table. Two methods as to how to incorporate a new sector into the analysis are presented by (Miller & Blair, 2009).

Firstly, there is the "synthetic industries" approach (Garrett-Peltier, 2017) (referred to the final demand approach by Miller and Blair (2009)). This approach maps renewable energy project expenditures as a vector for final demand. The final demand is the weighted average of the project expenditures for industries that already exist within the input-output table. The advantage of this approach is that data is not required for the structure and magnitude of demand for output of renewable energy industries (Garrett-Peltier, 2017).

Table 2.2: Input-output studies that have modelled the employment effects of renewable energy. Source: Author.

Literature	Including Renewable energy in IOA	Forward-Looking IOA	Presentation of results [units]
(Garrett-Peltier, 2017)	Synthetic industries & surveys	Scenarios	Jobs per technology. [Job-year/$ 1 Million]
(Lehr, Nitsch, Kratzat, Lutz, & Edler, 2008)	Synthetic industries	Scenarios	Cumulative jobs and jobs per MW per technology type [Job-years]
(IRENA, 2020)	surveys	Scenarios	Gross number of direct jobs per country. [Jobs]
(Pollin et al., 2014)	Synthetic industries & surveys	Dynamic empirical econometric model	Direct, indirect and induced jobs sector and per energy type. Distinguishes between capital investment and O&M phases. [Job-year/$ 1 Million]
(Hillebrand, Buttermann, Behringer, & Bleuel, 2006)	Synthetic industries	Scenarios	Net employment per sector [Job-years]
(Markandya et al., 2016)	Complete inclusion of the technical coefficients matrix	N/A	Cumulative jobs per sector. [unclear unit]
(Wang, Pashaei Kamali, Osseweijer, & Posada, 2019)	N/A	Scenarios	Direct and indirect jobs per sector per scenario. [unclear unit]
(Wu, Huang, & Wu, 2021)	Sectoral disaggregation & surveys	RAS method	Cumulative jobs per sector. [unclear unit]

The second approach as presented by Miller and Blair (2009) refer to the complete inclusion of the technical coefficients matrix. This method requires inserting a completely new industry into the table. This approach has been also referred to as "sectoral disaggregation" in the literature (Wu et al., 2021). This involves disaggregating the input-output table into more sectors. Therefore, if an economy does have an established renewable energy industry, that is embedded within other sectors, these sectors could be disaggregted to form a new sector. Lindner, Legault, and Guan (2012) propose a way to do this with incomplete information. However, this method has only been found in one study, namely (Wu et al., 2021). Data requirements are still required for the structure of the economy. Furthermore, this method does not seem to provide more value than what would be found from the synthetic industries approach, as the disaggregated "child" sectors would still rely on the structure of the "parent" sectors – unless there is complete information about how this sector supplies and demands resources from other sectors. In other words, this method requires detailed data for the full supply chain for the new renewable energy sector. As most renewable energy is in its infancy around the globe, South Africa included, this kind of information is missing and data would have to be substituted by modeller assumptions. These modeller choices remain arbitrary when the relevant data is missing. Therefore, the synthetic industries approach has been used for this analysis.

Stakeholder engagement

Six of the eight studies in Table 2.2 integrate information into their IOA which has been taken from stakeholder engagements. This was mostly done through extensive surveys, which require a lot of time and resources to do properly. These authors have understood the necessity for grounding the macroeconomic analysis with detailed data on the ground. In the studies above, data from the surveys has been used to develop the exogenous demand vectors as well as the scenarios simulated. Accordingly, this dissertation has also grounded the modelling results with engagements with stakeholders, particularly in the development of scenarios - See Section 3.1.

Net employment effects

Lambert and Silva (2012); Pollin et al. (2014) discuss that to calculate the net employment effects, one needs to consider the number of jobs gained by clean energy investments as well as the jobs lost by contraction of non-renewable operation and maintenance costs. Pollin et al. (2014), therefore compare the jobs gained by investing in renewables to fossil fuels in the following two ways:

1. 1 million USD on construction of renewable energy projects versus 1 million USD on the O&M of fossil fuel plants.
2. 1 million USD on O&M of renewable energy projects versus 1 million USD on O&M of fossil fuel plants.

The authors found that renewable energy O&M labour intensity [3] is almost the same as non-renewable O&M in the case of the US. In the construction phase, they found renewables had higher labour intensity than fossil fuels. Therefore, the net employment effects of an energy transition were always positive. Figure 2.1 shows how the net employment effects may be determined from a transition from fossil fuels to renewable energy (Blyth et al., 2014).

Correspondingly, the gross number of jobs resulting from clean energy investments and fossil investments has been compared to the current status quo, as was done in Hillebrand et al. (2006). Thereafter, the gross gains can be compared to the gross losses to calculate the *net* effects.

2.4.2. Forward-Looking Input Output Analysis

Input-output analysis provides a snapshot of an economy at a particular moment in time. This research aims, however, to provide insight into what may happen to South

[3] Labour intensity is the jobs per unit of spending. It is the relative proportion of labour in any given process (Kenton, 2020)

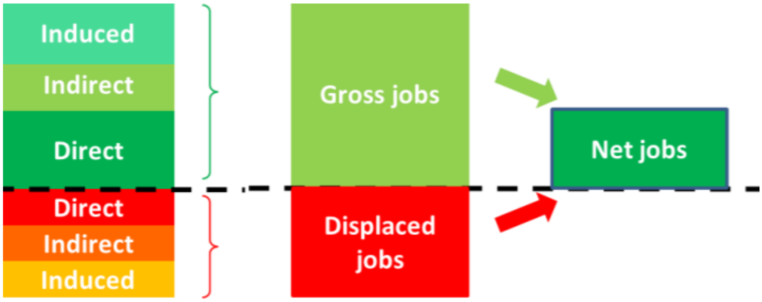

Figure 2.1: How net employment effects are calculated as the difference in jobs gained versus jobs lost. The line between the positive renewable effects and the negative effects from contracting fossil fuels can be understood as the current status quo. Source: (Blyth et al., 2014).

Africa's employment by 2030, not for the year the data was collected. While this study will be aligned with the IRP 2019 which has targets for 2030 (Department of Mineral Resources and Energy, 2019), there remains uncertainty as to how the future will actually unfold.

Scenarios may help to deal with the uncertainty as they explore the space of possible futures of complex systems (Kowalski et al., 2009). Furthermore, Wiebe (2018), suggests scenario exploration for a forward-looking input-output analysis once the input-output table accurately incorporates energy transition factors. Scenario analysis has been cited because it helps to integrate uncertainties for the different aspects which are to be explored as plausible futures (Kishita, Nakatsuka, & Akamatsu, 2017; Kowalski et al., 2009). Each scenario is an alternative representation of how the future may materialise (Peterson, Cumming, & Carpenter, 2003). Kowalski et al. (2009) distinguish three different types of scenarios. These are:

1. Extrapolatory, which forecasts the future as a continuation of the past.
2. Normative scenarios, which are oriented towards milestones and assume that the future can be created by the actions of the present.
3. Exploratory scenarios, which do not aim to predict the future, rather they describe a "possibility" space. Therefore, it should be emphasised that the scenarios developed do not include the probability that the scenario would occur.

Exploratory scenarios provide alternative descriptions of uncertain future states. By linking qualitative narrative with quantitative elements, exploratory scenarios may help us understand how a system works and evolves (Berkhout, Hertin, & Jordan, 2002). Consequently, they can be helpful for informing policy makers (Davis, 1999; Jefferson, 1983). This research takes an exploratory scenario approach. The future, is not claimed to be predicted here. Rather, we show what can happen if certain actions are taken, and conditions are met.

Scenarios may be developed, either as changes in money invested as in Garrett-Peltier (2017); Pollin et al. (2009, 2014). Alternatively scenarios can be reflected as different capacity mixes as in was done in Burton et al. (2018); Hartley, Burton, et al. (2019); Hartley, Merven, et al. (2019). These studies are the other South African studies that estimate the effects upon employment of renewable energy, using CGE models instead of input output analysis. Despite the methodological difference between this dissertation and these other studies, the scenarios developed are useful for comparison. For example, Hartley, Burton, et al. (2019) also presents a scenario with the capacity mix aligned with the capacity targets for the IRP 2019 (Department of Mineral Resources and Energy, 2019), which will also be done in this dissertation. Therefore, scenarios based on capacity rather than spending has been chosen for this research.

2.4.3. Level of aggregation when reporting on jobs

It was found in the literature search that studies vary in how their findings are presented. This depends on how many regions for which the analysis was done, the number of renewable energy technologies considered, as well as the number of scenarios. For example, IRENA (2020); Markandya et al. (2016) perform a multi-regional analysis and report on jobs per country. Conversely, Garrett-Peltier (2017); Pollin et al. (2014) report on jobs per technology for a single country. Markandya et al. (2016); Wu et al. (2021) report on jobs per sector as well as per type of technology. Wang et al. (2019) reports on the number of jobs per scenario and type of technology. Clearly, the reporting of jobs depends on what data has been available and what approach the authors took to measure employment for a forward-looking analysis. For a multi-regional IOA, the location of the jobs may become most important, for example. Therefore, this study will provide a breakdown of the net employment effects (in job-years) per scenario for the most stimulated sectors for the transition.

2.5. Incorporating Decent work into the IOA

In Section 1.1 the concept of "decent work" was introduced. This section shows how this broad topic may be approached using the results from an input-output analysis, particularly in the way the results are disaggregated and presented. This section also presents the potential policy implications of the results which are revisited in the conclusions — Chapter 5.

When considering decent work in the just transition, insight into the skill levels associated with the old and new jobs may be useful. One of the indicators of decent work according to International Labour Organisation (1999) are adequate earnings. In South Africa, these pillars to some extent are captured in the skill-level of workers. This is owing to the high correlation between skills and earnings in South Africa (Wittenberg, 2017). Skills development is a theme mentioned in much of the literature as a means to achieving decent work (Cohen & Moodley, 2012; Ghai, 2003). Therefore, investigating the skills dimension of the net employment effects of renewable energy may be useful. Hartley, Burton, et al. (2019) disaggregated employment by skill-level, providing useful insights into the old vs new jobs. Consequently, the level of requisite skills for the the employment effects per technology and per sector will also be reported on in this dissertation.

Lambert and Silva (2012) highlights the challenges in determining job quality for renewable energy jobs. Among the insights were that temporary jobs are less skilled than more stable jobs. Sastresa, Usón, Bribián, and Scarpellini (2010) assigned a quality factor to jobs using various inputs including temporal and territorial nature of the job. There are drawbacks in this method too as non-transparent "adjustment factors" are required. Lambert and Silva (2012) argues that it is judgemental to assume that that low specialisation jobs are of lower quality. Similarly, Del Río and Burguillo (2008) argue that in rural areas low-skilled jobs are likely to provide more benefits to the local community than highly skilled jobs. Clearly, there are many challenges to estimate the decent work prospects of renewable energy -requiring an extensive analysis of the topic. Consequently, a full analysis on the prospects of decent work and renewable energy in South Africa has been recommended for future work — see Section 5.5. This dissertation only attempts to provide introductory insights into decent work based on skill level of employees.

2.5.1. IOA and Industrial Policy

It is possible to preempt the nature of some of the results before the analysis has started. The input-output analysis will show a structural change in the economy. Whereby, some sectors are stimulated more than the current capacity and other sectors will diminish in importance. Policy advice will be given for an employment-centred energy transition, therefore the policy implications for a structural change in the economy will be explored. Policies of this kind begin to resemble industrial policy.

Industrial policy refers to government interventions to alter the structure of the economy, encouraging resources to move to particular sectors that are deemed to be economically advantageous (Altenburg et al., 2017). By anticipating long-term trends and market developments, respective governments can provide incentives to adapt the structure of the economy to benefit from these changes. Green industrial policy builds on industrial policy, whereby the environmental and economic conditions need to be key parts of the industrial policy making (Hallegatte, Fay, & Vogt-Schilb, 2013; Lütkenhorst, Altenburg, Pegels, & Vidican, 2014; Pegels, 2017; World Bank, 2012). Black and Gerwel (2014) argue that pro-employment policies are necessary in the agricultural and manufacturing sector. Therefore, government intervention is necessary to grow the manufacturing sector to achieve some sort of structural change. Altenburg et al. (2017) from the UN Environment and German Development Institute suggest various policy options to strengthen labour market performance with green industrial policies. These include deliberate government facilitation for workers in renewable energy in the following areas: i) mobility assistance and skill adjustments, ii) promoting entrepreneurship, and iii) decent work and social dialogue. Therefore, industrial policies will be drawn upon in the policy implications drawn from this research in Section 5.4.

2.6. Chapter Summary

The literature review may be summarised with the following implications for this research:

1. A knowledge gap was found inasmuch as more studies were needed that are able to model and quantify the employment effects of an energy transition in South Africa.

2. Most of the quantitative studies that investigated the net employment effects of renewable energy in South Africa, found in the literature search, used CGE models in their methodology.

3. Of the three primary methods used to estimate the employment effects of renewable energy, an input-output analysis was chosen. Input-output analysis may provide insight into the maximum potential of employment, hence the boundary for what is possible.

4. Most studies used scenario analysis for a forward-looking analysis. Accordingly, scenarios have been used for exploring the future of South Africa's energy space until 2030. The scenarios are based on different capacity mixes for South Africa's electricity system.

5. Most studies included the renewable energy sector into the input-output analysis using methods that resemble the synthetic industries approach presented by (Pollin et al., 2014). Therefore, this approach has been used for incorporating renewable energy into the input-output analysis.

6. Most studies calculated the net employment effects by comparing the cumulative job outcomes for different scenarios compared to the current status quo or "business-as-usual" case. The same will be done for this analysis.

7. Studies have varied on the level of aggregation to present results depending on the research purpose and data available. The results here have been presented in cumulative job-years per sector.

8. The level of skill was a concern raised by many studies and therefore the results have been disaggregated by skill level.

9. Results from the input-output analysis are likely to show a drastic shift in the structure of South Africa's economy due to the rapid introduction of renewable energy. To facilitate the structural change that the results will yield, the lessons and aims of green industrial policies will be used to interpret the results.

3

Methods and Data: Modelling net employment effects of renewable energy

It was determined that an input-output analysis (IOA) will be the quantitative modelling method used to estimate the net employment effects of utility solar and onshore wind in South Africa. This modelling method has been supplemented by data gathered by multi-actor stakeholder engagement. This chapter addresses the methodological sub-questions used to answer the main research question:

What are the possible net employment effects of South Africa's transition from coal to wind and solar forms of electricity generation?

Here the net employment effects are the differences in the number of jobs gained by the introduction of solar and wind and the jobs lost to coal dissolution. Therefore, the following three sub-questions were developed to make this estimation:

1. How does the lack of demand for local coal-fired electricity production and coal exports influence employment in South Africa?
2. How does the increased demand for solar and wind energy influence employment in South Africa?

As the research question aims to provide insight into what may happen to employment, the third sub question was developed:

3. Which scenarios should be considered when evaluating the employment effects of renewable energy by 2030?

The following sections will provide more elaboration on this method and how it can be used to calculate the net employment effects of renewable energy. The chapter is organised as follows:

- Description of how the input output analysis was used with the findings from stakeholder engagements. Section 3.1;
- Description of the basic framework of an input-output analysis. Section 3.2;
- Description of the I-JEDI tool and the data issues with the current model. Section 3.3
- Inclusion of a Negative Demand Vector for Coal to I-JEDI. Section 3.4
  - Addresses Sub-question 1
- How I-JEDI calculates jobs gained due to solar and wind energy. Section 3.5
  - Addresses Sub-question 2.
- Description of Scenarios and Sensitivity Analysis. Section 3.6
  - Addresses Sub-question 3

3.1. Input-output analysis and stakeholder engagements

The IOA is a macro-economic analysis of a system. To synthesise the analysis with some of the realities regarding the just energy transition in South Africa on the ground, a series of stakeholder interviews was held with experts in the energy space in South Africa- see Appendix A for the full list of stakeholders. Included are coal community representatives, academics, trade union representatives and private companies manufacturing solar energy equipment. This was done in collaboration with Institute for Economic Justice[1]. The format of the interviews were semi-structured, where the interviewees were asked questions regarding the just energy transition in South Africa. These included questions such as:

1. What does a just energy transition mean to you?
2. What are the issues that are of most concern to you regarding a just energy transition?
3. What are the challenges you see for achieving a just energy transition in South Africa?
4. What are the changes needed for a just energy transition in South Africa?

[1] https://www.iej.org.za/

These interviews were conducted in conjunction with the the IOA. Where possible, the data needed for how the scenarios were developed was supplemented by data from these interviews. The insights of the interviews were also used for interpreting the results of the IOA - see Chapter 4 for model results and discussion.

These interviews with experts were also supplemented with findings from a workshop attended, including approximately 25 energy sector workers and union members within the sector. During this workshop, the author's role was the position of a neutral observer and did not facilitate the discussion in any way. Figure 3.1 shows how the stakeholder interactions were used in conjunction with the IOA.

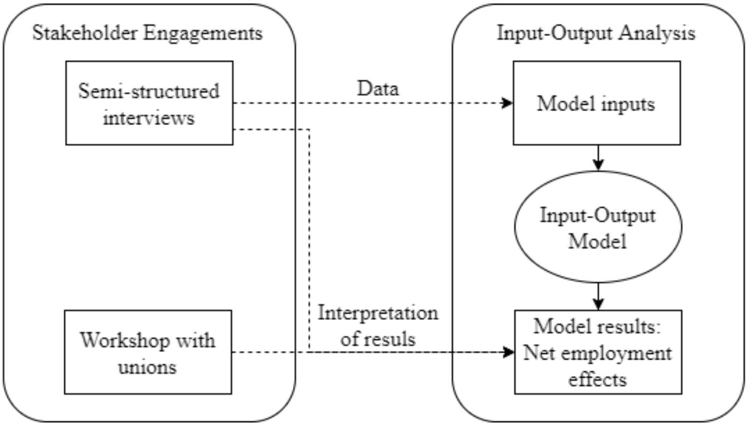

Figure 3.1: Methods diagram for the input-output analysis supplemented with stakeholder engagements. This diagram shows how the stakeholder engagements were used to supplement the input-output analysis (IOA). The model used in the IOA had several inputs, including parameters for the scenarios simulated and the sensitivity analysis that incorporated data from the semi-structured interviews. The workshop with union members has been used to interpret the findings from the model.

Model inputs that were informed by the data from the semi-structured interviews included inputs into the parameters for the scenarios simulated and the sensitivity analysis. The specific data for these parameters can be found in Section 3.6.2 and Section 3.6.4 respectively.

3.2. Input-Output Analysis: The Basic Framework

This section will outline the basic workings of an input-output analysis according to the leading textbook in the field authored by Miller and Blair (2009). The input-output analysis is typically shown for a particular country's economy for a particular year. It has the three components shown below that form the foundation of the model:

$$\mathrm{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, \mathrm{Z} = \begin{bmatrix} z_{11} \dots z_{1j} \dots z_{1n} \\ \vdots \ddots \vdots \ddots \vdots \\ z_{i1} \dots z_{ij} \dots z_{in} \\ \vdots \ddots \vdots \ddots \vdots \\ z_{n1} \dots z_{nj} \dots z_{nn} \end{bmatrix}, \text{and } \mathrm{f} = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} \tag{3.1}$$

Where, x is a vector showing the total outputs produced by an economy. Z is an $n \times n$ matrix that shows the inter-industry sales or monetary flows between sectors of an economy. n is the total number of sectors in the economy. Whereby goods sold to column j are produced by row i. From the row perspective, the inter-industry flows are each sector's outputs. Similarly, from a column perspective the inter-industry flows are the each sector's inputs. In other words, the columns show the intermediate outputs and the rows show the intermediate inputs needed to meet the demand. Hence the name input-output table. All primary inputs together are termed the value added for that sector j. f is a vector for final demand. Together, these three matrices form the following equation:

$$x = Zi + f \tag{3.2}$$

Here, i in Equation 3.2 is a column vector of 1's of dimension n. A fundamental assumption in the input-output analysis is that is assumes that the inter-industry flows from i to j depend entirely on the output of sector j for that same period. Based on this assumption, input-output coefficients can be determined with the following equation:

$$a_{ij} = \frac{Z_{ij}}{x_{ij}} \tag{3.3}$$

These coefficients require inputs in fixed proportions where a fixed amount of input is required to produce one unit of output. These technical coefficients are assumed to be fixed for a particular period. It therefore becomes possible to calculate how changes in an exogenous demand for a sector will change the output for all the industries that supply this sector in proportion to these fixed technical coefficients. For example, if exogenous demands for the sectors were forecast to be specific amounts next year, we can determine how much output from these sectors would necessary to supply these final demands in proportion to these coefficients. For this reason, an input-output analysis ignores economies of scales and thus operates on constant returns to scale. An $n \times n$ matrix of technical coefficients can be found with the following equation:

$$A = Z\hat{x}^{-1} \tag{3.4}$$

Where, $\hat{x}^{-1}$ is a diagonal matrix with the inverse of total output of each sector along the diagonal. Using the definitions in Equations 3.1, 3.2 and 3.4 the Leontief Input-Output model can be defined:

$$x = (I - A)^{-1} f = Lf \tag{3.5}$$

Where $(I - A)^{-1} = L$, which is known as the Leontief inverse or the total requirements matrix. I is an $n \times n$ diagonal matrix. With this model it is then possible to calculate how other economic indicators such as employment change in proportion to output due to the fixed technical coefficients and changes in final demand.

The exogenous demand for goods such as solar and wind energy generation components will increase the output of each sector that supplies those goods. It is then assumed that employment will be proportional to this extra output, hence new renewable energy jobs are created based on the exogenous demand for renewable energy services.

3.3. I-JEDI Model Overview and Improvements Made

This section outlines the model that was used to estimate the net employment effects of renewable energy in South Africa. First, a brief description of how the model works will be provided, followed by the issues identified with the model and hence some improvements and contributions made by this dissertation. The issues with the model include data issues, and its ability to only be able to calculate *gross* employment effects. Accordingly, the following are additions that this project added to the existing model to improve its capabilities:

1. Updated data and model assumptions. The current I-JEDI model uses the input-output transaction table (IOTT) for South Africa for 2011, sourced from the OECD [2]. This research will use more recent data with more industrial detail.

2. I-JEDI estimates the *gross* employment effects of renewable energy. This project added a vector to the model that estimated the direct, indirect and induced job losses owing to coal power plant dissolution in South Africa. Hence, making it possible to estimate the *net* employment effects.

The International Jobs and Economic Development Impacts (I-JEDI) model was developed by The National Renewable Energy Lab and USAID (Keyser et al., 2016). I-JEDI is an open-source model that estimates the employment effects from wind, solar and geothermal projects for several different countries, South Africa included. The tool uses an IOA and is able to estimate the direct, indirect and induced jobs created by solar and wind energy projects. This tool will be used as the core of the quantitative analysis of this dissertation.

