Article

Biodiversity and economy but not social factors predict human population dynamics in South Africa

Bopaki Phogole[1] and Kowiyou Yessoufou[1]*

[1]Department of Geography, Environmental Management and Energy Studies, University of Johannesburg, Johannesburg, Auckland Park 2006, South Africa

* Correspondence: kowiyouy@uj.ac.za

Abstract: Abstract: The ongoing exponential growth of human population poses a risk to sustainable development goals (SDGs). Unless we understand the drivers of this growth and inform policy development accordingly, SDGs would remain a dream. One of the old theories of population growth known as the Malthusian theory predicts that resource availability drives population growth to a certain time when population growth outrun resource availability, leading to all sort of crises known as Malthusian crisis. Although the link between economic growth and population has been widely investigated while testing the theory, little is known about environmental and social factors potentially driving population growth. Here, because of various crises of our time recalling the Malthusian crisis, we revisited the theory by fitting structural equation models to environmental, social and economic data collected over 30-year period in South Africa. None of the social variables tested predicts population growth. Instead, we found that biodiversity (species protection index) correlates positively with population growth. Biodiversity provides various resources through ecosystem goods and services to human, thus supporting population growth as predicted in the Malthusian theory. However, we also found that this population growth may lead to conservation conflict as we found that biodiversity habitat (wetland area) correlates negatively with population growth, thus raising the compromising effect of population growth on life on earth. What's more, we found a significant link between economic growth measured as GDP and population growth, further supporting the Malthusian prediction. Overall, our study re-affirms the value of biodiversity to human and suggests that the Malthusian theory should continuously be tested with predictors other than economic.

Keywords: Malthusian theory, Population growth, Species protection index, Sustainability, Wetland area

1. Introduction

The population debate is one of the most critical topics in sustainability discourse [1]. Broadly, there are three major themes that guide the debate. Firstly, the nature and extent of population change is interrogated [2-4]. Secondly, the role and importance of underlying drivers of population dynamics are also explored [5,6], and lastly, the population-sustainability nexus is investigated [7]. These themes constitute the bases of the debate regarding the importance of population dynamic in sustainability studies.

Indeed, the global population was estimated to be 7.9 billion people in 2021 [8], the majority of which is found in Asia and Africa which host 59.8% and 16.9% of the human population, respectively [1,9]. Most notably, China and India are the most populous countries, each with a population of over 1 billion people [8]. Although Africa has considerably lower population size in relation to Asia, the continent exhibits the highest population growth rate among all the continents with an annual growth rate of 2.45% [9]. This makes Africa one of the key contributors to the global human population change and an important case study for population studies.

Studies of the relationship between population and the economy usually adopt population growth as the predictor of economic performance [10-12]. However, the economy has lot of potential to impact population dynamic by improving the standard of living which in turn increases life-expectancy, net migration, and reduced mortality rates due to improved healthcare systems [12-15]. Although economic drivers of population dynamics are key, the impact of social and environmental factors on population dynamics, two of the three pillars of sustainability, are equally important but remain largely overlooked (but see [16]).

In general, the population-sustainability studies aim to understand the relationship between population and the different pillars of sustainability to guide public discourse and decision-making processes. This debate has historical origins which can be traced back to the conception of the Malthusian theory [17]. The theory noted the exponential increment of the human population and predicted that this exponential growth will ultimately outstrip the available resources which are constrained to linear growth, leading to all sorts of catastrophes such as famine and war [18,19]. However, the Malthusian theory remains controversial because the initially predicted collapse of human population did not occur mainly due to technological development [20].

Nevertheless, the recent surge of various socio-economic and environmental calamities (e.g., famine, political unrests, covid-19 or Ebola pandemics, etc.) which recall the predicted Malthusian crisis makes the theory still relevant in the sustainability space [19]. As such, the emerging socio-economic and environmental calamities necessitate the re-evaluation of the Malthusian theory particularly in the developing world, a world experiencing a slow-to-no technological development [21,22]. Since technological development is acknowledged as the major factor preventing the Malthusian crisis [1,16], the focus on the developing world to test the theory becomes justified. More critically, the test of Malthusian theory focused mainly on the relationships between food availability or economic growth versus population growth (e.g., [19]), thus neglecting socio-environmental factors as drivers of population dynamics [16]. We suggest that both social and environmental factors are as equally important as the economic factors in driving population dynamics.