The model starts with user inputs for the power capacity (MW) of the particular type of energy project. This is the power demand. Based on this demand for power, the model calculates the monetary demand based on the expenditures of the project. For example a solar project of 100MW will demand a financial value from certain industries such as construction and manufacturing. See Figure 3.2, for how I-JEDI maps demand project expenditures to create vectors for demand and hence calculate jobs per sector.

I-JEDI creates two demand vectors for each technology type by distinguishing between the construction and the operation and maintenance (O&M) phases of the projects

[2] https://www.oecd.org/sti/ind/input-outputtables.htm

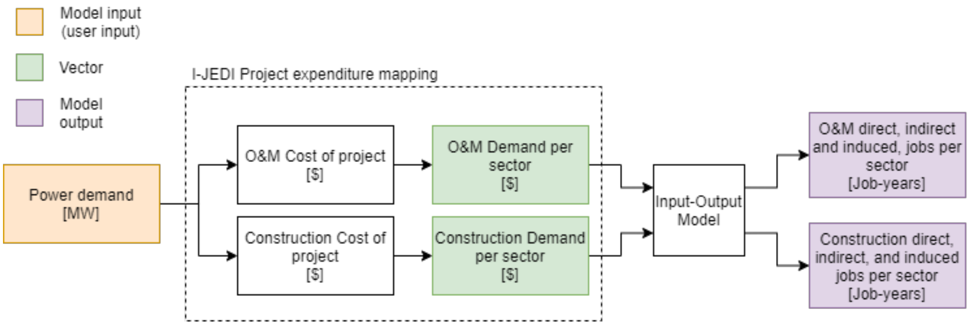

Figure 3.2: How the I-Jedi model calculates jobs based on power demand. The dotted line is how I-JEDI maps project expenditures to economics sectors, and is the main unique feature of the model. The user inputs a power demand. With various variables including country-specific data for the capital and operational and maintenance costs per MW [$/MW], the model calculates the cost of a project[$]. These project expenditures are mapped to sectors [$] to create demand vectors. These demand vectors are then used within the input-output model to calculate the jobs per sector [job-years] See Figure B.1 in Appendix B for a more detailed illustration of how whole the model works. See Section 3.5 for Figures B.2 and B.3 for a detailed illustration of the project expenditure mapping for solar and wind technologies respectively. "Job-years" refer to one person working full time for one year. See Section B.3 for a full explanation of the unit "job-years". Source: Author on I-JEDI.

lifespan. Construction and O&M differ in terms of the time scale. Construction jobs are once off. The results are equivalent to one year. Therefore if construction takes longer than one year it the number of jobs is divided proportionately. For example, if 500 jobs are supported in the construction phase of the project, but the project takes two years to construct, then 250 jobs are created annually for construction. O&M jobs are reported annually and are assumed to be constant for the entire life cycle of the project (Keyser et al., 2016). The I-JEDI tool, by default presents the results in "job-years", calculated based on the size of a renewable energy investment (MW). This was verified by reviewing the relevant literature — Lambert and Silva (2012); Pollin et al. (2014). "Job-years"/ MW installed capacity can easily be converted to "Job-years"/MWh electricity generated with the relevant capacity factors. Lambert and Silva (2012) reports on job-years/GWh, therefore this was done in this dissertation too. See Appendix B.3 for an extensive review on units for reporting on employment.

3.3.1. Data issues with I-JEDI and Improvements Made

The purpose of this section is to highlight the data issues identified in the default I-JEDI tool, as well as how these issues were improved by updating these data with data from Quantec Easydata[3]. These issues are summarised in Table 3.1. Each of these issues will

[3] https://www.quantec.co.za/easydata/

be elaborated on further in the subsections to follow.

This section will highlight the data issues identified in the default I-JEDI tool, as well as how these issues were improved by updating these data with data from Quantec Easydata. These issues are summarised in Table 3.1. Each of these issues will be elaborated on further in the subsections to follow.

Table 3.1: Data sources required for the input-output analysis

Data Issue	Default I-JEDI Data	Updated I-JEDI Data
Outdated data: Year of IOTT	2011	2019
Outdated data: Year of wind & solar PV expenditures	2014	2017
IOTT Aggregation level: number of sectors	OECD: 33 Sectors	Quantec EasyData: 91 Sectors
Data to calculate number of jobs	Average wages	Average wages for skilled, semi-skilled, low-skilled and informal employees

Outdated data

The period for the data that has been used in the model has two issues. First, there is the issue of the outdated IOTT. Secondly, there is the issue of outdated solar and wind project expenditures. These two issues are discussed in turn below:

While the model adjusts for inflation, this is still not valid as the structure of an economy will change over ten years, not just prices. Therefore, the stock-flow relationships and fixed input-output coefficients are to change in the long term. Leontief (1955) (the original theorist behind IOA) explained that the exploration of longer run IOA should exercise caution with regards to stock-flow relationships, structural time lags as well as technological change. As this dissertation examines the period 2019-2030, the data by 2030 would be 19 years old by last year of the simulation. Gumata and Ndou (2019) showed that there has been significant structural change in the South African economy for the period 1990-2017. This has occurred in terms of employment, nominal and gross value added, and sectoral growth. These are all indices which are relevant to an IOA. The issue of time IOA is an intrinsic limitation to the method. The only way around this issue is to use the most up to date data where possible and to avoid using a particular IOTT for projections to far into the future. Accordingly, the data used in this updated version was sourced for 2019, and can be considered superior to the original data sourced from 2011.

In the last decade, solar and wind technologies have been modernising at a rapid pace (Bischof-Niemz & Creamer, 2018). Economies of scale have been implemented in the technologies and thus the weightings of project expenditures has changed for each technology. For example, manufacturing would have constituted a larger proportion of project expenditures ten years ago as it would today, owing to the improved efficiency that certain components can be manufactured. The default weightings of project expenditures used in the I-JEDI come from 2014 (Wiser & Bolinger, 2014). The updated weightings for solar and wind come from these two reports published by IRENA respectively: IRENA (2017a, 2017b).

High level of Aggregation

The level of aggregation of the IOTT does not have the sectoral granularity to capture the transactions related to renewable energy accurately. For example, one of the sectors reflected in the table is "Manufacture of Basic Metals". Therefore, when creating a demand vector for the manufacture of the components of wind turbines, the demand for all different metals needed for a wind turbine has to be aggregated too. Therefore, the manufacture of non-ferrous metals such as aluminium and copper and ferrous metals such as steel will have to have a single aggregated demand. These metals, however, have a different market structure in South Africa. Accordingly, these sectors demand different amounts from other sectors (different inter industry coefficients) and they have different wage structures. Correspondingly, the demand for these metals will result in a different output, consequently different numbers of jobs created/destroyed do to the changing demand. Therefore, a lower level of aggregation is desired because with more resolution, more accurate results can be generated from the model.

The I-JEDI model does not attempt to model the job losses from coal-fired power plant dissolution. Even if it did, the data available from the OECD is insufficient to capture enough transactions to be representative of the whole coal energy supply chain. For example, the OECD data has a sector "Mining and Extraction of Energy Producing Products". This does not differentiate between coal and natural gas. Additionally, there is a sector: "Electricity, gas, water supply, sewerage, waste and remediation services". However, it is not clear how this sector could be disaggregated to isolate the electricity sector.

This issue has been improved with the Quantec EasyData IOTT [4].The data represented by Quantec EasyData shows the South African Economy disaggregated into 91 Sectors. This level of granularity increases the accuracy to which it is possible to pinpoint coal, solar, and wind activities. For example, with respect to coal there is a distinct coal mining sector, in the primary industry and a distinct electricity and gas sector.

With respect to solar and wind, there are distinct sectors in secondary sector for manufacturing that are useful for pinpointing the synthetic industries needed for the two technologies. For example, there is the sector for the manufacturing for "other fabricated metals". This is separate from the "manufacture of structural metals", which would be useful for mapping the expenditures for the tower of a wind turbine. The OECD database, nevertheless, aggregates the two of them. See Section 3.5 for a detailed description for how project expenditures are mapped to economic sectors.

[4] https://www.quantec.co.za/easydata/

Average wages to calculate jobs and decent work

Average wages are used in I-JEDI to calculate the number of jobs. Using the average wages may lead to a misleading egalitarian overview of South Africa's job market, which is not representative of the reality. South Africa has some of the highest pay gaps between skilled and unskilled labour in the world (Leibbrandt, Finn, & Woolard, 2012; Tregenna & Tsela, 2012). Wittenberg (2017), found through using household survey data found that wage inequality has increased over the period 2004-2011.

The decent work prospects evaluated here were based solely on skill level data and renumeration data of these skill levels available. Other factors that constitute decent work have not been considered. Semi-skilled and skilled work in these sectors are considered decent for this analysis due to the increase in pay compared to unskilled and informal work. Quantec EasyData contains detailed employment data per sector. The data sets include the number of people employed per sector disaggregated into i) formal skilled employees, ii) formal semi-skilled employees, iii) formal low-skilled employees, and iv) informal employees. Additionally, Quantec EasyData has average yearly remuneration for each of these categories of workers. These data were used to calculate the net employment effects disaggregated by skill level.

3.3.2. Summary of Data for the Updated I-JEDI Model

A summary is shown shown in Table 3.2 for the sources of data in the updated I-JEDI model which was used for making calculations in this dissertation.

Table 3.2: Data issues in the I-JEDI model and improvements made

Data type	**Data Source**
Input-output transaction table (IOTT)	Quantec EasyData
Solar & Wind Energy Industry project expenditure data	I-JEDI, IRENA (2017a, 2017b)
Coal Industry Demand Data	(Lyons & Gross, 2017), (South African Coal Roadmap, 2013)
Employment Data	Quantec EasyData.
Scenario Data	(Burton et al., 2018; Department of Mineral Resources and Energy, 2019; EScience Associates, Urban-Econ Development Economists, & Ahlfeldt, 2013; Hartley, Burton, et al., 2019; Hartley, Merven, et al., 2019; Urban-Econ Development Economist & EScience Associates, 2015) supplemented by expert interviews.

3.4. Modelling Jobs Lost Due to a Declining Coal Industry

This section answers the methodological sub-question:

How does the lack of demand for local coal-fired electricity production and coal exports influence employment in South Africa?

The I-JEDI model calculates output, hence the number of jobs by mapping project expenditures to the relevant economic sectors. This mapping is done by creating a vector for project expenditures - see Figure 3.3 for how this was done.

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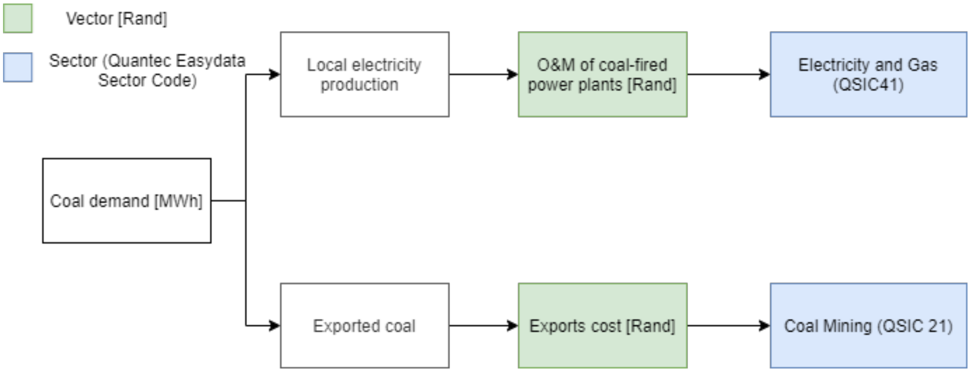


Figure 3.3: How demand for coal is mapped to economic sectors. Two coal vectors were created. One was created for local electricity production. The other was created for exported coal. Coal demand is measured in MWh of energy used as opposed to installed capacity due to fuel costs. For sectoral descriptions of the "Electricity and Gas"and "Coal mining" sectors, please visit `https://www.quantec.co.za/easydata/`.

As can be seen in Figure 3.3, two vectors were created based on the expenditures associated with the demand for coal. Only the direct demand vectors need to be developed. The input-output model then calculates the indirect and induced effects. Demand for coal has two functions in South Africa: coal is used locally for electricity production and exported abroad due to the supply surplus. The ratio is two-thirds used locally, while one-third is exported as per the South African energy balance for 2017 (Department of Mineral Resources and Energy, 2017). However, transforming South Africa's electricity sector to incorporate more solar and wind and less coal is independent of demand for South Africa's coal exports by international actors. Nonetheless, global demand for coal is decreasing. As per the International Energy Agency, investment into new coal fired-power plants is expected to drastically diminish (International Energy Agency, 2021). Therefore, it is important to consider the jobs that may be lost due to the a decrease in coal demand globally and how this may affect employment in South Africa. The question of exports is not a focus of this dissertation, but has been included as a factor in the sensitivity analysis - see Section 3.6.4.

It has been decided to exclude a vector for building new coal power plants. International Energy Agency (2021) has stated globally there should be a lack of investment into new coal power plants. Similarly, it was decided to exclude the activities that come with decommissioning coal fired power plants. This arises from the uncertainty in costs associated with coal fired power plant decommissioning as well as what options there are for post retirement. The costs of decommissioning arises from, as per Malley (2016):

1. The quantity of asbestos and regulated materials.
2. Presence of scrap markets.
3. Means of demolition etc.

Coal-fired power plant post-retirement options range from abandonment, decomissioning and retirement, conversion to natural gas plants or storage for pumped hydro energy. Malley (2016) stated that the costs of decommissioning a typical 500MW power plant costs 5-15 million USD *once-off*. This amounts to approximately 7% to 21% of the annual *ongoing* O&M costs of a 500MW coal-fired power plant in South Africa (Lyons & Gross, 2017). Assuming that the same employees (earning similar wages and work in the same sector) who work at these power plants also decommission the plant, it may be inferred that the jobs gained by coal-fired power plant decommissioning activities are not only temporary but also marginal when compared the jobs that could be lost. Therefore, even though precise data for the activities associated with decommissioning coal is missing or uncertain, the employment effects are likely to be small. For this reason, decommissioning activities have been excluded from the job calculations and have rather been recommended for future work - See Section 5.5. Accordingly, the coal vectors considered for this analysis are only for the operational and maintenance costs as well as for exports. Similarly, Pollin et al. (2014), only considers renewable jobs compared to the O&M phase of fossil fuel plants. This decision is consistent with the relevant literature.

3.4.1. Coal Energy Data

The I-JEDI model calculates demand through project expenditures. Correspondingly, it is necessary to determine the average operations and maintenance (O&M) costs for coal-fired power plants. O&M costs of a coal-fired power plant include all the activities that come with distributing electricity to consumers. These may be divided into variable and fixed O&M costs as outlined below. Moreover, data for coal exports is presented.

Variable O&M costs

Variable O&M costs change according to the amount of electricity produced in a year. Lyons and Gross (2017) distinguishes between variable O&M and fuel costs -see Table 3.3. Variable O&M costs refer to all variable expenses excluding fuel costs. The costs included are chemicals, water and waste disposal charges. Fuel costs for coal include all activities related to mining and extracting coal and the transportation of coal from the mines to the power plants.

Fixed O&M costs

Fixed O&M costs are constant regardless of the amount of electricity produced in a year. These costs include labor costs as well as costs for materials.

The IRP 2019 was developed by input from several resources. One such resource is the Power Generation Technology Data for the Integrated Resources Plan of South Africa, by the Electric Power Research Insitute (EPRI) (Lyons & Gross, 2017). This resource informed the capital and operational and maintenance costs for the IRP 2019. The EPRI was reviewed with the key data being extracted for the demand vector needed shown in Table 3.3.

Table 3.3: Key Data Extracted from Lyons and Gross (2017) needed for the operation and maintenance costs of coal-fired power plants.

Pulverised Coal Without Flue Gas Desulphurization (FGD)	**2017 Prices**	**Inflation Adjusted to 2019**
Variable O&M [Rand/MWh]	65.9	71.53
Fuel cost estimates [Rand/GJ]	31.1	33.76
Fixed O&M [Rand/kW*yr]	670	727.28
Capacity Factor	85%	85%

The figures in Table 3.3 are for coal-fired power plants without FGD as this is the most common type of power plant in South Africa. The data sourced from Lyons and Gross (2017) quoted figures for prices at of January 1 2017. These were then adjusted to prices equivalent January 1 2019 prices using https://inflationcalc.co.za. The variable O&M costs exclude fuel costs and refer to costs costs include "chemicals, water, and other consumables, plus waste disposal charges". Fuel costs here refer to the price of coal. Fixed O&M refer to labor costs as well as costs for materials. The verification of coal energy data can be found in Appendix B.2.

Coal Export Data

Pollin et al. (2014) do not consider coal exports in their calculations for the USA. Therefore, this vector was not used in the development of the two primary scenarios - see Section 3.6.3. It was, however, used in the sensitivity analysis, where the demand for exported coal was reduced in isolation of other variables to analyse its impact on employment - see Section 3.6.4.

The export price of coal was extracted from the data already present in the Quantec Easydata IOTT for 2019. This was to use the coal export value for the "Coal mining" sector. This value was 55726.85 MRand. Correspondingly, by dividing this monetary value by the amount of coal exported per year in MWh as per the South African energy balance Department of Mineral Resources and Energy (2017), we arrive at a value of 102.10 R/MWh. Two methods were identified to determine the costs for demand for coal exports. First, using the average coal export price multiplied by the mass of coal exported per year was considered. However, this has been at the selling price of coal, whereas the IOTT uses basic prices. Basic prices are the prices the consumer receives from the producer less taxes, plus subsidies and excluding any transport costs invoiced separately (OECD, 2013). Therefore, using the export price of coal in a table that uses basic prices would count the transport costs twice.

3.5. Input-output analysis and renewable energy

As discussed in Section 3.3, the I-JEDI model maps project expenditures to economic sectors to calculate the jobs created. The I-JEDI model maps project expenditures based on demand for renewable energy capacity to relevant economic sectors to create demand vectors for solar and wind projects. See Appendix B for how this mapping was done for solar and wind projects. This dissertation used an updated and more disaggregated input-output transaction table (IOTT) than what was in the original I-JEDI model. Hence the mapping was done to the new disaggregated sectors.

3.6. Scenarios for 2030

It was discussed in Section 2.4.2 that a scenario analysis is an appropriate method to conduct a forward-looking IOA. The scenarios developed here are *exploratory*. Exploratory scenarios describe a "possibility" space, where each scenario has a qualitative narrative linked to the quantitative elements (Berkhout et al., 2002; Peterson et al., 2003). Therefore we can see what may happen if certain actions are taken and conditions are met.

3.6.1. Experimental setup

The scenarios developed are all based on government-level interventions and do not consider the effects of exogenous factors, like price change due to technological improvement. To understand the development of the scenarios to calculate the *net* employment effects, the following thought experiment is posed:

> What are the net employment effects if coal generated electricity is *substituted* for solar and wind energy?

The key word in the above thought experiment is "substituted". Therefore, we investigate the difference in jobs based on the introduction of renewable energy displacing an equivalent amount of coal. This one-to-one substitution was done based on MWh of electricity generated for the period 2019 to 2030. Pollin et al. (2014), compares the construction and O&M of renewable energy to the O&M of fossil fuel disinvestment. Therefore, the same was done in this dissertation. This equivalent substitution is illustrated in Figure 3.4.

As shown in Figure 3.4, the installed capacity (MW) of renewable energy will demand a certain number of jobs. The jobs gained from the construction and O&M phases of renewable energy depend only on the power installed, not the electricity generated. This is due to the absence of marginal fuel costs of renewable energy. This is how the I-JEDI tool works. However, coal-fired power plants do demand jobs based not only on installed capacity for non-variable operational and maintenance costs but on variable fuel costs

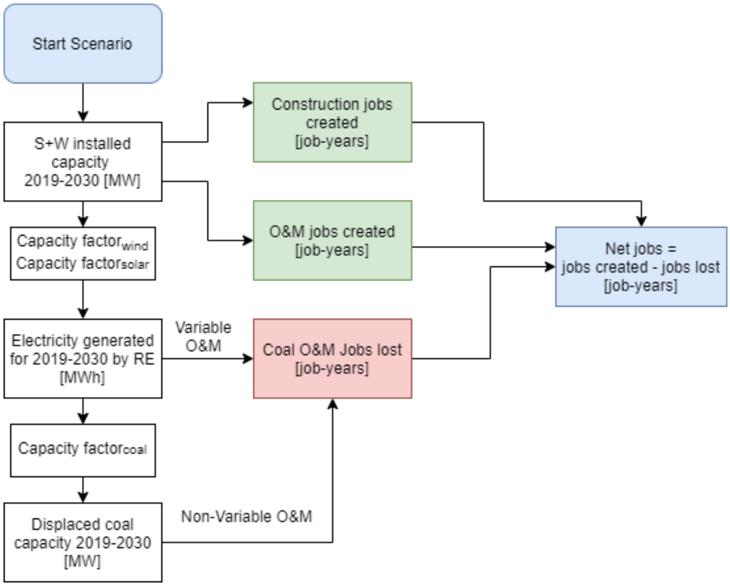


Figure 3.4: Scenario Setup. This diagram shows the process for developing the scenarios used in this research. Each scenario begins with an installed total renewable energy capacity [MW] for the period 2019-2030. This installed capacity creates jobs. The installed capacity of solar and wind technologies generates electricity based on average capacity factors of the technologies. This amount of electricity was used to calculate the variable O&M jobs lost owing to displaced coal electricity generation. Based on the electricity generated and the average capacity factor of coal-fired power plants, the installed capacity of coal can be calculated. Accordingly, the non-variable O&M jobs lost due to the displaced coal capacity can be calculated. Source: Author.

depending on the amount of electricity generated in a year. Therefore, the displaced coal jobs are calculated based on installed capacity and for non-variable O&M expenses and electricity generated for variable O&M costs.

The amount of electricity generated by wind and solar technologies was done Equation 3.6 below. E in Eq 3.6 was used for the variable O&M and fuel costs of coal-fired power plants. Note that fuel costs are based on power plant output and therefore coal fired power plant efficiency is not required.

$$E = \sum_{i=2019}^{2030} (P_{wind\,i} \times C_{f\,wind} \times (2030 - i + 1) + P_{solar\,i} \times C_{f\,solar} \times (2030 - i + 1)) \tag{3.6}$$

Where E equals the electricity generated by the combination of installed solar and wind capacity, P_{wind} is the installed wind capacity, P_{solar} is the installed solar capacity , $C_{f\,wind}$ and $C_{f\,solar}$ are the capacity factors for wind and solar projects respectively, i is the year that the renewable energy capacity was installed, hence $(2030 - i + 1)$ is the total time these technologies will be operating. The time assumed that these technologies will be operating was taken for the IRP roll-out schedule (Department of Mineral Resources and Energy, 2019). The time was based on when the technology was was installed. For example, a wind turbine installed in 2025 was assumed to be operational for the six years up to and including 2030. The committed capacity for solar and wind technologies was simply linearly scaled depending on the scenario. For example, if 1000MW was committed for solar in 2025 in the IRP 2019, this was then scaled to $1000 \times 50/32 = 1562.5MW$ in the Ambitious Solar and Wind (ASW) scenario, and was assumed to be operational for the years 2025-2030 see Table 3.4.

The capacity factor, C_f, is ratio of the average power generated divided by the peak rated power. It is vital in computing the amount of electricity generated by the power installed as both wind and solar technologies are intermittent and weather-dependent. Ayodele, Jimoh, Munda, and Agee (2012), estimated the capacity factor to be between 26.34% and 45.45% for the best wind turbines based on placement and technology in South Africa. The capacity factor ranges seasonally and at night. Similarly, Wright and Calitz (2018) found the average measured capacity factor for wind in South Africa to be 36%. Therefore a constant assumed capacity factor for wind was assumed to be 36% for the period 2019-2030. Similarly, Wright and Calitz (2018), found the average capacity factor for solar PV in South Africa to be 25%, which will also be used in this dissertation.

Table 3.4: IRP 2019 Power capacity roll-out schedule. Adapted from Department of Mineral Resources and Energy (2019). The net roll-out of coal is shown . Therefore, new coal installed minus decommissioned coal.

Year	Years in operation	Solar (MW)	Wind (MW)
2018	13	1474	1980
2019	12		244
2020	11	114	300
2021	10	300	818
2022	9	1400	1600
2023	8	1000	1600
2024	7		1600
2025	6	1000	1600
2026	5		1600
2027	4		1600
2028	3	1000	1600
2029	2	1000	1600
2030	1	1000	1600
Total installed		8288	17742

Similarly to Equation 3.6 the capacity coal decommissioned was calculated using the following formula:

$$P_{coal} = \frac{P_{solar} \times C_{f\,solar}}{C_{f\,coal}} + \frac{P_{wind} \times C_{f\,wind}}{C_{f\,coal}} \tag{3.7}$$

The above formula assumes that the decommissioned coal capacity happens in the same year that new renewable capacity is installed.

3.6.2. Two identified scenarios for 2030

Two scenarios were developed here that are designed to test the boundaries of the system. Hence, when comparing across the scenarios, a range of net number of employed persons can be analysed. Exploratory scenarios should be linked to narratives and should be informed by participation of relevant stakeholders (Berkhout et al., 2002). Therefore, while the primary source of data for the construction of scenarios was literature, where possible these were supplemented by information from interviews -see Section A.

The scenarios developed, in this research were created by using different values for the following input variables:

- South Africa's Renewable Energy Demand
- South Africa's Coal Demand
- Ratio between goods locally manufactured solar and wind products and imported products
- Demand for coal exports
- Export demand for South African manufactured solar and wind technologies

These five variables in the model can be interpreted as being responsive to government policies. For example, the ratio of locally manufactured content cannot be solely attributed to government intervention, but it does show the potential impact of certain industrial policy instruments such as local content requirements. The two scenarios developed are summarised in the Table 3.5. These are then elaborated on further in the subsections to follow.

Table 3.5: Scenarios run for the year 2030 in the input-output analysis

Scenario [ID]	Description	Data
Targets for IRP 2019 [IRP2019]	Solar: 6814MW. Wind: 15762MW. Total 8680MW coal decommissioned. Wind localisation: 47.4% - see Table 3.7. Solar localisation: 60.5% -see Table 3.6	(Department of Mineral Resources and Energy, 2019; EScience Associates et al., 2013; Urban-Econ Development Economist & EScience Associates, 2015).
Ambitious solar and wind deployment and manufacturing [ASW]	Solar: 10647MW. Wind: 24628MW. Coal decommissioned: 13562 MW. Solar exports: 1000MW. Wind exports: 7813MW. Wind localisation: 68.6% - see Table 3.7. Solar localisation:80.5% -see Table 3.6	(EScience Associates et al., 2013; Urban-Econ Development Economist & EScience Associates, 2015) Supplemented by industry interviews.

Table 3.5 refers to local content production. This also includes the balance of plant which refers to regular operation and maintenance of the plant which is assumed to be demanded from the electricity and gas sector. EScience Associates et al. (2013) and Urban-Econ Development Economist and EScience Associates (2015) made estimates for current local content of these technologies and potential local content in optimistic scenarios. Localisation possibilities are summarised for solar and wind in Tables 3.6 and 3.7 respectively. Scenario: IRP2019 uses localisation figures at present and ASW scenario use the ambitious localisation figures.

3

Table 3.6: Localisation of Solar technologies. Percentage cost of project from IRENA (2017a) and percentage localisation potential from EScience Associates et al. (2013)

Key component	% cost of project	% current local content	Current Total contribution	% Ambitious local content	Total content contribution
Module	30	23.9	7.17	84.3	25.29
Inverter	10	55	5.5	73	7.25
Balance of system	60	80	48	80	48
Total	100		60.67		80.5

Table 3.7: Localisation of wind technologies. Adaptation of Urban-Econ Development Economist and EScience Associates (2015).

Key component	% value of project	% Current local content	Current Total contribution	% Ambitious local content	Total content contribution
Tower	14.2	80	11.4	80	19.5
Balance of plant	45	80	36	80	27.4
Blades	9.1	0	0	60	5.5
Nacelle Assembly	2.1	0	0	80	1.7
Rotor Hub	4.3	0	0	38.7	1.7
Nacelle Drivetrain	12	0	0	15.4	1.9
Nacelle Exterior	2.7	0	0	90	2.4
Nacelle Interior	9.3	0	0	84.4	7.9
Nacelle Other	1.3	0	0	45	0.59
Total	100		47.4		68.6

Scenario: Targets for IRP 2019 [IRP 2019]

The purpose of this scenario is to evaluate what may happen to employment if the Department of Energy follows through on their decarbonisation commitments until 2030. Hartley, Burton, et al. (2019), used the predecessor to the IRP 2019, the IRP 2016 as the baseline, representing the policy planning status quo in the power sector . Correspondingly, the same has been done here only for the most recent IRP document - the IRP 2019. Therefore, the model results can be used as a used as a source of comparison to this study that used a different modelling method.

For the period 2019-2030, a total 6814MW and 15762 MW of solar and wind capacity will be installed respectively. The IRP 2019 does not specify any targets for locally manufactured solar and wind technologies. Therefore, these will all be treated as the status quo for localisation of project expenditures, with a total of percentage of the project cost of solar to be 47.4% as per Urban-Econ Development Economist and EScience Associates (2015) and 60.5% for solar as per EScience Associates et al. (2013). See Tables 3.6 and 3.7.

It should be noted that the IRP 2019 has a specific coal-fired power plant decommission schedule. The IRP 2019 has a schedule that includes 10590MW[5] of decommissioned coal (Department of Mineral Resources and Energy, 2019, p. 35). As per Equation 3.7, 8680MW coal capacity was calculated to be displaced and was used in this analysis. Therefore, the displaced coal capacity in this dissertation amounted to 17.3% less than what is specified in the IRP 2019 when considering the gross coal capacity displaced. Consequently, the net employment effects would be an indication of the upper bound of what is possible. This 17.3% difference has a marginal affect on the results. The aggregated net employment in job-years considering the construction and O&M phases of solar and wind projects changes by only 2.1%. Additionally, the employment figures are reported in job-years/GWh, in which case the the change in installed capacity makes no difference to the resuts at all. The reason for this decision to ignore the schedule was because the IRP 2019 decommissioning schedule is not based solely on the fact that solar and wind will replace the retired plants. Therefore, a direct comparison between clean energy and coal cannot be made using this decommissioning schedule.

Scenario: Ambitious Solar and Wind deployment and manufacturing [ASW]

This scenario may be interpreted as the best case scenario for expanding renewable energy while also maximising the options for local employment. Hartley, Burton, et al. (2019); Hartley, Merven, et al. (2019), both have a version of a rapid deployment of renewable energy scenario. This is useful as we can compare the best case scenario for wind and solar and see how that compares to the status quo. For example, if the best case scenario for wind and solar deployment still yields less jobs than what the coal supply chain employs then it will be very difficult to convince unions representing workers that a transition to wind and solar is beneficial to employment. Conversely, if the best case scenario show that more jobs are possible then having an employment centred just energy transition will be more feasible. This scenario has three pillars that would make it the ASW scenario as shown in Table 3.8. These three pillars will then be discussed.

Installed capacity of solar and wind assumes 50% of the capacity mix of South Africa. This is an increase on the IRP 2019 targets of 32%. This scenario also includes a high level of manufacturing of solar and wind technologies. For South Africa to be able to manufacture enough solar and wind technologies to meet demand, a substantial shift would have to be made in the economy. Rather than relying on mining, South Africa would

[5] The IRP 2019 also includes 5732MW of already contracted/committed coal capacity. Using this parameter, approximately 4858MW of coal capacity will be displaced according to the IRP 2019 for the period 2019 to 2030. It was decided not to consider the construction costs of new coal-fired power plants therefore this additional installed coal capacity was ignored.

Table 3.8: Scenario: Ambitious Solar and Wind Parameters

	Solar	Wind
Ambitious local solar and wind deployment	10647 MW	24628 MW
High level of local manufacturing of solar and wind technologies	80.50%	68.80%
Minor solar and wind technology exports	1000 MW	7813 MW

have to rely on manufacturing. South Africa currently manufactures very little solar and wind components. In 2016, solar PV manufacturing was just 520.5MW/year locally. Furthermore, while these were assembled and manufactured locally, only 40MW was done by a locally owned company ArtSolar (D. Baker et al., 2016).

An interview was held on 9 April 2021 with Respondent E — see Appendix A the owner and founder of ArtSolar, South Africa's only locally owned solar manufacturer. ArtSolar manufactures solar panels in South Africa. They do not do any of their own design work and they rely on imported goods from China. They are not a Tier One[6] company and therefore they are not able to bid directly for tenders from the South African government. Rather, there is a Tier 1 Chinese company, LONGi who bids for the tenders and then outsources some of their assembly activities and lamination activities to ArtSolar. They are currently expanding their current facility that has a maximum manufacturing capacity of 300MW per year. They are expanding their operations to increase an additional 500MW by July 2021. They believe at full capacity they will directly employ 450 workers. The indirect and induced effects are not known. This shows the movement currently within the manufacturing space in South Africa, whereby a few manufacturers are capitalising on the opportunity to manufacture what they can. Table 3.6 shows the localisation potential of solar PV technologies. Therefore this scenario will implement the ambitious localisation figures presented in this table.

This scenario may reveal the benefits of successful green industrial policy implementation. If the scenario has the potential to create many jobs, it is possible to advise which sectors the government may want to stimulate to create more manufacturing in the country to increase employment, not only directly but also the ripple effects this would have on indirect and induced employment. Finally, in the same interview , he revealed the following:

> **"I believe one of the reasons that the Chinese Tier 1 company decided to partner with us was because of our potential to be a large exporter to the rest of Southern Africa."** (Respondent E as interviewed by B. Kamanzi (IEJ) and A. Willis, see Appendix A)

According to the quote above, it seems that there are companies in China who see

[6] In general Tier 1 solar module manufacturers have been producing for five years or more, are publicly listed on the stock exchange, high degrees of automation and vertical integration, and have a strong reputation within industry (Sendy, 2021)

South Africa as an outpost to supply solar panels to the rest of Africa. In the interview it was revealed that the same Tier 1 Chinese company is currently assessing the prospects as using South Africa as an entry point to export to the US.

The scenario developed here considers South Africa as a exporter of solar and wind equipment. Here, we may examine a future in which South Africa relies not on exporting coal but rather one in which supplies the demand for wind and solar technologies to the rest of Africa. There is much uncertainty as to how much South Africa may be able to export. Therefore, an assumption was made to have a cumulative capacity of only 1GW exported from South Africa between 2019 and 2030. Averaging at 83MW worth of solar panels per year.

With respect to wind turbines, very little of the supply chain is localised. Towers, which make up approximately 14.2% of a project's expenditures are currently made up of approximately 80% locally manufactured content, contributing to approximately 11.4% of total local content (Urban-Econ Development Economist & EScience Associates, 2015). See Table 3.7 for the weightings of project expenditures as well as the localisation of each expense. In terms of wind exports, Urban-Econ Development Economist and EScience Associates (2015), found in an evaluation of the sub-Saharan African markets that have a high probable roll-out scenario: Ethiopia, Kenya, Lesotho, Nigeria and Mozambique. This is due to these countries having no local content requirements and wind potential in terms of electricity demand and wind availability. The potential market is 7813MW that South Africa may be able to penetrate by 2025, and is therefore used in this thesis.

3.6.3. Scenario Assumptions

As mentioned above, two scenarios were developed, each with its own narrative about the future of South Africa's energy mix. It is necessary to explain certain assumptions that were made and kept constant for all scenarios. These include decisions on time frame, inflation, and periods of substitution. These are outlined below.

Time frame

The scenarios show the cumulative effects of different energy mixes on employment from 2019 to the year 2030. This decision was made for the following reasons. The IRP 2019 has set targets for 2030, therefore this research aims to be as practically possible aligned with government policies on energy. Furthermore, since IOA assumes a permanent sectoral structure, projections too far into the future may not be relevant as the structure of the economy may change due to technological improvements or other factors. Pollin et al. (2014) justify their conclusions that by the year 2030 the labour structure of an economy will not change too much with technological change owing to renewable energy and therefore 2030 is considered sufficiently short term. The ratio of inter-industry flows and real wages[7] are assumed to be constant which is sufficient in the short to medium term (5 to 15 years).

[7] Real wages are distinguished from nominal wages. Nominal wages include inflation.

Furthermore, while we are interested in a transition (which implies a change over a period of time) from coal to wind and solar, there is uncertainty how this will actually unfold year to year. This is especially true due to the economic disruptions caused by the Covid-19 pandemic, for which the IRP 2019 was not able to consider. Therefore, analysing the results year by year will not be as useful as an in-depth analysis of disaggregated sectors that will provide an opportunity for employment for an aggregate period 2019-2030.

Inflation

Prices were kept constant for all scenarios simulated. Costs for project expenditures were all brought to the base year of 2019, as this is the year that the data for the IOTT. This was done using a inflation deflator of 2% per year for the quantities specified originally in USD. For the quantities specified in Rands, www.inflationcalc.co.za was used. Thereafter, prices were not adjusted for the period 2019-2030, as it was assumed that inflation for wages as well as inflation for project expenditures would increase by the same amount, thus cancelling each other out.

Period for substitution

A major assumption made for the calculation was that that the substitution of coal for wind a solar would occur in the same year.

3.6.4. Sensitivity Analysis

This section describes how the sensitivity analysis was conducted. Four variables were tested in isolation to determine the impact that the variable has on the aggregate (direct+indirect+induced) net employment effects of an energy transition for the construction phase and O&M phase of wind and solar projects. These variables were changed relative to the IRP 2019 scenario. The variables tested were:

- Reduced coal exports;
- Localisation content of solar and wind equipment and activities;
- Quantity of solar and wind manufactured in South Africa for exports;
- Exchange rate.

The scenarios above are descriptions of plausible futures. Within each scenario there are multiple compound effects and it is difficult to see how certain model assumptions affect the result in isolation. Sensitivity analysis, is a study of how the uncertainty in the model outputs can be attributed to the uncertainty in model inputs (Saltelli, 2002). The modeller assumptions are mainly in how the scenarios have been constructed. Therefore, a sensitivity analysis is useful for testing assumptions in the scenario development.

Reduced coal exports

Coal exports were reduced by 10% for the period 2019-2030.

Localisation content of solar and wind equipment and activities

An interview was held on 25 March 2021 with an environmental law researcher and advocate. When asked about their concerns over a just energy transition in South Africa, they responded with:

> **"One of my fears for the just energy transition is that many jobs may go to Chinese manufacturers instead of South Africans."** (Respondent D as interviewed by B. Baloyi (Institute for Economic Justice (IEJ) and A. Willis, see Appendix A)

Therefore, by comparing what would happen if all manufacturing jobs were demanded locally vs abroad, we may see if concerns such as this are justified.

Quantity of solar and wind manufactured in South Africa for exports

There is much uncertainty in the prospect of South Africa's green export capacity. Therefore, green exports were raised to the level stipulated in the ASW scenario, while keeping all other parameters constant. By increasing the exports capacity by a fixed amount, we may observe whether the impact upon employment is proportional to this increase or not.

Exchange rate

Owing to the fact that most of the solar and wind imports and coal exports rely on exogenous markets, the exchange rate that these assets are traded at may have a significant effect on the model outcomes.

3.7. Chapter Summary

This chapter is summarised as follows:

1. An input-output analysis was conducted to calculate the net employment effects of a potential transition in South Africa from coal to solar and wind forms of electricity generation.
2. A series of stakeholder engagements as well as a workshop with members of labour unions was used to supplement the findings of the input-output analysis.
3. The model used for this dissertation used the I-JEDI tool. The model was updated with more recent data with more industrial detail. The IOTT was sourced from Quantec Easydata.
4. Coal vectors for local electricity production and coal exports were added to the model.
5. Data for renewable energy was updated with recent, South African specific data.
6. Jobs were disagreggated by into direct, indirect and induced effects.
7. Jobs were disaggregated by skill level.

8. Scenario analysis was used for a forward-looking input-output analysis.

9. Two scenarios were created. First, there is the IRP 2019 scenario that corresponds to official government solar and wind targets. Secondly, there is the Ambitious Solar and Wind (ASW) scenario that is the most ambitious scenario for South African roll-out of renewable energy, with increased local manufacturing and development of a marginal market for solar and wind equipment exports.

10. A sensitivity analysis was conducted that examined the impact of four variables in isolation compared to the IRP 2019 scenario: i) reduced coal exports, ii) localisation content of solar and wind activities, iii) quantity of solar and wind manufactured in South Africa for exports, and iv) exchange rate.

4

Model Results and Discussion

This chapter presents and discusses the results of the input-output analysis in a multi-actor system. The results are presented in the following order:

- Section 4.1: net number of direct, indirect, and induced jobs;
- Section 4.2 jobs per unit energy generated;
- Section 4.3: jobs on the sectoral level;
- Section 4.4: employee skills;
- Section 4.5: sensitivity analysis;
- Section 4.6: model validation;
- Section 4.7: resistance to an energy transition and;
- Section 4.8: chapter summary.

The results compare the findings from of the two scenarios constructed IRP 2019 and the Ambitious Solar and Wind (ASW). The details of the scenario are reiterated in Table 4.1.

Table 4.1: Scenarios run for the year 2030 in the Input-Output analysis. Source: Author

Scenario [ID]	Description	Data
Targets for IRP 2019 [IRP2019]	Solar: 6814MW. Wind: 15762MW. Total 8680MW coal decommissioned. Wind localisation: 47.4% - see Table 3.7. Solar localisation: 60.5% -see Table 3.6	(Department of Mineral Resources and Energy, 2019; EScience Associates et al., 2013; Urban-Econ Development Economist & EScience Associates, 2015).
Ambitious solar and wind deployment and manufacturing [ASW]	Solar: 10647MW. Wind: 24628MW. Coal decommissioned: 13562 MW. Solar exports: 1000MW. Wind exports: 7813MW. Wind localisation: 68.6% - see Table 3.7. Solar localisation:80.5% -see Table 3.6	(EScience Associates et al., 2013; Urban-Econ Development Economist & EScience Associates, 2015) Supplemented by industry interviews.

4.1. Net Number of Direct, Indirect and Induced Jobs

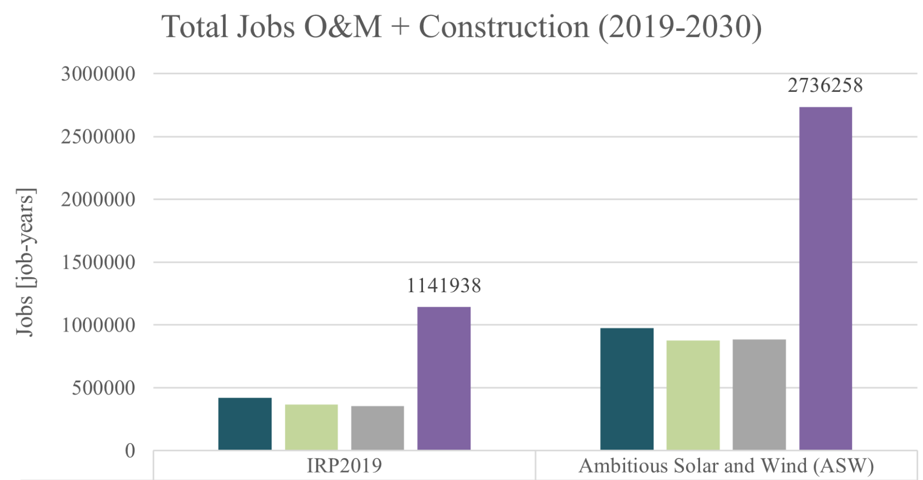
This sections presents the results for the net number of direct, indirect and induced jobs created by substituting coal-fired electricity generation with solar and wind energy. These definitions are reiterated below, using the an exogenous shock to the Electricity and Gas Sector as an example:

- Direct jobs: jobs that involve people working directly on the activities required to produce electricity. Example: employees of Eskom working as technicians at a power plant.
- Indirect jobs: jobs that are needed to supply goods to the industry directly impacted by a change in final demand. Example: jobs created in other economic sectors demanded by the Electricity and Gas sector such as jobs in the Coal Mining Sector.
- Induced jobs: refer to the jobs created or destroyed by changes in household expenditures because of the direct and indirect effects. Example: jobs created in a supermarket as coal miners spend their earnings working on groceries.

4.1.1. Total Jobs

This section presents the total employment impacts, in job-years, by the introduction of renewable energy into South Africa. The total jobs here are the sum of the net direct, indirect and induced job-years for both the construction and O&M phase of solar and wind projects.