For example, the developing world experiences the poorest environmental conditions. Both air quality, biodiversity, and natural habitat parameters, among others, show continuous decline in quality with high potential for human and ecological calamities [23,24]. The coal-intensive energy sector, increasing land-use change, and overexploitation of natural resources are seen as imminent threats to air quality, species survival and ecological health [25-27]. These parameters have notable effects on human population dynamics, and this link has recently been termed the "new Malthusianism" [16]. Air pollution, in particular, is regarded as one of the leading causes of premature mortality, especially in developing regions [28]. Consequently, it is expected that the increasing environmental degradation may have a controlling effect on population dynamics [16].

Furthermore, the impact of social and political factors on population dynamics is usually studied in relation to the functioning and effectiveness of socio-political institutions [29]. Most commonly, political stability, policy effectiveness, and corruption have been used to assess effectiveness of social and governance institutions [30-32]. Also, these factors have been shown to affect population dynamics either through direct population control measures (e.g., China) or through indirect impact on human behaviour [33,34]. Like most developing regions, South Africa has historically experienced and continues to experience a surge of political unrest, corruption, and social instability [35,36], and these social stressors are expected to affect population growth.

Do these socio-environmental factors also drive population dynamics as predicted for economic factors in the Malthusian theory? The present study, as opposed to most studies which rather tested the Malthusian theory through the economic or food lens, aims to investigate this question in the context of developing regions. Specifically, we determined whether the social and environmental factors alongside various economic metrics drive population change in South Africa.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2022 doi:10.20944/preprints202206.0011.v1

2. Materials and Methods

2.1. Study Area

South Africa is a developing country located at the southern-most tip of the African continent (Figure 1). With a latitudinal span of 22°S to 35°S and a longitudinal span of 17°E to 33°E, South Africa has a land surface area of 1 219 602 km^2 [37]. South Africa host a wide diversity of terrestrial and marine biodiversity and ecosystems, making it one of the most ecologically rich regions in the world. However, there are prevalently high rates of atmospheric emissions from both household and industrial origins [38].