As can be seen in Figure 4.1 nearly 1.15 million economy-wide jobs could possibly be created in South Africa as per the IRP 2019 that specifies newly installed capacity of 15762MW and 6814MW of wind and solar energy respectively. The net direct, indirect and induced jobs are distributed almost evenly at approximately 400 000 job-years each. Under the ASW scenario, the total number of jobs of could be increased by a factor of



	IRP2019	Ambitious Solar and Wind (ASW)
Net Direct	421110	975267
Net Indirect	367660	874851
Net Induced	353168	886140
Total	1141938	2736258

Net Direct Net Indirect Net Induced Total

Figure 4.1: Aggregate jobs for the construction and O&M requirements for the period 2019-2030. The jobs for the construction of solar and wind projects were added to the net O&M jobs associated with wind, solar and coal. Source: Author.

approximately 2.7. As a result approximately 2.7 million jobs are demanded. This is the main finding of this research that shows the overwhelming number of jobs that expanding renewable energy may create. Therefore, despite losing jobs to coal-fired power plant displacement by solar and wind, the net employment effects are substantially positive under the IRP 2019 scenario. The ASW scenario that included increased level of local content requirements as well as the a small amount of solar and wind equipment exports. It is interesting to highlight how these changes do not appear to change the ratio of direct, indirect and induced jobs.

Hartley, Burton, et al. (2019) calculated the gross employment effects in the construction phase of renewable energy. The results of this dissertation show that the IRP 2019 scenario is most similarly reflected in the results of their CSIR_LC scenario, that also yields approximately 1.2 million jobs. The IRP 2018 scenario simulated by the authors generated approximately 600 000 jobs in terms of gross employment for the construction and operations and maintenance of solar and wind projects. The differences in results may be due to the following:

- Different data in the input-output analysis. They used the I-JEDI tool that has an IOTT from 2011 and other design assumptions discussed in Section 3.3.

- Different input parameters. The authors simulate a scenario for the IRP 2018 in which 15.5 GW of renewable capacity is installed. This is compared to the IRP 2019 that specifies more ambitious targets of 22.576GW installed. In their IRP 2018 scenario, approximately 600 000 jobs for the period 2018-2030 were generated.

- Gross impacts as opposed to net impacts. The authors used I-JEDI to calculate the gross impacts. When it came to net employment effects they used the SATIMGE, which includes a a CGE model. Their definition of net employment effects was different to what was defined in this dissertation. In this dissertation, a one-to–to-one comparison was made between jobs created by the electricity generated by solar and wind to jobs lost by an equivalent amount of electricity generated by coal to be consistent with Pollin et al. (2014). The authors define the net employment effects to "account for the gross impacts as well as other employment changes that occur due to the impacts that the change in activity has on the overall economy (e.g., changes in prices, crowding out investment, etc.)." (Hartley, Burton, et al., 2019, p. 7)

The net direct employment effects of solar and wind by 2030 calculated by the authors under the CSIR_LC scenario amounted to approximately 94 000 job-years. This number is significantly less than the 42 0000 job years calculated in the IRP 2019 scenario for net direct employment effects. Despite the differences in the job-years, both studies indicate positive net effects, indicating that investing in renewable energy is beneficial to creating jobs.

Hartley, Burton, et al. (2019) used the I-JEDI model, therefore to evaluate the trustworthiness of the results of this dissertation, the IRP 2019 capacity was also simulated with the I-JEDI tool in Section 4.6.

4.2. Jobs per unit electricity generated

This section presents the results of the IOA per GWh of electricity generated. Lambert and Silva (2012) presents the results per GW installed capacity and per GWh electricity generated. Pollin et al. (2014) also presents the results per unit energy generated in Q-BTU. Due to the differing capacity factors of wind, solar and coal technologies, it was decided to use electricity generated (in GWh) as the reference unit for all the forms of electricity generated. The method used in this dissertation substituted an amount of coal capacity based on the amount of electricity generated per year by solar and wind sources of electricity. Therefore, the employment impacts of 1000MWh coal substituted for solar and wind is merely the impact of 1MWh substituted, scaled by a factor of 1000. This way, for different scenarios, with different electricity mixes not considered in this study, it will be possible to infer whether this will have positive or negative effects upon employment.

As can be seen in Figure 4.2, job-years per GWH of electricity generated by wind and solar is larger than the jobs created due to the O&M of coal by orders of magnitude. The direct, indirect and induced jobs in construction all appear to have the same form in

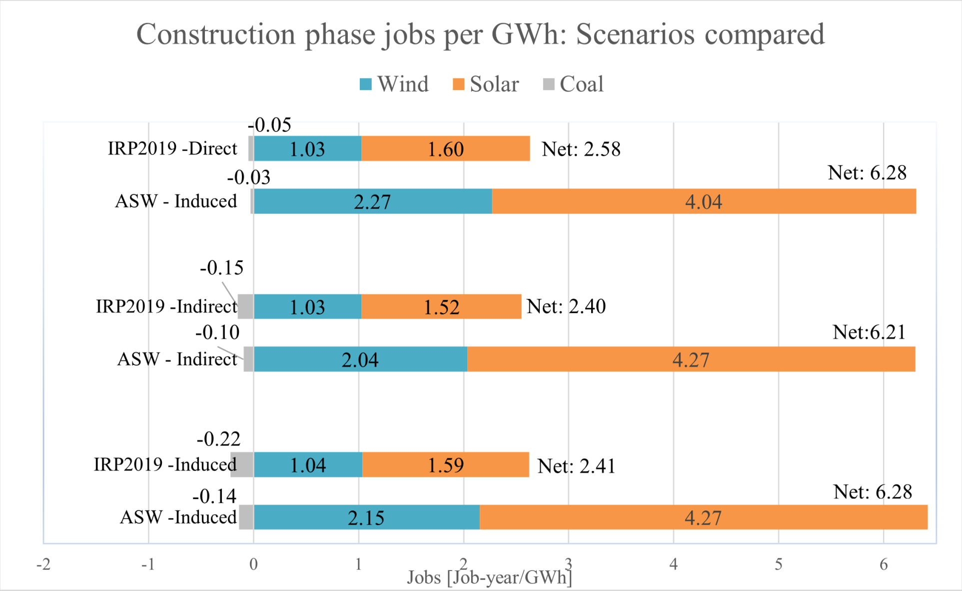


Figure 4.2: Construction jobs per GWh for each scenario. This figure shows the employment impacts in job-years per GWh electricity generated. Therefore, the differences that can be seen between the IRP 2019 scenario and ASW scenario are a result of the localisation of the technologies as well as the increase in exports of the green technologies. Pollin et al. (2014) compares the O&M jobs of fossil fuels to the construction jobs as well as to the O&M of renewable energy. Therefore, in these graphs job-years/GWh for the O&M of coal is compared to both the construction and O&M job-years/GWh of solar and wind. The net effects are shown at the end of each of the stacked bars. Source: Author.

that the job/GWh are similar for the different types of employment. If the changes were to be made as in the ASW scenario, employment would approximately double for direct, indirect and induced effects.

Figure 4.3 show the direct, indirect and induced O&M jobs per GWh of electricity generated. There are several notable results from these figures:

- The net direct employment effects are positive for the IRP 2019. The net indirect effects are negative for the IRP 2019, however this is at -0.03 GWh and can be considered negligible. The net induced jobs are negative for the IRP 2019 at -0.09GWh.
- The direct, indirect, and induced job-years/GWh are comparable for both wind and solar respectively. The indirect and induced jobs are much larger for coal than for wind and solar.
- The ASW scenario has positive net employment numbers for direct, indirect and induced effects.

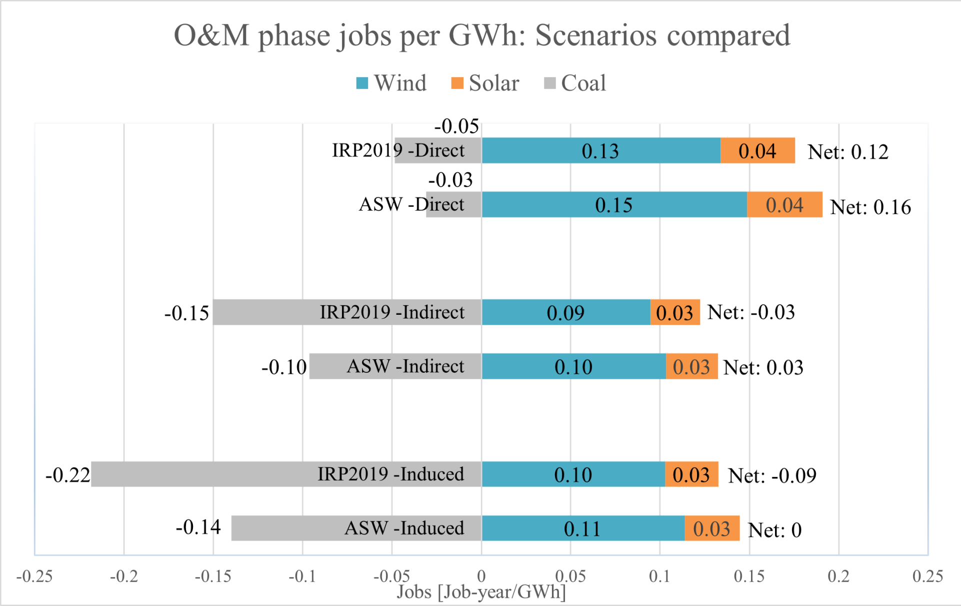


Figure 4.3: Operation and maintenance phase jobs for solar and wind projects per GWh. This figure compares the two scenario: IRP2019 and ASW Scenarios compared for direct, indirect, and induced effects. The net effects are shown at the end of each of the stacked bars. Source: Author.

Figure 4.3 shows net effects during the O&M phase of solar and wind as coal is simultaneously displaced. It is clear that in the IRP 2019 scenario there are net losses as a result of indirect and induced effects. The reason for the indirect and induced job losses being negative, while the direct jobs are positive may be a result of the strong inter-industry linkages that the Electricity and Gas sector has with other sectors such as Coal Mining. However, in the ASW scenario these negative indirect, and induced effects are mitigated.

Based on these key findings, it is clear that the jobs to be gained from construction far outstrip the jobs that may be lost due to coal power plant displacement. Therefore, under different plausible futures of alternative quantities of electricity generated, the net employment effects seem to always be positive for the construction phase.

For the O&M phase, the employment effects of renewable energy are understandably less labour intensive. However, the direct employment effects of solar projects cancel out the adverse effects of coal projects, while the wind projects create employment that is comparable to the net effects. The ASW scenario shows how the adverse net negative employment impacts could be mitigated with higher levels of localisation and manufacturing for exports.

The job-years/GWh for solar are greater for the construction phase, while the job years for wind are greater for the O&M phase. This suggests for long-term employment, it is better to invest in wind projects. However, for short-term employment gains, it is better to invest in solar projects.

Much of the suspicion of renewable energy comes from the fear that the jobs are once off and that once the construction of the power plants is finished, employees will be left stranded. The results here show that this sentiment could be mitigated if South Africa is able to increase its local manufacturing and green exports. Additionally, it should be clear that by 2030, coal will still constitute the majority of the electricity mix. Therefore, if more of the electricity mix were to transform, even more jobs would be needed for the construction phase of new solar and wind projects. In other words, while the construction phase involves an initial capital investment that is once off for a particular project, there is ample opportunity for South Africa to continue to expand its solar and wind capacity beyond 2030 creating construction phase jobs for the foreseeable future.

Additionally, the decommissioning/end of life and recycling phases of the renewable energy projects have not been considered in this analysis that could also provide opportunities for employment for those who were stimulated in the construction phase. As was revealed in an interview (see Table A.1 in Appendix A):

> **"Currently, solar panels that are old get sent back to China to be recycled"** (Respondent E as interviewed by B.Kamanzi (IEJ) and A. Willis, see Appendix A)

4.3. Jobs on the sectoral level

This section presents the jobs on a sectoral level. The dataset used for this analysis from Quantec EasyData has 91 economic sectors. For scoping reasons it was decided to analyse the top ten most impacted sectors per electricity generation source. The analysis was done for both the IRP 2019 scenario and the Ambitious Solar and Wind scenario.

As can be seen in Figure 4.4, the net employment effects are greatest in the top ten sectors. The employment fluctuations are noticeable for the top ten to twenty sectors. However, the employment impacts experienced in these sectors is much less significant than in the top ten sectors. From approximately the twentieth sector the net number of job years converges towards zero for the three different generation types for both the construction and the O&M phases of the solar and wind projects. Therefore, the decision to only focus on the ten most impacted sectors per technology type for each phase of the project and for each scenario is sufficient to capture the most consequential employment impacts. Figure 4.4 shows that the sectors directly affected by solar and wind, hence causing direct employment constitute a large proportion of the total jobs including the indirect and induced effects.

It is important to show the gross jobs gained owing to solar and wind energy expansion separately from the gross jobs lost from coal displacement. This way it is possible to investigate how the structure of South Africa's economy may shift during the energy

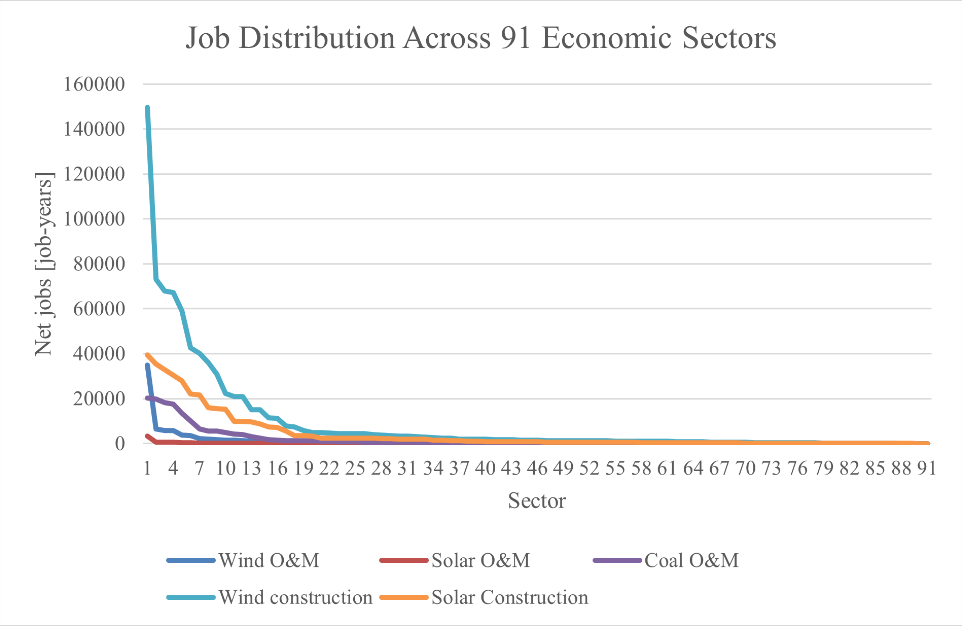


Figure 4.4: Job distribution across the 91 economic Sectors. This figure shows how the jobs are distributed across the economic sectors for the IRP 2019 scenario. The economic sectors were sorted largest to smallest according to net number of jobs for both the construction phase and OM phase of solar and wind projects. Source: Author.

transition. Therefore, the results to follow present the sectors most affected by wind, solar, and coal technologies. The employment effects of solar and wind have been added together for the construction and O&M phases, resulting in the total employment effects for the period 2019 to 2030 per sector.

4.3.1. Sectors most affected by a transition from coal to wind and solar

This section compares the different sectors stimulated by the different energy types. The results are presented in the following order. First, the top ten sectors stimulated for solar and wind electricity generation are compared to coal for the IRP 2019 scenario. Thereafter, the top ten sectors stimulated by the IRP 2019 scenario are compared with the top ten sectors stimulated by the ASW scenario.

The total sectoral employment impacts (direct+indirect+induced jobs) of the three electricity generation types are ranked and compared in Table 4.2. There are several key takeaways from Table 4.2 as outlined below:

- Five of the top ten sectors are common for solar and wind and for coal-fired power plants : "Retail trade"; "Business activities"; "Other activities"; "Sale, maintenance, repair of motor vehicles"; "Wholesale trade, commission trade".

Table 4.2: top ten Sectors impacted by the transition from coal to wind and solar for the IRP 2019 Scenario. Source: Author.

Rank	Construction + O&M Wind and Solar [IRP 2019]	Wind + Solar [job-years]	Coal-Fired power plants	Coal [job-years]
1	Building of complete constructions [QSIC 502]	190312	Electricity and gas [QSIC 41]	18289
2	Retail trade [QSIC 62]	112447	Business activities n.e.c. [QSIC 889]	17874
3	Business activities n.e.c. [QSIC 889]	109424	Retail trade [QSIC 62]	16581
4	Other activities [QSIC 99]	93187	Other activities [QSIC 99]	15897
5	Other electrical equipment [QSIC 364-366]	89912	Coal [QSIC 21]	12199
6	Wholesale trade, commission trade [QSIC 61]	77298	Sale, maintenance, repair of motor vehicles [QSIC 63]	9056
7	Sale, maintenance, repair of motor vehicles [QSIC 63]	56097	Agriculture [QSIC 11]	5799
8	Architectural, engineering and other technical activities [QSIC 882]	45046	Wholesale trade, commission trade [QSIC 61]	5030
9	Other fabricated metal products [QSIC 355]	42920	Catering and accommodation services [QSIC 64]	4961
10	Building installation [QSIC 503]	40372	Auxiliary transport [QSIC 74]	4479

- The net employment effects are positive when comparing the jobs gained vs the jobs lost for all top ten sectors.
- "Building of complete constructions" is the most stimulated sector during the construction phase for both solar and wind projects.
- "Business activities" and "Retail trade" are within the top three sectors for all three generation types.
- "Architectural and other engineering activities" become prevalent for solar and wind technologies.
- "Other fabricated metal products" becomes a significant sector for solar and wind, implying an increase of manufacturing jobs.
- "Other electrical equipment" is ranked fifth for wind and solar while being absent from coal.
- "Electricity and gas", "Coal mining", "Agriculture", "Catering and accommodation services", and "Auxiliary transport" are the sectors that will experience the biggest job losses due to the collapse of coal-fired power plants without being stimulated by solar and wind projects.

Based on the above points, it can be inferred that there are both threats and opportunities for jobs. The opportunities arise from the fact that five of the top ten industries are common to all generation types. It can in inferred that jobs will be relatively transferable based on the demand for a different product. The threats arise in that jobs will be most significantly threatened in the following sectors: "Electricity and gas", "Coal mining", "Agriculture", Auxiliary transport" and "Catering and accommodation services". These sectors should therefore be a focus for reskilling programmes.

However, there are new opportunities too in the following sectors: "Building of complete constructions", "Other fabricated metal products", "Other electrical equipment", "Architectural and other technical activities", "Land transport" and "Research and development". The most significant sector by far is the "Building of complete constructions" sector that demands approximately 150 000 job-years from wind and 40 000 job-years for solar over the 12 year period (2019-2030). It should be reiterated that these quantities above do not consider supply side factors, simply the demand for these jobs in the relevant sectors.

4.3.2. Sectors stimulated in the IRP2019 vs Ambitious Solar and Wind (ASW) scenarios

In Table 4.3 the top ten sectors for solar and wind are compared for the two scenarios: IRP 2019 and ASW. The change in the top sectors stimulated are highlighted in in purple for the different scenarios. Therefore, in the ASW scenario that includes more localisation of manufacturing of solar and wind equipment as well as increased manufacturing for exports of these green technologies it is possible to analyse how these changes impact the structure of the economy. It is clear that the sectors "Electric motors, generators and transformers" and manufacture of "Non-metallic mineral products" enter the top ten sectors for the ASW Scenario for wind and solar power projects. Consequently, the two sectors that exit the top ten for the IRP 2019 scenario are "Architectural, engineering and other technical activities" and "Building installation". While these two sectors are the only new entrants it is also important to note the rank order of the sectors. "Other electrical equipment" becomes the second most most important sector under the ASW scenario, showing that there will be a substantial increase in the manufacturing jobs as a result of the changes that come with the ASW scenario.

4.3.3. Discussion on the overall employment impacts per sector

It is clear that the sectors that may demand employment from solar and wind projects are different from the sectors that may demand employment from the coal-fired power plant supply chain. The most significant finding is that the sectors providing construction services are the most important for solar and wind projects. For the construction phase this is the "Building of complete constructions" sector. For the O&M phase this is the "Building installation" sector. The employment numbers demanded by these sectors are not out of reach of what South Africa’s labour force has to offer, considering its unemployment rate of 32.6% (Reuters, 2021). South Africa has established construction

Table 4.3: Sectors compared for the IRP 2019 scenario and Ambitious Solar and Wind (ASW) scenario. Source: Author.

Rank	IRP 2019 Sectors for solar and wind	Wind + Solar [jobs-years]	ASW scenario sectors for solar and wind	Wind + Solar [job-years]
1	Building of complete constructions [QSIC 502]	190312	Building of complete constructions [QSIC 502]	303803
2	Retail trade [QSIC 62]	112447	Other electrical equipment [QSIC 364-366]	271072
3	Business activities n.e.c. [QSIC 889]	109424	Retail trade [QSIC 62]	264242
4	Other activities [QSIC 99]	93187	Business activities n.e.c. [QSIC 889]	233956
5	Other electrical equipment [QSIC 364-366]	89912	Other activities [QSIC 99]	209406
6	Wholesale trade, commission trade [QSIC 61]	77298	Wholesale trade, commission trade [QSIC 61]	164201
7	Sale, maintenance, repair of motor vehicles [QSIC 63]	56097	Sale, maintenance, repair of motor vehicles [QSIC 63]	121301
8	Architectural, engineering and other technical activities [QSIC 882]	45046	Electric motors, generators, transformers [QSIC 361]	112295
9	Other fabricated metal products [QSIC 355]	42920	Other fabricated metal products [QSIC 355]	91970
10	Building installation [QSIC 503]	40372	Non-metallic mineral products [QSIC 342]	84153

and civil engineering industries that should be capable of recruiting workers to roll out renewable solar and wind projects. However, there are many other considerations for decent work that come with an increase in demand for construction workers. This is discussed in Section 4.4.2. The other finding is that many of the top ten industries are common across solar, wind and coal-fired power plants. This also implies that these sectors should be able to change their business model relatively easily based on the demand for a different product and then employ people as needed. This means that the need for industrial policies aimed at restructuring the economy are only necessary for a few sectors. Therefore, employment-centred green industrial policies should focus on facilitating the transition from the following sectors that stand to lose employees due to coal-fired power plant decomissioning:

- "Electricity and gas",
- "Coal mining",
- "Catering and accomodation services",
- "Agriculture", and,
- "Auxiliary transport".

Similarly, employment-centred green industrial polices should focus on the following sectors that provide the greatest opportunities for new employment:

- "Building of complete constructions",
- "Other electrical equipment",
- "Other fabricated metal products",
- "Architectural and other engineering activities"

Finally, the results of this analysis show that should South Africa achieve the levels of localisation as well as the market for solar and wind technologies as stipulated by the ASW scenario, the following sectors become of greater importance:

- For wind technologies:
  - "Electric motors, generators and transformers",
  - "Non-metallic mineral products",
- For solar technologies:
  - "Other electrical equipment"
  - "Agriculture"
  - "Catering and accommodation services"

The lack of investment into the "Electricity and Gas Sector" will undoubtably have implication on the future of Eskom. These implications have not been considered in this dissertation. In 2019 Eskom was unbundled into generation, transmission and distribution. According to the IRP 2019, the changes that will come from the energy transition will have to review Eskom's role as a buyer (Department of Mineral Resources and Energy, 2019).