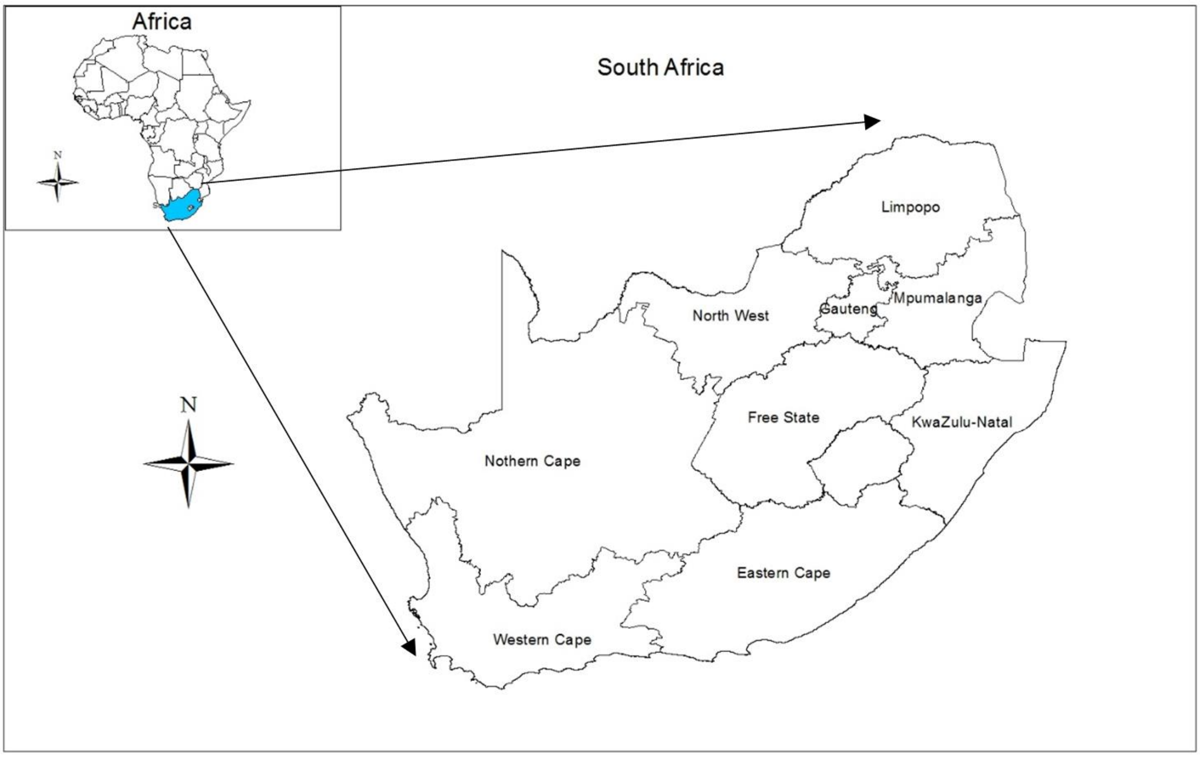


Figure 1: ***Location of South Africa in Africa***

South Africa is one of the most populous countries in Africa with an estimated population of 60, 142 million people in 2021 [39]. The high population is jointly attributed to high fertility and migration rates. Additionally, similar to global patterns, there is a rapid increase in the country's urban populations which present unique socio-environmental challenges [40]. The economic landscape of South Africa is characterised by a high unemployment rate [41]. Furthermore, South Africa is rated one of the most unequal societies based on social and economic indicators. Additionally, South Africa is faced with increasing cases of social and political unrest, high incidences of corruption and lack of accountability, especially among government institutions [42-44].

2.2. Data Collection

Data analysed in this study were retrieved from the database of the Yale University, USA, domiciliated at www.epi.yale.edu, accessed August 2022. Data in this repository were primarily collected for the calculation of the 2020 Environmental Performance Index for 180 countries [45] and span 30 years (1990 - 2019) with a one-year temporal resolution.

These data were sourced from various origins, including international organizations, research institutions, academia, and government agencies (Table S1) and were documented using various data collection instruments, including Remote sensing, Observations from monitoring stations, Surveys and questionnaires, Estimates derived from both on-the-ground measurements and statistical models, Industry reports and verifiable government statistics [45].

For the present study, five (05) variables were retrieved to cover, for South Africa, all three (03) pillars of sustainability, that is, environmental, social, and economic pillars. These five variables include i) Biodiversity and Habitat, ii) Air pollution, iii) Environmental Management, iv) Governance and v) Economy (Table S1). Biodiversity and habitat, air pollution, and environmental management form the environmental pillar of sustainability in this study, whereas governance was employed as the social pillar, and the economy made up the last pillar of sustainability (Table S1). Several indicators were used to measure each of these 5 variables: i) biodiversity and habitat were measured by 9 indicators (Marine Protected Area, Protected Areas, Species Habitat Index, Species Protection Index, Fish Stock, Fish Catch, Terrestrial Protected Areas, Wetland Areas, and Grassland Area), ii Air pollution by 7 indicators (Fluorinated Gases emissions, N_2O Emissions, NOX Emissions, Black Carbon emissions, Sulphur dioxide emissions, and CO_2 emission from land cover changes), iii) Environmental Management by 1 indicator (Sustainable Nitrogen Management), iv) Governance by 6 indicators (Control on Corruption, Government Effectiveness, Rule of Law, Regulatory Quality, Political Stability and Absence of Violence, Voice and Accountability) and v) Economy by 4 indicators (value added by services, Area of economic exclusion zone, Gross Domestic Product, Economic Freedom) (Table S1). All data collected are presented in Table S2.

2.3. Data Analysis

All analyses were done in R4.1.2 [46] and the R scripts used are presented in Supplemental Information. Prior to analysis, data were treated as explained below.

2.3.1. *Data imputation and data rescaling*

The time series data that were collected have missing observations for some of the years (Table S2.1); see also Figure S1 for missing patterns). We then imputed the missing values using the multivariate imputation by chain equations (MICE) method [47] employing the *mice* function in the MICE package [48]. In addition, because variables are in varying scales, we have rescaled them as follows: rescaled variables = (observation– mean) / standard deviation, and rescaled variables were used in the analyses described below (Table S2.2).

2.3.2. Selection of indicators to represent each of the 5 variables

Apart from the variable 'environmental management', all other variables have more than one indicator (Table S1). Two different approaches were used to select the most suitable indicators to represent each variable.