4.4. Employee Skills

This section presents the net employment effects by by skill level. The data used for the disaggregation by skill level comes from the Quantec EasyData database for employment and remuneration whereby the data is disaggregated according to Table 4.4.

The key findings based on Figure 4.5 are as follows:

- The overall skill levels are similar across the sources of electricity generation.
- All the sources of electricity generation need approximately 40% of their workers to be semi-skilled.
- The informal sector provides a significant proportion of the work force ranging from 25% to 28% across the sources of electricity generation.

Table 4.4: Skill level definitions. Skills levels are derived from Stats SA (2021, p.40)

Skill level	Description
Skilled:	Professional, semi-professional and technical occupations. Managerial, executive and administrative occupations. Certain transport occupations, e.g. pilot navigator.
Semi-skilled:	Clerical occupations. Sales occupations. Transport, delivery and communications occupations. Farmer, farm manager. Artisan, apprentice and relate. Production foreman, production supervisor occupations
Low skilled:	Elementary workers. Domestic workers. All occupations not elsewhere classified.
Informal	The informal sector has the following two components: i) Employees working in establishments that employ fewer than five employees, who do not deduct income tax from their salaries/wages; and ii) Employers, own-account workers and persons helping unpaid in their household business who are not registered for either income tax or value-added tax.

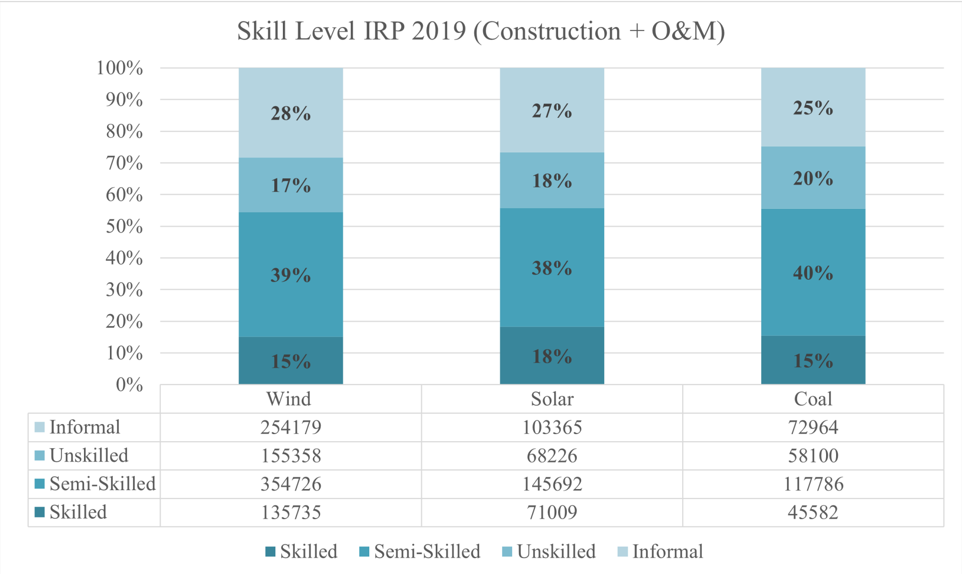


Figure 4.5: Jobs aggregated by skill level for the construction and O&M phase of solar and wind electricity projects per source of electricity generation. A stacked percentage bar graph was used to show the ratios of skill levels for each of the sources of electricity generation. The absolute number of job-years is proportional the cumulative jobs shown in Figure 4.1. These absolute values are shown in the data tables below each of the columns. The jobs for skill level for coal refers to O&M jobs. Source: Author.

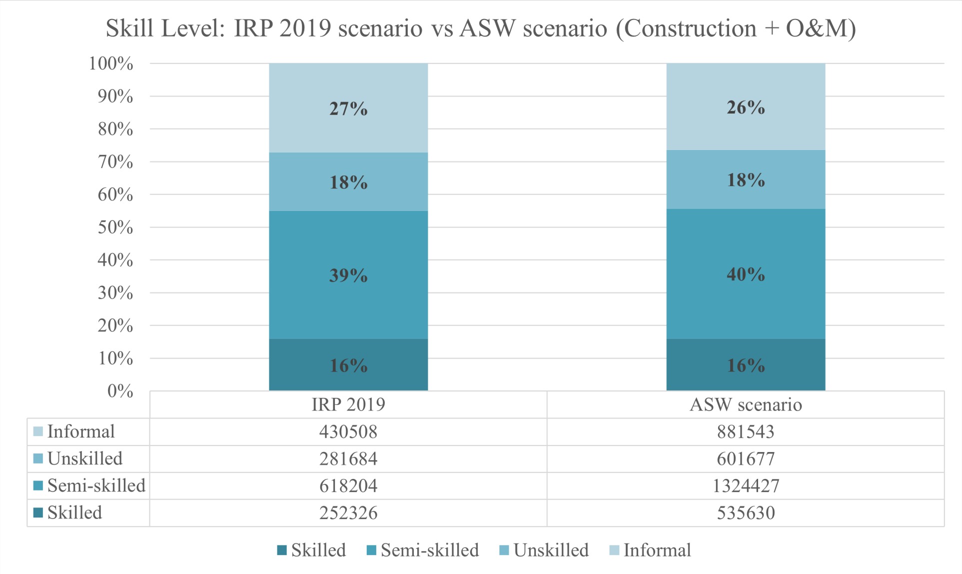


Figure 4.6: Total (direct+indirect+induced) jobs aggregated by skill level during the construction phase of solar and wind electricity projects per source of electricity generation. A stacked percentage bar graph was used to show the ratios of skill levels for each of the sources of electricity generation. The absolute number of jobs is proportional the cumulative jobs shown in Figure 4.1. These absolute values are shown in the data tables below each of the columns. The jobs for skill level for coal refers to O&M jobs and are the same for both the construction phase and the O&M phase of renewable energy generation. Source: Author.

- Skilled labour accounts for the smallest proportion of workers at approximately 15% for coal and wind. The exception is solar energy that demands 18% of the workers to be semi-skilled.

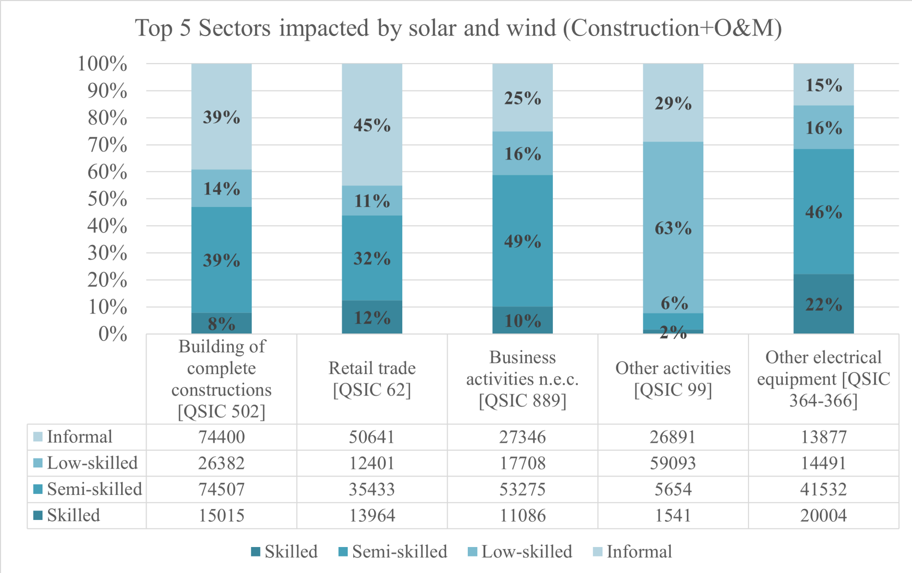
Figure 4.6 show that the skill levels do not change significantly with the proposed changes that come with the ASW Scenario vs the IRP 2019 Scenario.

4.4.1. Employee skills per sector

This section presents the employee skill level for the top five most impacted sectors by the introduction of wind and solar for the IRP 2019 scenario. Figure 4.7a show the skills aggregated for the construction and O&M phases for solar and wind projects. Figure 4.7b shows the skills in the top five sectors most impacted by coal displacement.

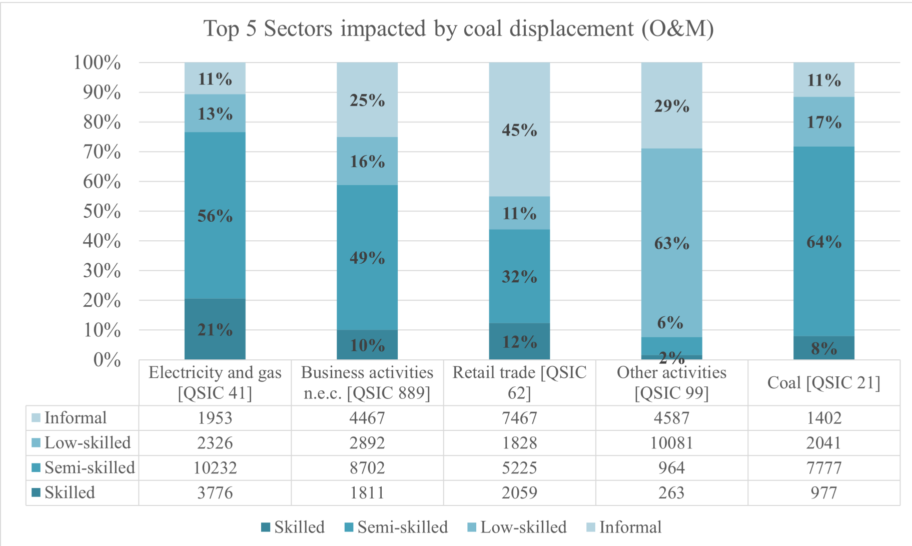
The key results based on Figures 4.7a and 4.7b are as follows:

- "Business activities n.e.c", "Retail trade" and "Other activities" are common to solar and wind and coal and therefore have the same skills profile. This may explain why, on average, the skills balance out.



	Building of complete constructions [QSIC 502]	Retail trade [QSIC 62]	Business activities n.e.c. [QSIC 889]	Other activities [QSIC 99]	Other electrical equipment [QSIC 364-366]
Informal	74400	50641	27346	26891	13877
Low-skilled	26382	12401	17708	59093	14491
Semi-skilled	74507	35433	53275	5654	41532
Skilled	15015	13964	11086	1541	20004

(a) Skills of the top five most impacted sectors by solar and wind projects. These results show the cumulative total of direct, indirect and induced jobs for the construction and O&M phases for solar and wind projects. Source: Author.



	Electricity and gas [QSIC 41]	Business activities n.e.c. [QSIC 889]	Retail trade [QSIC 62]	Other activities [QSIC 99]	Coal [QSIC 21]
Informal	1953	4467	7467	4587	1402
Low-skilled	2326	2892	1828	10081	2041
Semi-skilled	10232	8702	5225	964	7777
Skilled	3776	1811	2059	263	977

(b) Skills of the top five most impacted sectors by the displacement of coal-fired power plants. O&M phase direct, indirect and induced jobs shown.

Figure 4.7: Skill levels of sectors most impacted by the energy transition. Source: Author.

- The "Building of complete constructions sector", the most impacted sector by solar and wind projects has a large proportion of low-skilled and informal workers, amounting to 53% of the total workforce.
- The "Electricity and gas" sector has a large proportion of skilled and semi-skilled workers amounting to 77% of the workforce.
- "Other electrical equipment" stimulated by solar and wind projects has a similar skill profile to "Coal mining" with 68% of workers being skilled and semi-skilled and 72% of workers being skilled and semi-skilled for the two sectors respectively.

Based on the above findings, it is clear that there are similarities in skills between the five most stimulated sectors for solar and wind project and coal O&M. It should be highlighted that the "Electricity and gas" sector demands higher proportion of skilled and semi-skilled labour than any of the sectors most stimulated by wind and solar projects. These results suggest that that solar and wind projects provide more of an opportunity to employ informal and low-skilled workers than what coal is capable of doing owing to the high levels of construction employees required. This may be a way to create new jobs and potentially curb the devastating unemployment rate in South Africa that peaked at 32.6% in the first quarter of 2021 (Reuters, 2021).

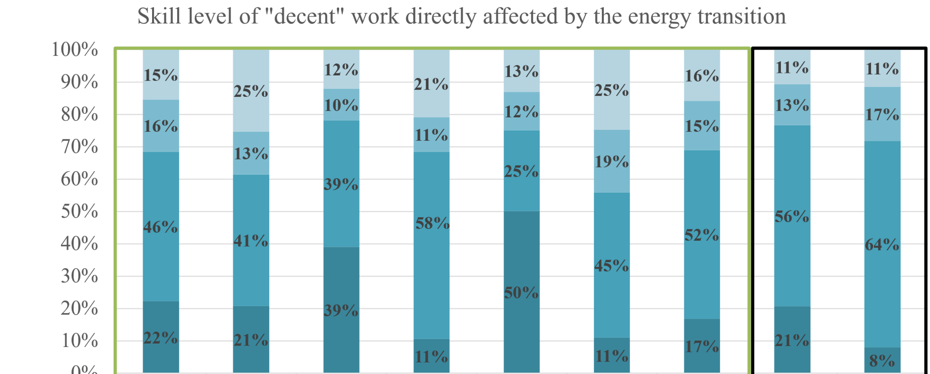
4.4.2. Employee Skills and Introduction to Decent work

A just energy transition is not only about creating employment but creating *decent* employment. As an introduction to the topic of decent work, insights from this analysis may be useful. Based on this input-output analysis, implications may be drawn from the level of skill which is highly correlated to worker remuneration in South Africa (Wittenberg, 2017). Adequate pay is an essential component to decent work (International Labour Organisation, 2018). The decent work prospects evaluated here were based solely on skill level data and renumeration data of these skill levels available. Semi-skilled and skilled work in these sectors are considered decent for this analysis due to the increase in pay and working conditions compared to unskilled and informal work. Moreover, semi-skilled and skilled work tends to have greater job security and employee protection.

The construction sector: "Building of Complete Constructions" appears to be the most stimulated by the energy transition as can be seen in Figure 4.7a. These sectors have high levels of unskilled and informal workers. Consequently, the working conditions and wages for these employees are likely to be very low and are considered by many to be exploitative [1] (Cohen & Moodley, 2012). This negative perception of construction jobs was a theme that came through in the stakeholder discussions and workshop with union members. Conversely, the "Electricity and Gas" and "Coal mining" sectors have high levels of skilled and semi-skilled workers -see Figure 4.7b. Therefore, it is unlikely

[1] This is not to suggest that the construction sector does not provide any opportunities for decent work. Figure 4.7a shows that the construction sector has approximately 47% skilled and semi-skilled workers. Rather, for those who may be wary of the low paying nature of the majority of construction workers, it may be interesting to investigate the opportunities for decent work outside the construction sector.

that those employed in these sectors would want to work in lower skilled positions and earn less as construction workers. International Labour Organisation (2019) state that in a greening economy, manufacturing for renewable energy systems are an opportunity for decent jobs workers with medium-level and high-level skills. Example jobs include product designers and production engineers. Renewable energy has the potential to create decent jobs as solar and wind installers, technicians, plant managers, quality engineers. Figure 4.8 highlights the sectors that are stimulated in the procurement and manufacturing of solar and wind technologies and compares the employment gains in these sectors with the employment losses in the "Electricity and Gas" and "Coal Mining" sectors. This figure shows the results for the ASW scenario. Therefore, we can see what the implications for decent employment are for the best case scenario for renewable energy.



	Other electrical equipment [QSIC 364-366]	Wholesale trade, commission trade [QSIC 61]	Architectural, engineering and other technical activities [QSIC 882]	Other fabricated metal products [QSIC 355]	Research and development [QSIC 87]	Non-metallic mineral products [QSIC 342]	Electric motors, generators, transformers [QSIC 361]	Electricity and gas [QSIC 41]	Coal [QSIC 21]
Informal	13877	19570	5428	8980	2020	3896	159	1953	1402
Unskilled	14492	10298	4443	4552	1834	3052	153	2326	2041
Semi-skilled	41533	31353	17592	24844	3844	7072	523	10232	7777
Skilled	20004	16082	17579	4538	7724	1726	169	3776	977

Figure 4.8: Skill level for decent work for the ASW scenario. The sectors in the green box show the skill levels for the sectors most stimulated in the construction and O&M phases of solar and wind projects. The sectors in the black box are the sectors that provide jobs to the most skilled and semi-skilled workers in the coal-fired power plant supply chain. Skilled and semi-skilled work may be considered decent for this analysis. Source: Author.

Based on Figure 4.8 the number of semi-skilled and skilled workers that may lose their jobs in the "Electricity and gas" and "Coal mining" sectors in the energy transition amount to approximately 30 500 jobs for the period 2019 to 2030 under the ASW scenario. These jobs lost constitute approximately 12% of the semi-skilled and skilled jobs directly demanded by solar and wind projects in the non-construction sectors. Therefore, these figures suggest that decent jobs in the "Electricity and Gas" and "Coal mining" sectors may be absorbed by the sectors providing decent work by new solar and wind projects as shown in the green box in Figure 4.8. For example the sector "Other electrical equipment" has the potential to absorb all the skilled and semi-skilled workers who may lose their jobs due to coal displacement. This sector would be responsible for employing workers who manufacture solar modules and inverters as well as those who manufacture equipment for wind projects such as transformers and transmission lines (Dvorak, 2020).

Baran et al. (2020) found that in the case of Poland the barriers affecting the job transition for coal miners included education and age, high earnings and work stability of coal mining, and public ownership and unionisation. They found that coal miners may not have the requisite skills in today's economy. Therefore, the results of this analysis and the implications for decent work are not to suggest that there is not a skills barrier and that the switch in vocation would be easy based solely on the education data. However, this does show that there may be a significant demand for many skilled and semi-skilled workers in the energy transition for manufacturing as well as unskilled and informal workers in the construction sectors. Therefore, there is the potential to create many decent jobs. Based on education levels from Quantec Easydata, those who currently have decent jobs in the coal energy sector may still benefit from the energy transition if these workers are provided with the opportunity to shift vocation. Example new jobs include wind turbine operators and solar technicians (International Labour Organisation, 2019). A more extensive investigation of the employment conditions in the sectors shown in Figure 4.8 is required to draw decisive conclusions about decent work and has been recommended for future work — see Section 5.5.

4.4.3. Insights from labour on a job transition

A one-on-one discussion was had at the lunch break of the workshop discussed in Section 3.1 with an operations and maintenance trainee supervisor. The supervisor was in charge of facilitating the training programmes for semi-skilled workers in the Electricity and Gas Sector. The conversation was in private without his comments being compromised by the presence of others. He was asked whether he thought young apprentices who were trained to work as O&M technicians on coal-fired power plants would relocate if there were jobs offered for renewable energy elsewhere in the country. He responded saying that he thought they would relocate since the jobs they currently have are not permanent owing to the Section 189 Act that allows employers to dismiss employees according to operation and maintenance requirements (South Africa, 1995).

This is an encouraging sign when considering the reskilling programmes that may be offered to workers to be able to transition from working on coal-fired power plants to solar and wind projects. During this same discussion he mentioned that every coal-fired power plant has an office to which workers can go to raise their concerns. Social dialogue such as this is considered one of the pillars of "decent work" (International Labour

Organisation, 1999). It is clear that workers in South Africa value this dialogue and are anxious of it being removed in the energy transition. Miners have worked tirelessly for decades to achieve the worker bargaining power and representation that they currently have. Clearly, there is a fear that this bargaining power may not be transferable when workers start working in the private sector. This was also a sentiment raised in an interview with a market policy coordinator of a labour union on 13 May 2021 when asked about what the key issues are for workers:

> **"Workers want to know if their previous collective bargaining rights will remain in the just energy transition"** (Respondent K as interviewed by B. Baloyi (IEJ) and A. Willis, see Appendix A)

4.5. Sensitivity Analysis

This section presents the results of the sensitivity analysis. As mentioned in Section 3.6.4, four variables were changed in isolation to analyse their impacts upon employment. The results below are the total employment effects whereby direct, indirect and induced employment figures have been summed together. The variables were only changed in one direction (either + or -) as due to the linear nature of IOA, the opposing sign would have the same effects structurally with a different sign.

The four variables changed in isolation were:

- reduced coal exports,
- localisation percentage,
- green exports,
- exchange rate

The effect of the above variables is shown in Table 4.5 and Table 4.6 following two tables. Table 4.5 presents the employment changes relative to the IRP 2019 base case in job-years. Table 4.6 presents the change relative to the IRP 2019 base case in percentage.

Table 4.5: Sensitivity analysis in job-years. Source: own calculations

	Wind [job-years]	**Solar [job-years]**	**Coal [job-years]**	**Net jobs**
IRP 2019 (base case)	**900357**	**388625**	**-162795**	**1126187**
Reduced coal exports	0	0	-143372	-143372
100% Localisation	+959114	+289884	0	+1248998
Green Exports	+60143	+10383	0	+70526
Exchange rate	+99680	+43208	0	+142888

Tables 4.5 and 4.6 both show the first row as the IRP 2019 base case. The rows below it show the *change* relative to the IRP 2019 in job-years and percentage in Tables 4.5 and 4.6 respectively. For example "+959114" (row 4, column 2) in Table 4.5 shows an increase

Table 4.6: Sensitivity analysis percentage. Source: own calculations.

	Wind [%]	Solar [%]	Coal [%]	Net jobs [%]
IRP 2019 (base case)	**100%**	**100%**	**100%**	**100%**
Reduced coal exports	+0%	+0%	+88%	-13%
100% Localisation	+107%	+75%	+0%	+111%
Green Exports	+7%	+3%	+0%	+6%
Exchange rate	+11%	+11%	+0%	+13%

in job years of this amount compared to "900357" job-years for wind under the IRP 2019 scenario. The key observations from Table 4.5 and 4.6 are discussed per variable in the following subsections.

4.5.1. Reduced coal exports

This variable shows the number of jobs that South Africa may lose if global demand for coal decreases. Approximately one third of all indigenously produced coal is exported (Department of Mineral Resources and Energy, 2017). This amount was decreased by 10% to analyse the effects on the model outputs.

The results show that reducing coal exports by 10% cumulatively by 2030 reduces the total number of jobs by approximately 140 000 job-years. In percentage this is a decrease of approximately 13% compared to the IRP 2019. This shows the importance of South Africa's coal exports. Clearly, exporting coal is highly labour intensive in South Africa. The model input was changed by 10% but its effect on the model outputs was 13% showing the disproportionate importance of South Africa's coal exports. A direct comparison in job-years/GWh between locally produced coal and coal exports was done too, outside of the sensitivity analysis - see Appendix C.

4.5.2. Localisation

This section shows the results for the employment impacts if South Africa is able to localise all of the direct costs for solar and wind power projects compared to the IRP 2019 scenario. If South Africa were to internalise all the activities needed for solar and wind power projects, the total number of jobs would increase by 111% according to the results.

It may be interesting to note that if all the direct employment activities are localised for the O&M activities for solar, the jobs are only increased by 6% when compared to the IRP 2019. This is owing to the low O&M costs for solar farms. Solar modules have no moving parts and are easy to maintain. Consequently, they need few job-hours to ensure they are maintained and operate sufficient. Solar modules are also famously robust and generally do not need many replacement parts. Therefore, localising all the replacement parts does not effect employment significantly. The low cost of O&M for solar projects presents a dilemma. Whereby, the costs are low therefore making them an attractive investment option and alternative over coal, however this also has its drawbacks in that the number of employees required to maintain the plants is proportionally low too.

4.5.3. Green Exports

By manipulating this variable we can see what may happen if South Africa is used as an outpost for green energy technologies by international companies or governments without increasing the percentage of locally manufactured content. For example, if solar modules are manufactured in China but sold through South Africa.

Green exports were raised to the level they were for the ASW scenario, while keeping all other parameters constant. This resulted in 7813MW worth of locally manufactured wind generation equipment and 1000MW worth of locally manufactured solar energy generation equipment. For wind this amounts to 49.6% of the newly installed capacity stipulated in the IRP 2019 for the period 2019-2030. For solar this resulted in 14.7% of the installed capacity stipulated in the IRP 2019 for the same period. This resulted in net employment increases of 7% and 3% for wind and solar projects respectively and 6% overall when compared with O&M costs too.

We can see that using South Africa as an output for solar and wind equipment to various international markets without increasing the locally manufactured content has marginal affects upon employment. This is something to be wary of as companies and politicians may boast significant export figures and claim the positive ramifications of it. However, this appears to prove successful only if it is also coupled with an increase in locally manufactured goods for solar and wind projects.

4.5.4. Exchange rate

The exchange rate variable was tested in isolation as this variable has a important role in the model. Many costs were originally quoted in USD and these were then converted to Rands. South Africa is currently dependent on importing solar and wind technologies. Therefore it is important to see how fluctuations in this model input affect the model's output.

The ratio of USD to Rand was increased by 10%, thereby decreasing the actual value of the rand and increasing the construction and O&M costs of solar and wind projects. This resulted in an increase of jobs by 13%. There is still uncertainty in this metric. South Africa does not have its own renewable energy sector as yet. Consequently, data for the exact costs of solar and wind projects is not known specific to the South African system. If South Africa manages to develop its own renewable sector and its own costing for projects and equipment, the dependency on the exchange rate should decrease.

4.6. Model Validation

This section presents the validation of the model results. Hartley, Burton, et al. (2019) calculated their *gross* employment effects using the I-JEDI tool, developed by (Keyser et al., 2016). The I-JEDI tool has many default parameters set for South Africa's wind and solar capabilities as well as data for South Africa's economy that may be considered outdated. See Section 3.3.1 for an evaluation of the JEDI data issues and the changes made in this dissertation. That being said it is the closest model for source of comparison. A direct comparion cannot be made to Hartley, Burton, et al. (2019) as they used the installed capacity for the IRP 2018, whereas this research used the updated proposal in the IRP 2019. Therefore, for validation purposes, the installed capacities for wind and solar were used as inputs into the I-JEDI tool. Consequently, the gross employment effects can be compared for the updated model and the I-JEDI tool.

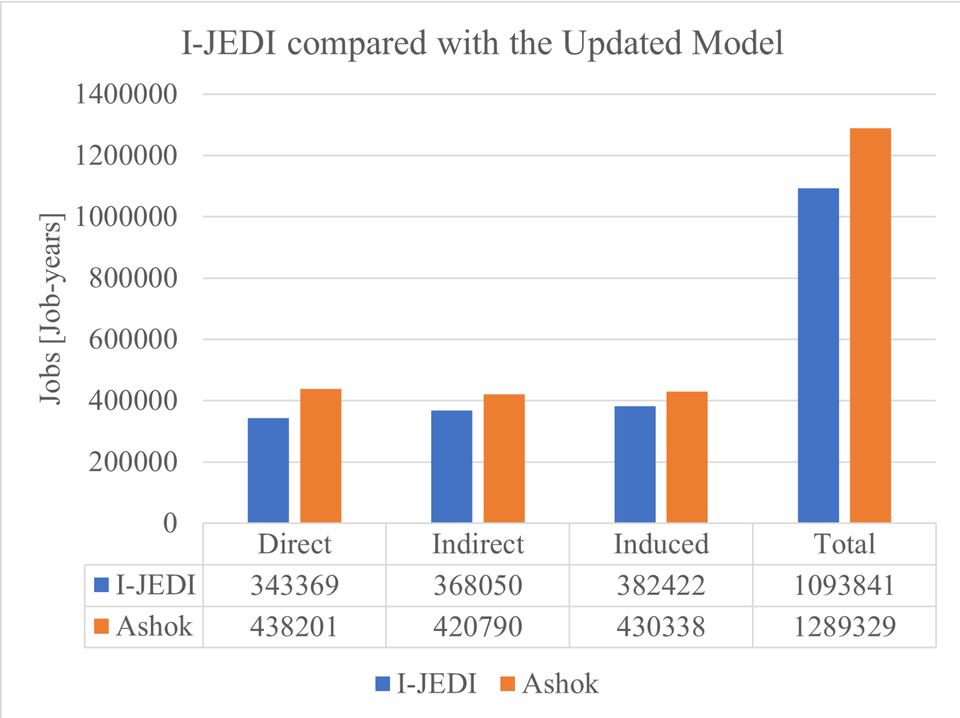


Figure 4.9: Model trustworthiness: original I JEDI model compared to the Updated model. The overall gross employment effects for the construction and O&M phases for solar and wind are shown. "Ashok" in the above model refers to I-JEDI tool with the changes made in this dissertation. Source: Author.

Figure 4.9 show that despite many changes in the data used, the models produce similar results when looking at the aggregate impacts. The overall employment impacts from the updated model yield about 20000 more jobs in total for the construction and O&M phases. The overall structure of the results and the relationships between direct, indirect, and induced effects are similar. Therefore, the changes in this made in this thesis may be considered trustworthy and fit for purpose when examining the employment effects.

4.7. Union Resistance to an Energy Transition

This section discusses the tensions and dilemmas that are apparent when discussing climate change with labour unions[2]. Discussions on the position of labour on the just transition, particularly in the energy sector, can create tensions, particularly among workers that feel that a transition can negatively affect their livelihoods. In a workshop with energy sector workers and union members within the sector, clear areas of contention arose. After the introduction to the topic of climate change and renewable energy, the workshop became so contentious that it was canceled by union members. During this workshop, the author's role was the position of a neutral observer and did not facilitate the discussion in any way. This section uses findings from this workshop as well as statements made by unions in the past to discuss these tensions and dilemmas. A dilemma can be understood as a problem situation that has at least two possible solutions that both positive and negative consequences (De Bruijn, Ten Heuvelhof, et al., 2010).

4.7.1. Dilemma: threats of climate change versus threats of an energy transition

There is a dilemma in that the effects of climate change may adversely affect workers in myriad ways. Similarly, the necessary intervention to slow climate change may also adversely affect workers. Perhaps this could be summarised best by one participant in the workshop that exclaimed:

> **"What is more harmful, climate change or hunger?"** - Participant 1

This quote resonates as it is important to understand the privilege that comes with discussing climate change and that workers struggling to earn a living wage cannot afford to sacrifice in the short term for the long-term well-being of the planet. This gravity of this sentiment is often missed in the literature. This sentiment came after the participants were asked about what climate change is, its causes, and its effects on the livelihoods of workers. It was clear that union representatives understood the human influence on the changing climate as well as how it will affect the marginalised. Examples raised by the participants included recent floods in Mozambique owing to climate change, cattle starvation because of droughts, job losses due to workers unable to plough land due to extreme weather conditions, and an increase of basic food prices such as tomatoes.

When it came to the causes of climate change, tensions started to arise. Their response when it came to the causes of climate change mostly focused on the transport sector and the emissions released by motor vehicles. The effect that coal-fired power plants have on carbon emissions was downplayed by some respondents and denied by others. Therefore, people understood and felt climate change. However, they were not prepared to discuss the role of coal mining as a cause and the possible alternatives.

[2]The names of labour unions has been removed due to sensitivity issues.

They explained how there were technologies that would solve the problem such as carbon capture and sequestration. The participants moved the discussion towards climate change scepticism and renewable energy criticism. One participant explained that climate change was an opportunity exploited by capitalists to make a profit. Another member was sceptical of the timing of the meeting, considering a recent G7 summit to discuss climate change. It was clear that there was a fear that South Africa would simply adopt what the agenda of European countries.

This event shows that labour unions, like all other strategic actors, clearly make decisions based on what will be best for their bargaining and political interests. The workshop also shows the shows the slow pace of discussing change, even in a setting that was intended as being a safe space with actors with similar goals. The meeting while aimed at providing a platform for the union to voice their concerns, ended up collapsing due to mistrust, further delaying progress. Union members seemed to feel attacked and thought that their comments would be misrepresented if they continued with the workshop. Consequently, they asked for their names on the participation register to be removed. One of the concluding remarks of the meeting was:

> **"Let it be known that we reject [this discussion on] climate change."** -Participant 2

4.7.2. Tension: Privatisation of the energy sector

Participants in the workshop raised the issue that is currently affecting workers as the government has started to adopt more renewable energy: privatisation of the energy sector and the future of state-owned enterprises (SOEs). The Renewable Energy Independent Power Producers Programme (REI4P) is a programme designed by the Department of Mineral Resources and Energy (DMRE) to diversify South Africa's energy mix. The programme first began in 2011. In so doing, the programme includes the private sector to procure energy. The programme is structured to contribute to the broader development objectives of job creation, social upliftment, and broadening economic ownership (Department of Mineral Resources and Energy, 2021). The REI4P has bidding windows[3] for competitive tenders that are awarded for various renewable activities from manufacturing to installation. The programme has proven very effective at attracting the private sector expertise and investment (D. Fourie, Kritzinger-van Niekerk, Nel, et al., 2015). While being heralded by some, it has also been criticised for its lack of success for reducing South Africa's aggregate carbon emissions and viscous cycle of poverty (Lawrence, 2020). In spite of these criticisms, REI4P is, at present, South Africa's main industrial policy measure.

It was clear at the workshop that the unions were wary of this process and were concerned about the future of SOEs at large and how workers were currently being affected by certain policies such as the Section 189 Labour Relations Act (South Africa, 1995). The meeting collapsed before the respondents expanded on this topic.

[3] Bidding windows are periods for which companies bid for tenders.

The issues regarding workers in the face of an energy transition raised by the participants were:

- Privatisation of energy
- Section 189 of the labour relations act, which allows employees to be dismissed for operational requirements
- Fears of losing all our coal to exports to China and Japan.
- The future of state-owned enterprises.

After raising concerns, union members decided to cancel the meeting and not proceed with the workshop. This was a decision made as they believed discussing climate change was a conflict of interest and compromised their position politically.

4.7.3. Tension: lack of a single voice within labour

This section uses findings from positions of labour unions that have been made in the past. Some unions representing workers in South Africa have made it clear that they are open to discussion pathways towards a just transition, whereas other unions have not made official statements on the matter.

Congress of South African Trade Unions (COSATU) is a labour union that has broad terms of workers, representing all workers in South Africa. Other unions such as National Union of Mineworks (NUM) and National Union of Metalworkers South Africa (NUMSA), specifically focus on miners and metalworkers, respectively. COSATU recognises the necessity of moving away from a high carbon economy powered by oil and coal to a low-carbon economy powered by wind and solar, while still rejecting privatisation of the energy sector (COSATU, 2011; Pamla, 2018). Similarly, according to IndustriAll (2018), General Secretary of NUMSA (National Union of Metalworkers South Africa), Irvin Jim, has stated that:

> **"We demand a Just Transition, which will ensure that workers at coal-fired power plants who may lose their jobs as a result of the transition from fossil fuels to renewable energy, will be trained and absorbed into the renewable energy sector."** - Irvin Jim (IndustriAll, 2018)

The above quote suggests that NUMSA is prepared to engage in discussions on worker demands in the just transition. This may be because metal workers may benefit from certain manufacturing activities with solar and wind activities. Conversely, from the search of official statements of NUM, there is no official position on sustainability or renewable energy, only a rejection of independent power producers (NUM, 2018). This may be owing to the fact that, inherent to the energy transition, is a lack of investment into coal. Consequently, coal miners will inevitably lose in the transition if there are no packages that adequately deal with their loss of work. Perhaps at this stage NUM does not see a way that the workers they represent may benefit from the transition. The results of this analysis have shown that the most stimulated sectors in the energy transition are the "Building of complete constructions" and the "Building installation" sectors for the construction and O&M phases of renewable energy respectively. As per the NUM website, NUM (2021), they are in the process of extending their representation from miners and workers in the electricity sector to workers in the construction sector. This research could be used to garner the support of NUM, and labour in general, as the construction sector workers are part of the cohort they are aiming to represent.

Furthermore, while this branch of NUM that is in the Mpumalanga coal region is concerned with coal, other mineworkers which NUM also represents in other regions of the country are slowly adopting renewable energy as a source of energy to electrify the mines (Roodbol, 2021). It is to be expected that any significant technological transition will be met with resistance. Therefore, despite the results of this analysis showing positive net effects upon employment in an energy transition in South Africa, the conflicting views within a multi-actor arena is still a challenge, even between the labour unions. Therefore, the presentation of these results must be done sensitively and consider the emotions that arise when the topic of employment is raised.

While South Africa does reduce her dependence on coal, it should also be made clear that coal will still have a significant role in South Africa's energy future. The IRP 2019 states that coal will have an installed capacity of 33364MW despite an increase in renewable energy too (Department of Mineral Resources and Energy, 2019). Therefore, unions representing coal workers will still have a significant role to play in South Africa's energy future going forward.

4.8. Chapter Summary

The results of this chapter are summarised as follows:

1. 1.14 million cumulative job-years for the period 2019-2030 for the O&M and construction phases of renewable energy roll-out under the IRP 2019 scenario for installed capacity.
2. The cumulative job-years for the period 2019-2030 could be more than doubled to approximately 2.7 million job-years for the same period under the ASW scenario. This scenario included, among other changes, 80.5% localisation of solar project activities and 68.8% of wind project activities, see Table 3.8.
3. Job-years/GWh are significantly higher for solar and wind than coal in the construction phase for both the IRP 2019 and ASW scenarios.
4. Job-years/GWh are higher for coal than for solar and wind in the O&M phase for indirect and induced jobs for the IRP 2019. With the ASW scenario these job losses are balanced out.
5. The skill level in terms of education required for all three electricity generation types are approximately the same.

6. There are opportunities to create employment for low-skilled and informal workers in the various construction sectors as well as opportunities for semi-skilled and skilled workers in the various manufacturing sectors. This suggests that there may be many opportunities for creating decent employment outside the construction sectors too.

7. The employment effects are concentrated in the top ten sectors for wind, solar and coal for the O&M and construction phases.

8. The most stimulated sector is the "Building of complete constructions" for the construction phase of solar and wind. The most stimulated sector for the O&M phase is "Building installations". This is the case for both wind and solar electricity generation.

9. The "Electricity and gas", "Coal mining", and "Auxiliary transport"sectors are the most threatened by coal displacement.

10. The sensitivity analysis revealed that there is a disproportionate increase in job losses due to a reduction of coal exports. This indicates that if South Africa loses a a coal export market due to global trends, direct, indirect and induced jobs as a result a diminishing coal mining industry are likely to be threatened.

11. Localising all the direct costs for solar and wind electricity production would increase employment by approximately 111% compared to the IRP 2019 scenario.

12. Exporting green technologies through South Africa only makes a significant impact upon employment if it is accompanied by local manufacturing.

13. Labour Unions are faced with the dilemma of climate change impacts versus energy transition impacts. Unions are not always unanimous in their positions towards renewable energy. The resistance of unions poses a significant barrier to achieving an energy transition. The interaction with unions is, however of utmost importance when achieving a just energy transition.

5

Conclusions

This dissertation aims to contribute towards the research on just transitions in South Africa in two ways. Firstly, by providing quantitative insight into the extent of the employment impacts caused by a potential energy transition in South Africa. Secondly, this research aims to contribute to the policy discourse for an employment-rich energy transition. This chapter concludes this dissertation by discussing these contributions. Subsequently, the main research question posed at the outset of this research is addressed, followed by the limitations and the implications that the results have for policy. Finally, the implications that this research has for future work are presented.

5.1. Contribution

Ward et al. (2020) found that socio-economic and climate modelling for national planning is one of the research gaps that, if filled, would be the most beneficial to the support of just transitions in South Africa. From the literature search, a knowledge gap was found that there is a scarcity of studies that used modelling methods to calculate the net employment effects of South Africa's potential transition from coal to wind and solar forms of electricity generation. Therefore, an input-output analysis (IOA) was conducted to address this knowledge gap. Owing to the capability of an IOA to estimate indirect and induced impacts on top of direct impacts, it provides useful, albeit imperfect, insights into South Africa's just energy transition employment potential. No resource limitations were imposed on the model, therefore the results show the maximum potential employment effects of this transition, considering South Africa's economic structure as of 2019. The results of the analysis are exploratory, testing the boundary of the system. Therefore, the implications drawn from the results are intended with this exploratory purpose in mind.

IOA may be considered superior to some other modelling methods such as CGE modelling owing to the method's transparency for other researchers, the relatively simple data requirements, and there are many case studies that have used this method providing a useful form of validation and comparison. Moreover, IOA does not make neo-classical hidden neo-classical assumptions such as perfectly competitive markets or full employment.

The I-JEDI input-output model was used, updated with more recent data for South Africa that has more industrial detail. This appeared not to significantly affect the structure of the results and trustworthiness of model was deemed uncompromised – see Figure 4.9. Additionally, a coal displacement vector was created to calculate the jobs displaced due to lack of demand for coal-fired power plants. Hence, the net employment effects were calculated by comparing the jobs gained by solar and wind to the jobs displaced due to coal-fired power plant disinvestment. This quantitative method was supplemented with findings from a series of semi-structured interviews and a workshop with union members to ground the results in some of the realities of South Africa's socio-political landscape. Two exploratory scenarios were created that were simulated in the model, each with their own narrative about South Africa's future electricity prospects: IRP 2019 scenario and the Ambitious Solar and Wind (ASW) scenario. The IRP 2019 scenario was aligned with the most recent government plans to transform the electricity mix. The ASW scenario included higher levels of local manufacturing of solar and wind technologies than currently employed.

The insights gained from this research, presented in Chapter 4, that may be scarce in other literature include:

- the net employment effects of South Africa's energy transition calculated solely by an input-output analysis;
- the presentation of the employment potential of the different sources of electricity per unit of electricity generated;
- breakdown of jobs per sector and skill level. Of particular interest may be the overwhelming demand for construction workers that come with the energy transition that are comprised of high-levels of informal and unskilled labourers;
- sensitivity analysis that investigated the employment effects of reduced coal exports, the impacts of localisation; and green exports and;
- insights into the deep tensions that comes with discussing labour disruptions and the impact that an energy transition may have on people's livelihoods. This was done by presenting findings from key stakeholders in South Africa's energy transition space as well as discoveries from union members and energy sector workers who will be affected by an energy transition.

5.2. Answer to the Main Research Question

The main research question posed in Chapter 1.4 was as follows: **What are the possible net employment of effects of South Africa's transition from coal to wind and solar forms of electricity generation?**

The results of this analysis show that the possible maximum net employment effects of an energy transition are:

- 1.14 million cumulative job-years for the period 2019-2030 for the O&M and construction[1] phases of renewable energy roll-out under the IRP 2019 scenario for installed capacity.
- The cumulative job-years for the period 2019-2030 could be more than doubled to approximately 2.7 million job-years for the same period under the Ambitious Solar and Wind scenario. This scenario included, among other changes, 80.5% localisation of solar project activities and 68.8% of wind project activities, see Table 3.8.

The results were also presented in job-years/GWh for electricity generated for the two scenarios. Therefore, we can analyse, regardless of the electricity generated, if investing in renewable energy is more labour-intensive than the direct, indirect, and induced activities associated with coal-fired power plant operations and maintenance (O&M). The results of the analysis show that net employment effects in the construction phase were significantly higher than the jobs that may be lost due to coal displacement. This was true for jobs created by the direct, indirect, and induced forms of employment. The net direct employment comparison between solar and wind and coal during the O&M phase was positive. The net employment effects were, however, negative for the indirect and induced jobs in the IRP 2019 scenario. In the ASW scenario, these negative effects were mitigated. These results suggest that by increasing localisation to approximately 80.5% for solar and 68.8% for wind, coupled with exporting some renewable energy equipment, the adverse indirect and induced employment effects of coal-fired power plant displacement may be mitigated.

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At the most fundamental level, decent work is about creating access to employment and income opportunities (International Labour Organisation, 1999). Taken together, the net employment effects for the construction and O&M phase of solar and wind expansion show a net increase in employment in South Africa and show that there are opportunities for decent work in South Africa's energy transition. Further opportunities and challenges for decent work are considered in Section 5.4.2.

5.3. Limitations

Before proceeding to the implications for policy, it is important to present the limitations of the study. Consequently, the purpose for which these results should be considered will be clear. The limitations below are for the IOA method and therefore can be considered limitations of any IOA study.

1. The model assumes that relative prices are fixed. Therefore, the of prices of commodities and wages are constant throughout the analysis.

[1] The construction phase of solar and wind projects is distinguished from the construction sectors. The construction phase refers to the jobs created in the period needed to roll out a particular project. The construction sectors however refer to the economic sectors providing services to renewable energy projects in either the O&M or construction phase a particular project's lifespan.

2. The model assumes fixed industrial structures. The inter-industry coefficients as of 2019 are assumed to be constant throughout the analysis. Consequently, the model behaves linearly. Therefore, economies of scale and "learning-by-doing" effects are ignored.

3. IOA is a demand-based analysis and therefore does not have any supply-side constraints. As a result, it assumes that the number of people, having the relevant skills, required to work in the various sectors are available in South Africa. Additionally, all the required resources and capital is assumed to be available.

Points 1 and 2 above have the following implications. The IOA should not be used to project results too far into the future. Authors such as Pollin et al. (2014) argue that 2030 is sufficiently short term for projections regarding renewable energy, especially for activities heavily reliant on the construction industry as is the case in this research. Additionally, the activities required for solar and wind projects including manufacturing, transport, and installation are unlikely to change in the short to medium-term. The lack of time dynamics means that for a different time horizon in the model, the nature of the results would not be different. However, using IOA for projections much further than 2030 is not recommended due to the fixed nature of the inter-industry linkages.

The specific job numbers are not to be interpreted literally. Rather the relative employment prospects between technologies is important as these are all subject to the same conditions. Similarly, the comparison of the direct, indirect and induced employment effects per technology are most relevant. Coal is a mature technology and it may be assumed that "learning-by-doing" effects and technological improvement do not play a role. Therefore, this limitation may have less importance when interpreting the job losses due to coal displacement. Moreover, the third point above indicates that the model results may be an overestimation due to the lack of supply-side constraints. These results should be interpreted as the upper boundary of what is possible in South Africa if the demands for solar and wind are met by supply-side considerations.

There are another limitations of this analysis, aside from the intrinsic limitations to the IOA. These include:

- The energy mix developed in the scenarios do not consider technical issues for solar and wind technologies such as intermittency and the need for a base load. Solar and wind technologies are fundamentally dependent on weather cycles that are intermittent, highly variable, and not always accurately predictable. The intermittent electricity supply that comes from solar and wind technologies does not necessarily align with the fluctuating demand of hourly electricity use across the country. This technical issue is so broad in its scope that it could not be considered for this dissertation.

- There is the limitation in terms of data, particularly the exchange rate. Data was gathered from multiple different data sources, some of the expenses for solar and wind projects which were in USD. These figures were all converted to Rands using the same fixed exchange rate as of 1 January 2019. It was found in the sensitivity analysis in Section 4.5 that the model outputs are proportionally sensitive to this input parameter. Nevertheless, the exchange rate over the last five years, while being volatile each month, has not changed significantly on average (OFX, 2021). For this analysis, the average stability of the exchange rate implies that the sensitivity of the results to this parameter should not impact the validity of the results.

The limitations mentioned above are sources of uncertainty. Some of these limitations have may have either a positive or negative effect upon employment. However, these limitations do not diminish the important comparison in terms of employment that can be made between different sources of electricity generation. Therefore the comparison can still be considered useful.

5.4. Implications for Policy

The implications for policy considered here are for an employment-centred energy transition. The results of this analysis suggest that an expansion of solar and wind capacity may lead to increased employment. Having established this, the problem turns towards how this energy transition could become a "just energy transition" in which justice and equity is incorporated into the decarbonisation of South Africa's energy supply.

5.4.1. Policy implications for creating new jobs

The results of the analysis have shown that the most stimulated sectors in terms of employment by the increase in solar and wind generation, were not the various manufacturing industries, but the "Building of complete constructions" sector and the "Building installation" sector for the construction and O&M phases respectively. This was true for both the IRP 2019 and the Ambitious Solar and Wind (ASW) scenario. Therefore, the promotion of entrepreneurship in these sectors is strongly recommended. This may be done in many ways such as tax incentives and inclusion of construction into the REI4P, a government-led programme awarding competitive tenders for the development of independent power producers — see Section 4.7.2. It was discovered that these construction sectors have high levels of unskilled and informal workers. This may be an opportunity to absorb many of the unemployed in South Africa, as unemployment in South Africa peaked at 32.6% in the first quarter of 2021 (Reuters, 2021). These workers are, however, most vulnerable to exploitation. Therefore, social dialogue with trade unions, private construction companies, and government is highly recommended. Formalisation of the informal economy in these sectors should be investigated with broad goals of decent work in mind (Bell & Newitt, 2010). Moreover, it was found that construction phase jobs for solar are more labour intensive than that of wind. However, the O&M phase jobs were more labour intensive for wind than for solar. This would suggest that investing in solar is better for short term employment, whereas investing in wind is better for long-term employment.

Furthermore, it was found in the sensitivity analysis in Section 4.5, that the net number of jobs is highly sensitive to manufacturing localisation. The results showed that if all direct costs for the solar and wind projects were localised, the employment figures would increase by approximately 111%. According to the literature, striving for local content of

80.5% for solar and 68.8% for wind is recommended . This would correspond to other indications in the reviewed literature for ambitious, yet feasible, levels of localisation (EScience Associates et al., 2013; Urban-Econ Development Economist & EScience Associates, 2015). This may be achieved in myriad ways. One such intervention is to enforce local content requirements for the private sector so that private partners have to utilise the labour force within South Africa to develop their projects. Local content requirements are part of the REI4P. Various regulations are a part of the programme including local content requirements. Other options available to the government are import tariffs, anti-dumping duties, and import control (SAPVIA, 2021).

Removal of unnecessary or undesirable regulatory burdens is an industrial development policy intervention for just transitions (Montmasson-Clair, 2021). Through the stakeholder engagements, it was clear that one of the barriers that prevent small local companies from benefiting from the manufacturing activities is that to manufacture these technologies they are needed to be of Tier 1 status. Tier 1 companies are responsible for the manufacturing of the main components of wind and solar technologies (SAPVIA, 2021). These tend to be large multi-national companies. Consequently, most of the tenders are awarded to foreign companies who manufacture outside South Africa, not making use of local labour. An opportunity arises therefore, to allow non-Tier 1 South African companies to benefit from less skilled activities in the manufacturing process such as testing of equipment to build up their expertise to eventually work their way up to Tier-1 status.

5.4.2. Ensuring adequate skill level and implications for decent work

The main challenge to a just transition considered in this dissertation was the discrepancy in the appropriate skill levels. The discrepancy analysed was between those who currently work as employees to ensure that coal-fired power plants are sufficiently operated and maintained versus the those who have the level of skill required for the large-scale construction and operation and maintenance of solar and wind projects. Skill level for direct, indirect, and induced jobs for each of the above categories of workers has been considered in terms of education level.

The results of this analysis suggest that the education levels required for workers to construct and maintain solar and wind projects are similar to the education levels required to operate and maintain coal-fired power plants overall. However, the skills needed for green jobs are more complex than only the education levels analysed in this dissertation. van der Ree (2019) found that there is a skills gap between what is provided by national and tertiary institutions and what what is required from jobs in the green energy sector. That being said, skills training programmes significantly enhances the employability of workers. Technical and vocational training educational programmes (TVEP) that are linked to the private sector have adapted quicker than exclusively government funded programmes, to the changing need for skills, such as in the case of Germany and France (van der Ree, 2019). Therefore, government and private collaboration is recommended to develop retraining programmes. The sectors identified as being the worst hit by the transition in Section 4.4 may be a useful starting point for focusing on which sectors to focus the retraining programmes such as "Electricity and Gas" and "Coal mining" sectors . Furthermore, there are many sectors that are common in the top five most stimulated sectors of each generation type that are common, therefore skills transfer within these sectors would appear to be more feasible than skills transfer across sectors.

In Section 4.4 it was found that many opportunities exist to create semi-skilled and skilled work outside the construction sectors too. International Labour Organisation (2019) found that TVEP, if implemented successfully, would be beneficial to re-skill people to work as medium-skilled workers on renewable energy projects. This implementation would require substantial investment. In this case study, the sector that would be provide this work would be "Other electrical equipment"[2]. Example jobs include wind turbine operators and solar technicians. According to International Labour Organization (2018b), changes required for skills in general for the different skill levels of workers may be:

- Low-skilled occupation: on the job learning, short reskilling programmes.
- Medium skilled occupations: short to longer upskilling and reskilling programmes. TVEPs.
- High-skilled occupations: university degrees, longer upskilling programmes.

For more specific skills - see International Labour Organisation (2018, p. 16). A more extensive investigation of the employment conditions in the sectors shown in Section 4.4 Figure 4.8 is required to draw decisive conclusions about decent work. Through interactions with stakeholders, see Section 4.4.3, it was found that if employees in the Electricity and Gas sector were given the opportunity to change vocation many would take the opportunity.

5.4.3. Social Dialogue

Social dialogue is a mechanism that can be employed by relevant stakeholders such as trade unions, business associations and government to build consensus (Altenburg et al., 2017). Renewable energy will not automatically create high-quality decent jobs. Therefore, measures need to be taken to allow workers and employees to organise and benefit from social dialogue and collective bargaining (Altenburg et al., 2017). Due to the profound changes that will come from production processes and technologies, social partners will be essential to a successful just energy transition. With any technological transition, there are bound to be "winners" and "losers". Intrinsic to an energy transition is the lack of investment into coal-fired power plants. Therefore, those who work along the coal-fired power plant supply chain will be threatened. It is unsurprising that there is considerable resistance from unions who represent workers who benefit from employment in coal. Increased social dialogue between policy makers, private sector

[2] See Quantec Easydata, https://www.quantec.co.za/, for full description of each sector

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and unions is recommended. Social dialogue is one of the four pillars of "decent work" (International Labour Organisation, 1999). It was discovered in Section 4.4.3 that every coal-fired power plant has an labour union office that workers can use to raise their concerns and use for collective bargaining. Solar and wind projects should take inspiration from this by implementing a similar form facilitated social dialogue.

Social dialogue should be facilitated by making sure that labour unions are involved in the process of developing policies. The discussions and reflections from a workshop with union members as described in Section 4.7 showed there are many tensions and dilemmas that come with moving towards renewable energy. Consequently, building trust is an essential component of including the stance of labour in the policy making process. It is recommended that more workshops are held by researchers and policy advisors that focus on the common characteristics of renewable energy and the "Electricity and gas" and "Coal mining" sectors. One such commonality that could be a focus of a future workshop would be the rise of the construction sector. This is important as NUM is in the process of including construction workers into the cohort that they represent (NUM, 2021). Future workshops should begin by discussing with the participants options for leaving the meeting as well as what the exact intention of the workshop was. De Bruijn et al. (2010) explain that an exit option reduces the threshold for parties to become involved in a decision making process.

The results show that the construction sectors "Building of Complete Constructions" and "Building Installation" will be the sources of much of the employment in South Africa's transition to wind and solar forms of electricity generation. Social dialogue is also essential in these sectors as these sectors have a majority of informal and unskilled workers. Programmes should be developed that support informal and unskilled workers that facilitate their better facilitation in national forums.

5.4.4. Implications for those who may "lose" in the energy transition

The results of this dissertation show that employees in the "Electricity and gas", "Coal mining" and "Auxiliary transport" sectors appear to be the most threatened in the energy transition. Employees working in these sectors should be the focus of mobility assistance for those who wish to relocate as well as skill adjustment programmes. van der Ree (2019) explains in the case of China, after a series of coalmine closures, a package of measures was created for approximately 1.8 million people who would lose their jobs these included:

- Re-employment training subsidy, a start your business subsidy, enhanced public employment services.
- Early internal retirement packages for workers less than five years away from retirement.
- Social protection, medical and pension benefits for closing mines and power plants.
- Public employment projects to help individuals find re-employment in which the government subsidised salaries and social services.

- Finally, the government provided tax incentives and preferential treatment to enterprises that absorbed laid-off workers.

Of these 1.8 million workers, 726 000 workers found re-employment since the measures were implemented in 2016. All of the above points should be considered in the South African context. Montmasson-Clair (2021) identify social protection policy tools for a those who may lose in a just transition including: social transfers (cash transfers, basic income grant), fee waivers and subsidies for (basic health, education, energy, water, sanitation transport) public employment/works programme.

The results of the analysis have shown that if the demand for coal-fired power globally declines, impacts may be felt by South African workers. It was found in Section 4.5 that if global demand for South Africa's coal exports decreases by 10%, the net employment compared to the IRP 2019 scenario would decrease by 13%. This shows that whether or not South Africa decides to transform its own energy portfolio, job losses in coal-based industries - due to global trends - seem to be inevitable anyway. Therefore, those specifically employed by the coal mining sector deserve protection, regardless of any other considerations as to the precise make-up of South Africa's future electricity mix.

5.5. Implications for future research

Methodologically, improvements could be made to the sensitivity analysis conducted in this research. Miller and Blair (2009) discuss that instead of sensitivity analysis, an in-depth analysis of the "important coefficients" is also feasible. This way it is possible to identify which inter-industry coefficients within the IOTT have a strong influence on the model . This may be of interest to the more statistically inclined researchers.

In terms of topics for future research, the following considerations may be of interest stemming from this research:

- This research did not consider the employment changes that may come with stable electricity. Notoriously, Eskom has been unable to generate enough electricity to meet demand, leading to nation-wide blackouts. The employment implications of unstable electricity are far reaching. For example, entrepreneurship is difficult without reliable electricity. The integration of solar and wind will add to South Africa's total power capacity and should lighten Eskom's supply burden. There may be many more developmental benefits that come with stable electricity in myriad different aspects of daily life in terms of cooking, refrigeration, heating, access to television and lighting at night. Lighting, for example, may have a "multiplier effect" that may provide, for example, opportunities for reading and study and self-improvement generally. The employment impacts the may stem from stable electricity should be investigated.

- Additionally, the employment effects owing to changing electricity prices as a result of more solar and wind energy were not considered. For many, electricity has become unaffordable as was mentioned by a local community activist as interviewed by B. Balyoi and A. Willis — see Appendix A. The respondent explained that electricity prices have become unaffordable for rural communities in South Africa and renewable energy provides a cheaper option to go off-grid.

- Future research could investigate the prospects of decent work in more detail in the most stimulated sectors by the energy transition. Investigating this may be supported by quantitative methods such as the inclusion of a "Quality factor" (Sastresa et al., 2010, p. 9). Additionally, qualitative methods could be employed, using findings from the employees currently in the sectors that this research found to be stimulated by solar and wind projects.
- This research did not consider the geography and location of the net employment effects. An investigation into this topic of employee relocation and the implications on decent work is recommended.
- This research focused on the electricity component of the energy transition. There are other aspects of our energy mix that may also transform to greener technologies. For example, the effect that redesigning and restructuring the transport sector has on employment should be investigated.
- It was mentioned in Section 5.3 that electricity issues such as intermittency was not considered. There are technologies that have been developed to remedy this issue in terms of energy storage such as large-scale pumped-hydro facilities. The employment effects that come with developing these technologies are recommended to future researchers.
- This research focused on utility-scale onshore wind. The prospects for South Africa's potential to be a supplier and generator of offshore wind should be investigated. This is owing to South Africa's unique positioning geographically as a connection to all corners of the globe as well as the long stretches of coastline, high wind availability, and prominent ports.
- The employment effects that come with post-retirement of coal mines and coal-fired power plants could be investigated. Similarly, the employment effects that come with the decommissioning of solar and wind projects could be investigated.

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5.6. Chapter Summary

The main research question in this dissertation has been addressed. The transition from coal to wind and solar forms of electricity appear to have positive employment effects for the period 2019 to 2030. Using job numbers as a metric for policy making, therefore would suggest promoting the development of more utility-scale solar and onshore wind power plants. This may be done in myriad ways including an increase in local content requirements, increase in government-sponsored skills development programmes in the relevant economic sectors stimulated by solar and wind projects, as well as removing unnecessary barriers for small local companies to benefit from the transition. There are many challenges to achieving these positive employment effects and "decent work" in a just energy transition in South Africa. This includes ensuring adequate skill levels, garnering the support of labour unions, as well as ensuring that those who may lose in the transition are adequately compensated. This research may be helpful in addressing these challenges as the results provide insight into employee skills, effects of localisation, green exports, coal exports, and jobs per economic sector. In addressing these challenges, deliberate increase in social dialogue between government, labour unions, and the private sector is recommended.

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A

Interviews

To synthesise the analysis of the input-output analysis with some of the realities regarding the just energy transition in South Africa on the ground, a series of stakeholder interviews were conducted with experts in the energy space in South Africa. These interviews were done in collaboration with Institute for Economic Justice. The format of the interviews were semi-structured, where the interviewees were asked questions regarding the just energy transition in South Africa. These included:

1. What does a just energy transition mean to you?
2. What are the issues that are of most concern to you regarding a just energy transition?
3. What are the challenges you see for achieving a just energy transition in South Africa?
4. What are the changes needed for a just energy transition in South Africa?

These interviews were conducted in conjunction with the the IOA. Where possible, data needed for the scenarios developed was supplemented by data from these interviews. The insights of the interviews were also used for interpreting the results of the IOA - see Chapter 4 for model results and discussion.

The people interviewed are shown in Table A.1. The names of the participants of the interviews were ananymised owing to the sensitivity of the topics discussed.

Table A.1: Table of Stakeholders interviewed

Respondent	Type of org	Role in organisation	Date
Respondent A	Academic/research	Energy policy researcher	19/03/2021
Respondent B	Investment holding company	Climate change specialist	25/03/2021
Respondent C	Grass roots community organisation	Founder	25/03/2021
Respondent D	Academic research/legal Institute	Head of Pollution and Climate Change	25/03/2021
Respondent E	Solar manufacturer	Founder & CEO	09/04/2021
Respondent F	Research Institute	International Coal Network Coordinator	12/04/2021
Respondent G&H	Funder for climate change and development issues in Africa	Directors	13/04/2021
Respondent I	NGO	Climate justice campaigner	20/04/2021
Respondent J	NGO, speaking in personal capacity	Senior programme manager	06/05/2021
Respondent K	Trade Union	Participant in presidential climate panel	13/05/2021

Each of the following subsections will address one the answers given to each question.

A.1. What is your definition of a Just Energy Transition?

- Five out of ten spoke about energy ownership and how to prevent the development of more monopolies;
- Many spoke about decent work being incorporated into the decarbonisation of the energy supply.
- Managing trade-offs and being realistic. Justice becomes about avoiding blatantly unjust scenarios
- Justice about access and security of supply
- Energy sovereignty
- Dealing with energy issues on local level
- Energy justice must fall into the definition of what justice means as a society
- Justice for the renewable energy communities (schools, hospitals etc)
- Addresses gender pay gap

- Ernest engagements with stakeholders during entire process

A.2. What are the key issues and challenges in South Africa around just energy transitions?

- Jobs and worker skills? Includes people indirectly employed.
- Labour has responded to plans but has not put forward their own.
- What happens to coal communities?
- What happens to subsidies for free basic electricity?
- Eskom may not get things right.
- Narratives about nuclear and gas refineries, and "clean" coal.
- Electricity is expensive, what will happen to electricity prices in rural areas?
- Just transition models are still working within the confines of the current extractive development model.
  - Humans are here to destroy and take from nature
  - We do not have an understanding of our role in destroying nature? Will we go back to living in rural areas?
  - Infinite economic growth not feasible. Therefore, we need to sacrifice somewhere.
- Poor Eskom governance and public mismanagement
- Fractured movement and lack of a common vision
- Cities are becoming increasingly informalised (no formal housing). What does a just energy transition look like in these communities?

A.3. What changes would you like to see?

When asked what changes they wold like to see in South Africa's energy future, the stakeholders responded with the following points:

- An increase of broad-based coalitions and focus groups with a common purpose. We agree on more things than we disagree.
- A move towards lower electricity prices so that more South Africans can have access to power.
- Firm commitments from the government not to invest in more coal fired power plants.
- Social ownership of electricity.

- Broad-based access to cheap electricity.
- Merging struggles between labour and green initiatives.
- An increase in systems thinking and how the different aspects of the energy transition interlink.
- Ernest engagement with multiple stakeholders.
- A change in the financialisation of renewable energy.
- Workers have to have an ownership role in the renewable energy sector.

B

Methodological Details

This section presents some additional methodological details. Figure B.1 shows how the I JEDI tool calculates the number of jobs based on demand for renewable energy capacity. Based on renewable energy capacity project expenditures are calculated. These expenditures are mapped to create various economic sectors to create output vectors for direct, indirect and induced effects. These direct effects are then used to calculate earnings, which is the share of employee compensation as a percentage of output. Based on earnings and the pages per industry in [R/Person/year] the number of job-years is calculated.

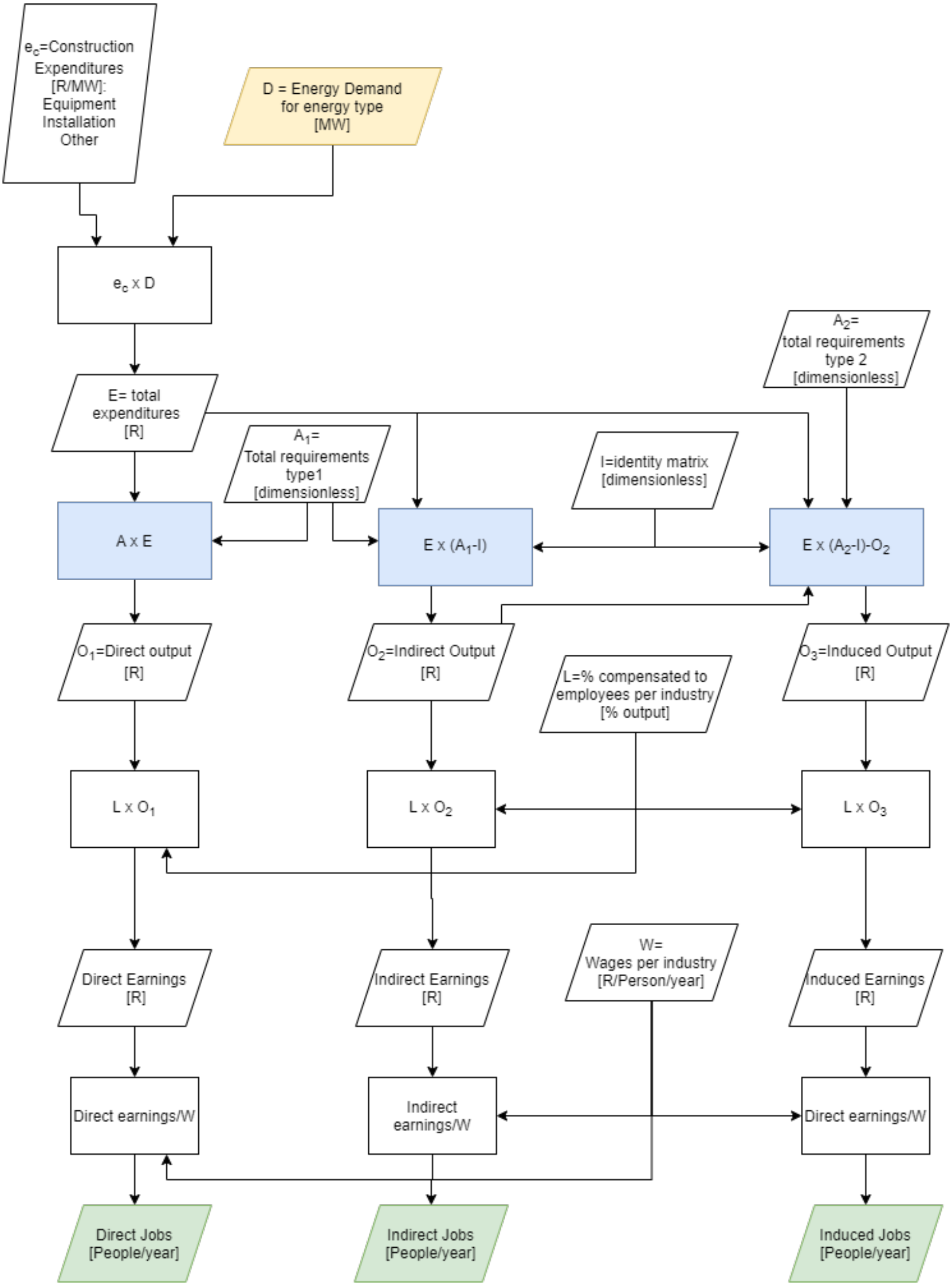


Figure B.1: How the I-Jedi Model calculates jobs based on demand. Source: own elaboration on I-JEDI

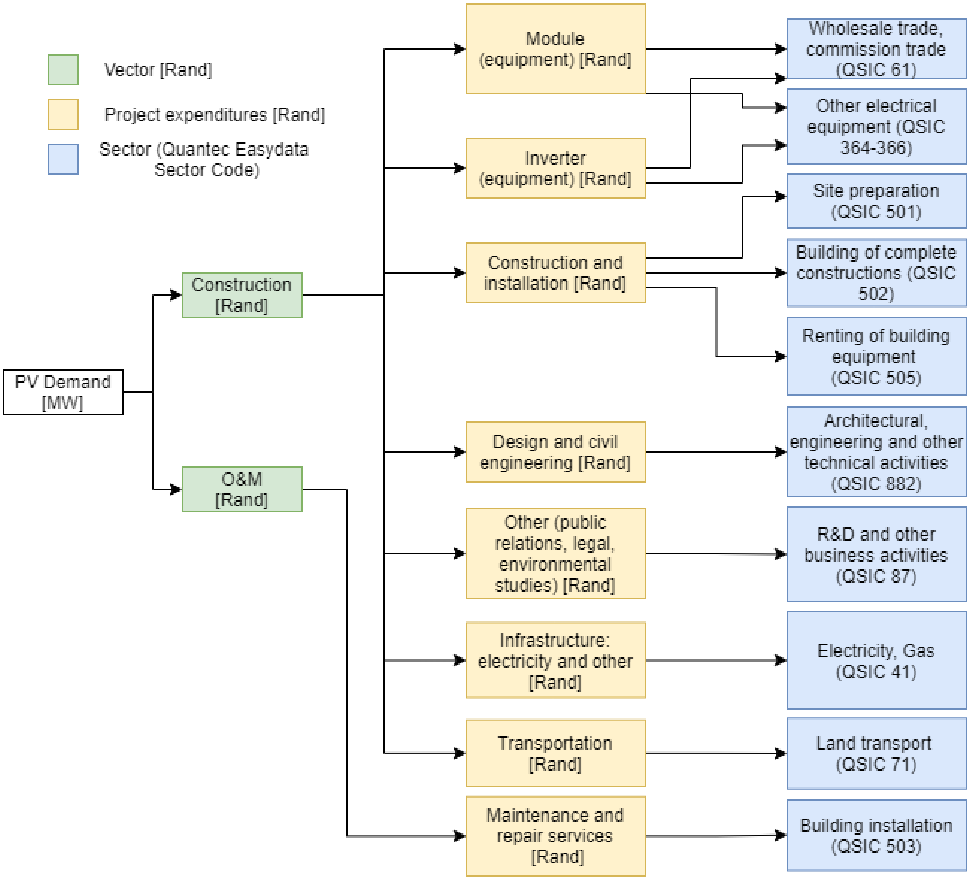


Figure B.2: How solar PV construction and operation and maintenance vectors were constructed from project expenditures. O&M costs occur on a yearly basis. The construction costs are once off equivalent to one year's expenditure. From this mapping direct jobs are calculated for each of the above industries. The input output model then calculates indirect and induced jobs for each of the 91 sectors. Source: Own elaboration on I-JEDI.

B.1. I-JEDI and solar energy

Figure B.2 shows how the project expenditures are mapped to the corresponding sector. Some of the expenditures are mapped to multiple sectors. For example, the module and the inverters are mapped to "wholesale trade/ commission trade" as well as to "other electrical equipment". Depending on the scenario, the ratio that these expenditures are mapped to the sectors will differ. For example if the equipment is manufactured locally, then South Africa's "Other electrical equipment" sector will be stimulated. If these are imported then "Wholesale trade, commission trade will be stimulated instead at a marginal rate.

B.1.1. I-JEDI and wind energy

Similar to the manner in which the solar energy construction and operational and maintenance demand vectors were constructed, Figure B.3 shows how these vectors were created for wind energy projects using the same logic.

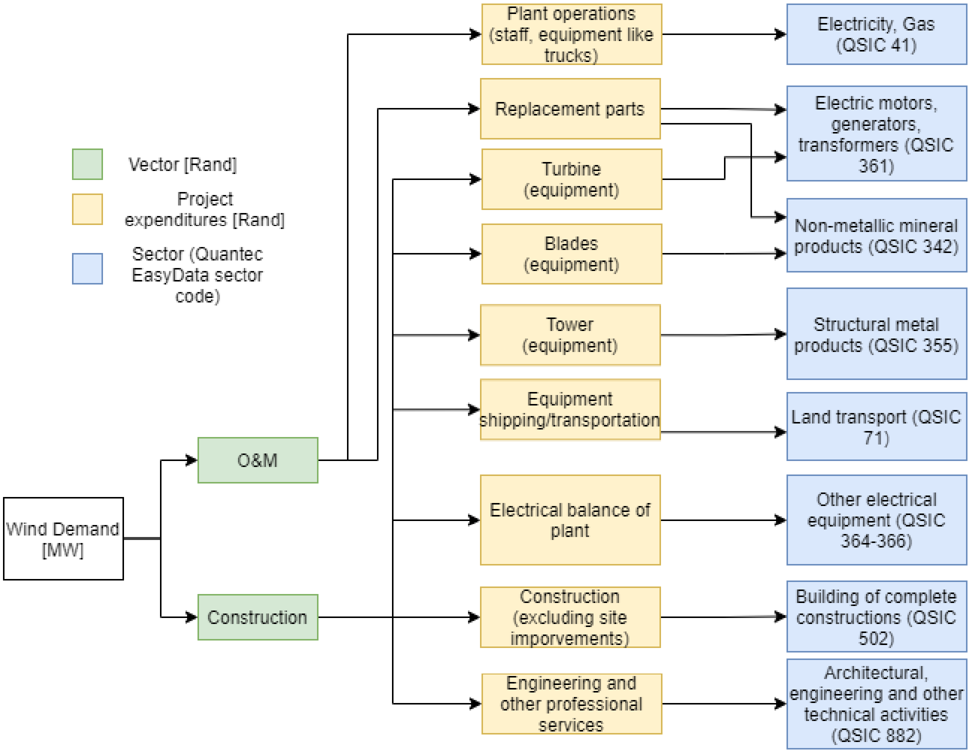


Figure B.3: How wind construction and operational and maintenance vectors were constructed. Source: Own elaboration on I-JEDI.

B.2. Verification of coal energy data

Coal energy data were used in Section 3.4.1. This section presents how this data was verified with alternative calculation techniques. The figures in Table 3.3 coupled with the installed coal capacity as stipulated in the IRP 2019 as well as the energy generated in a year as per Department of Mineral Resources and Energy (2017). The amount of coal used for local electricity production for one year was extracted from South Africa's energy balance for 2017 (Department of Mineral Resources and Energy, 2017) to be $E = 5.63 \times 10^8 MWh$. This resulted resulted in a total O&M cost of 243.56 Rand/MWh. This is shown in the calculation below:

$$
\begin{aligned}
\text{O\&M expenses (fixed+variable)} &= \text{Variable O\&M [Rand/MWh]} \\
&+ \text{Fuel Cost[Rand/MWh]} \\
&+ \text{Fixed O\&M [Rand/kW]} \times \frac{\text{installed coal capacity[MW]}}{\text{energy in year[MWh]}} \\
&= 71.53[\text{Rand/MWh}] \\
&+ 121.53[\text{Rand/MWh}] \\
&+ 7.3 \times 10^5 [\text{Rand/MW}] \times \frac{39126[\text{MW}]}{5.63 \times 10^8 [\text{MWh}]} \\
&= 243.56[\text{Rand/MWh}]
\end{aligned}
$$

Lyons and Gross (2017) were verified by a different calculation from other data sources. The total expenses for the "Electricity and gas" (sub-scripted as E&G below) sector was calculated using the Quantec Easydata IOTT with the following equation:

$$
\begin{aligned}
\text{O\&M expenses (fixed+variable)} &= \text{Total input}_{\text{E\&G}} - \text{Gross operating surplus}_{\text{E\&G}} \\
&= 2.28 \times 10^5 - 9.68 \times 10^4 \\
&= 1.31 \times 10^5 [\text{MRand}]
\end{aligned}
$$

The above equation includes all the expenses of the "Electricity and gas sector" including the inter-industry expenses as well as taxes minus various subsidies. The amount of coal used for local electricity production for one year was extracted from South Africa's energy balance for 2017 (Department of Mineral Resources and Energy, 2017) to be $E = 5.63 \times 10^8 MWh$.

Therefore, total O&M expenses (fixed+variable) per MWh:

$$
\begin{aligned}
\text{O\&M expenses}/MWh &= \frac{\text{O\&M(fixed+variable)}}{E} \\
&= \frac{1.31 \times 10^1 1[\text{Rand}]}{5.63 \times 10^8 [\text{MWh}]} \\
&= 232.4[\text{Rand/MWh}]
\end{aligned}
$$

The two different methods for calculating the O&M expenses per MWh resulted in results that were within 5% of each other. This 5% difference may derive from the fact that certain coal-fired power plants within South Africa have different O&M costs compared to the average. Additionally, the "Electricity and gas" sector is an aggregation of multiple different sources of energy, even though coal is dominant in constituting 86% of the electricity generation mix (Statistics South Africa, 2018). Therefore, the O&M costs in calculated using the IOTT from Quantec EasyData is slightly different. Therefore, it was determined that the O&M costs as stipulated by Lyons and Gross (2017) was "fit for purpose" for the calculations in this thesis.

B.3. Units for number of jobs and reporting on cumulative effects

Presenting the units for employment in the literature is not unanimous in the literature. This section explores some of the options available and explains why the unit of "job-year" was selected. The I-JEDI tool, by default presents the results in "job-years", calculated based on the size of a renewable energy investment (MW). Therefore for a particular renewable energy project size measured in MW, the number of jobs equivalent to one year full time employment are calculated. Therefore, the construction number of jobs created are considered for the equivalent of one year. If construction takes longer than a year then the number of jobs is divided proportionally to calculate the employment per year. These units were verified by reviewing the relevant literature.

Pollin et al. (2014) explain that there are two ways to treat the time aspect in measuring job creation. First is by measuring "job-years" (similar to person-years by (Lambert & Silva, 2012)). This unit measures the *cumulative* job creation for the total number of years that the jobs have been created. For example, an activity that employs one person for ten years, creates ten job-years. Similarly, an activity that employs ten people for 10 years creates one hundred job-years. The second option is to report in "jobs per year". This provides more granular detail on a year-to-year basis. Accordingly, it becomes more precise in distinguishing jobs that are temporary from those that are permanent. Pollin et al. (2014) emphasise the importance when using jobs/year when reporting on the construction compared to the operational and maintenance (O&M) phases of the lifetime of a project. This is because construction phase job years tend to be "once-off" while O&M jobs occur throughout the lifespan of a project. The authors argue that project expenditure may vary widely depending on the level of annual expenditure to complete the project. This would vary project to project and may easily change while the project is being constructed, increasing the uncertainty in year-to-year employment. Consequently, Pollin et al. (2014) reports in "job-years" for both the O&M and construction phases of a project's lifespan.

There is also the issue of whether to report jobs in terms of per installed electrical capacity (MW) or per unit of monetary spending ($ 1 million) . Garrett-Peltier (2017); Pollin et al. (2014) report their figures job years/$1 million. These authors do not simulate scenario based on capacity, but rather on government spending. Miller and Blair (2009), refer to this as the labour coefficients or employment multipliers. Most studies that use input-output analysis for measuring the employment effects, not specific to renewable energy will use this metric. For example, Schröder and Storm (2020) estimate the closed input-output employment multipliers for South Africa. Nevertheless, when simulating particular scenarios that include specific targets for MW installed capacities such as in the IRP 2019 Department of Mineral Resources and Energy (2019), then it makes sense to report on employment per MW as opposed to unit per $ 1 million.

It is clear from the search of the literature on reporting employment, that care must be taken when measuring the number of jobs created. But there is not a single correct application, rather it depends on the study. In this thesis, jobs for a total cumulative capacity from a number of different projects will be considered. Therefore, whether or not a company will keep their employees employed full time and have them work on different projects is not considered. For example, many construction companies will work on multiple different building projects and keep their employees employed full time while they move between projects, while others may outsource labour for a particular project. This sort of analysis would be much more on-the-ground and would need to be supported by empirical evidence and micro-data. Accordingly, it has been decided to report the findings based on "job-years". Given, the infancy of the wind and solar energy sectors in South Africa, and consequently the lack of data concerning employment dynamics, the year-to-year basis for reporting on jobs will be ignored.

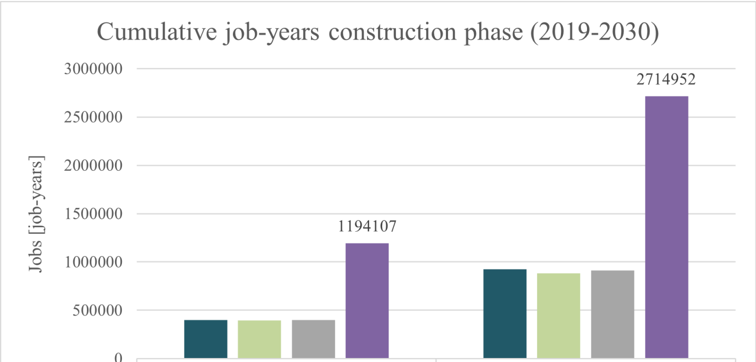
C

Additional Results

This section presents some additional findings that stemmed from this research.

C.1. Total jobs disaggregated by the construction and operations and maintenance phases

In Section 4.1.1 the total jobs for the construction and operations and maintenance phases were aggregated. This section shows the employment of these phases separately.



	IRP2019	Ambitious Solar and Wind (ASW)
Net Direct	399609	923674
Net Indirect	393647	880311
Net Induced	400851	910967
Total	1194107	2714952

Figure C.1: Aggregate jobs for the construction phase of solar and wind projects for the period 2019-2030. Source: Author.

Figure C.1 shows the possible net employment effects in the construction phase of solar and wind projects for the period 2019-2030. The results suggest that the direct, indirect and induced jobs when comparing the construction phase jobs to the O&M jobs in coal-fired power plants are positive. Approximately 1.2 million jobs may be created under the IRP 2019 scenario and this be be increase to approximately 2.7 million job in the ASW scenario.

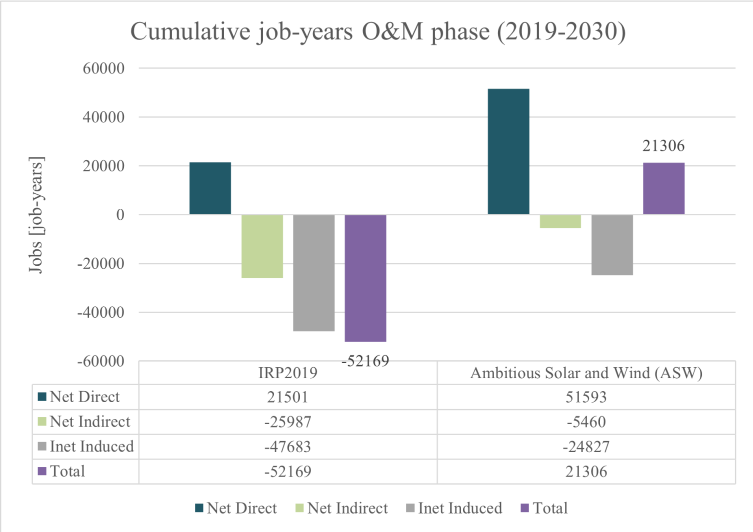


Figure C.2: Aggregate jobs for the O&M phase of solar and wind projects for the period 2019-2030. Source: Author.

Figure C.2 shows the net effects during the O&M phase of renewable energy as the coal is simultaneously displaced. The direct employment effects are positive, providing approximately 20000 jobs under the IRP 2019 scenario. It is clear that in the IRP 2019 scenario there are net losses as a result of indirect and induced effects. As a result there are approximately 52000 total jobs that could be lost over the twelve-year period. The reason for the indirect and induced job losses are negative, while the direct jobs are positive is a result of the strong inter-industry linkages that the electricity and gas sector has with other sectors such as coal mining and transport. However, in the Ambitious Solar and Wind scenario the total number of jobs is positive as a result of the increase direct jobs creased. Similarly, the indirect jobs become almost negligible at approximately 5500 job-years over the twelve year period. The induced job losses are also reduced.

C.2. Coal Exports compared to Local Electricity production

In Section 4.5.1, the impact of reducing coal exports as a parameter in the sensitivity analysis was presented. It may also be interesting to compare the jobs in job-year/GWh for local electricity production and exported coal. Local electricity production demands direct services from the Electricity and Gas sector, whereas the coal exports demands services from the Coal mining sector. The energy generated by locally produced coal and the energy stored in the coal exported was sourced from Department of Mineral Resources and Energy (2017). The results suggest that a the demand for coal exports by a unit of energy would impact direct employment more significantly than reducing demand for local electricity production by the same unit of energy. However, in terms of indirect and induced effects local electricity production has more significant effects upon employment. Hence, the total labour intensity of local electricity production is higher than for coal exports. This is owing to the strong inter-industry linkages that the Electricity and Gas sector has with other sectors within the South African economy. Nevertheless, the demand for coal exports creates many jobs in South Africa. Therefore, policy makers should consider global trends for declining coal demand when considering policy implications for local workers.

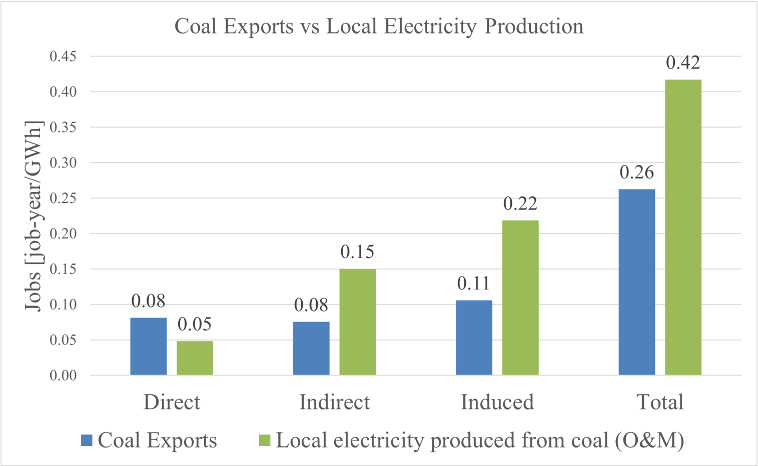


Figure C.3: Comparison between jobs created by O&M of local electricity production and demand for South Africa's coal exports

C.3. Type 1 employment multipliers per Sector

This section shows the Type 1 employment multipliers per sector directly affected by the expansion of renewable energy and the displacement of coal. Type one employment multipliers show the direct and indirect jobs created through one million rand of investment. Type 1 employment multipliers are calculated as follows, as per Miller and Blair (2009):

$$E = l \times (I - A)^{-1} \tag{C.1}$$

Where l is the number of jobs per one MRand gross output per sector. $(I - A)^{-1}$ is the Leontief inverse as described in Section 3.2 needed to calculate the direct and indirect employment effects.

Table C.1: Table showing the type 1 employment multipliers for the sectors directly impacted by each of the three technologies.

	Employment multipliers [Job-year/Mrand]	Wind [MRand]	Solar [MRand]	Coal [MRand]
Non-metallic mineral products [QSIC 342]	2.25	0		
Structural metal products [QSIC 354]	1.97	0		
Electric motors, generators, transformers [QSIC 361]	2.44	0		
Other electrical equipment [QSIC 364-366]	1.47	5.74E+10	1.82E+10	
Electricity and gas [QSIC 41]	2.88	1.72E+09	6.73E+09	7.45E+10
Site preparation [QSIC 501]	0.60		1.00E+00	
Building of complete constructions [QSIC 502]	4.98	8.80E+10	2.10E+10	
Building installation [QSIC 503]	2.07	2.00E+10	1.93E+09	
Renting of construction equipment [QSIC 505]	3.65		4.20E+09	
Wholesale trade, commission trade [QSIC 61]	8.24		8.01E+09	
Land transport, transport via pipe lines [QSIC 71]	6.61	1.84E+10	1.22E+00	
Architectural, engineering and other technical activities [QSIC 882]	3.59	7.66E+09	8.97E+09	
Research and development [QSIC 87]	0.86		1.79E+10	
Average Multiplier		**3.72**	**3.27**	**2.88**

Pollin et al. (2014) found that for the O&M phase of renewable energy, the employment multipliers were similar to that of fossil fuels for the United States. Therefore, they deduced that if the same investment was made into renewable energy as fossil fuels, the investment into renewable energy would create more jobs. The labour productivity of the sectors creating direct employment was calculated for South Africa - see Table C.1.

The average employment multipliers were calculated by taking the weighted average of the employment multipliers by using the average project expenditures for the IRP 2019 scenario. It was found that the total employment (direct+indirect) by investing into the activities needed for deployment is 3.72 job-years/MRand for wind, 3.27 job-years/MRand for solar and 2.88 job years/MRand for solar. Therefore, it can be affirmed that an equivalent investment into solar and wind projects yields more jobs than the equivalent investment into the O&M of coal-fired power plants.

These results are similar to in terms to what Pollin et al. (2014) found for the case of the US. They found a comparable amount of jobs created for the O&M phase of solar and wind to fossil fuels. They found that capital investments into solar and wind created far more jobs than the O&M of coal-fired power plants. Stilwell, Minnitt, Monson, and Kuhn (2000) was the only other study found that calculated the type 1 employment multipliers for South Africa's coal mining sector. They found for 1993, the coal mining sector generated 24.84 jobs/ MRand invested. Adjusting for inflation using inflationcalc.co.za, this results in 5.27 jobs/Mrand in 2019 money compared to the 2.88 jobs/Mrand found in this research. Therefore, this shows that the coal mining sector has become almost half as employment intensive than it was in 1993.