Firstly, because population dynamic is the response variable we aim to model in this study, each indicator of each of the 5 variables mentioned above was used as a predictor of population (re-scaled value) in an iterative stepwise regression process by fitting the Generalized Linear Models (GLM) with Gaussian error family. As such, 27 models were fitted during this process and, for the set of models involving different indicators of each variable, the Akaike Information Criterion (AIC) value was used to select the best model, thus the best indicator for that variable. This means that, for a given variable, the indicator used in the model showing the lowest AIC value was selected as representing that variable). From this exercise, the indicator 'species protection index' (SPI) was selected to represent the variable 'Biodiversity and Habitat' whereas 'methane emissions' (CH_4) was selected for 'air pollution', and 'sustainable nitrogen management' (SNM) represents the variable 'environmental management'. Also, the indicator 'control on corruption' (CCO) was selected to represent 'governance' (thus social pillar of sustainability; Table S1), and the 'gross domestic product' (GDP) represents the variable 'economy' (see Table S3). This approach of indicator selection is termed 'method 1'.

Secondly, for a variable, we run a pairwise correlation analysis among the set of indicators representing that variable, using Spearman correlation test. For a pair of indicators, when a correlation coefficient $r \geq 0.5$, we considered these indicators as strongly correlated. In cases where two or more indicators were found to be strongly correlated, only a single indicator was selected, and the others were excluded from further analyses (Table S4). From this selection process, three air pollution indicators (CO_2 emission from land cover changes, methane, and N20 emissions), five biodiversity and habitat indicators (Protected areas, species habitat index, fish stock, fish catch, and wetland area), three economic indicators (gross domestic product, economic freedom index, and area of economic exclusion zone), and three indicators for governance (government effectiveness, rule of law, political stability, and lack of violence) were selected and used for further analysis. This approach of indicator selection is termed 'method 2'.

2.3.3. Structural Equation Modelling

We fitted a structural equation modelling (SEM) to the data initially treated as explained above (re-scaled values for selected variables were used in the SEM analysis). This multivariate analysis technique includes a combination of factorial and regression analyses to test relationships along predefined structural paths. The theory and use of SEM is explained in detail elsewhere (see 5,49]. The SEM was fitted using the R library *Lavaan* [50] with the Maximum Likelihood (ML) estimation method [51,52].

Using the indicators that were selected in our 'method 1', an SEM (referred to as SEM1) was created (see R script). Although it is recommended that at least two model evaluation indices should be used to assess the goodness-of-fit of SEM and that the Chi-square test (X^2) be prioritised as one of the most robust evaluation indices, the X^2 measure was excluded from our evaluation based on the size of the sample that was used (X^2 is very sensitive to sample size; [49]). Rather, the goodness-of-fit of the SEM was determined based on the Comparative Fit Index (CFI) and the Root Mean Square Error of Approximation (RMSEA). These parameters were interpreted following ref. 49]: CFI $\geq$ 0.95 and RSMEA < 0.09 for a good fit. For our SEM, CFI =0.942 and RMSEA = 0.541, indicating a poor fit for the SEM. To improve the fit of our SEM, the variables that were used in the model were revised with reference to how best they correlate with the response variable in the model: the Environmental Management variable had the worst fit parameter (p=0.879) and was therefore excluded from the model. After the model was rerun (without the Environmental Management variable), the selected evaluation indices showed a good fit (CFI =1.00; RMSEA = 0.00). This means that the model provides a good representation of the data.

Using the indicators that were selected based on our 'method 2' (pairwise regression between indicators of a specific variable), all the 135 possible combinations of the selected indicators (3 air pollution indicators x 5 biodiversity and habitat indicators x 3 economic indicators x 3 governance indicators) were mapped as shown in Figure S2. An SEM for each possible combination were fitted and the goodness-of-fit for each model was evaluated using the AIC value. The best of the 135 SEMs fitted was selected based on AIC value (AIC = 207.809; CFI =1.0; RMSEA = 0.00). In this best SEM (referred to as SEM2) are the following indicators: methane representing the variable 'air pollution', wetland area (WTA) representing 'biodiversity and habitat', GDP for 'economy' and government effectiveness (GOE) for 'governance'. The AIC values for all the SEMs are summarized in Table S5.

2.3.4. *Ethical Considerations*

We adhered to all the ethical principles of the University of Johannesburg whose ethical committee approved the present study under the reference # 2022-02-04/Phogole_Yessoufou.

3. Results

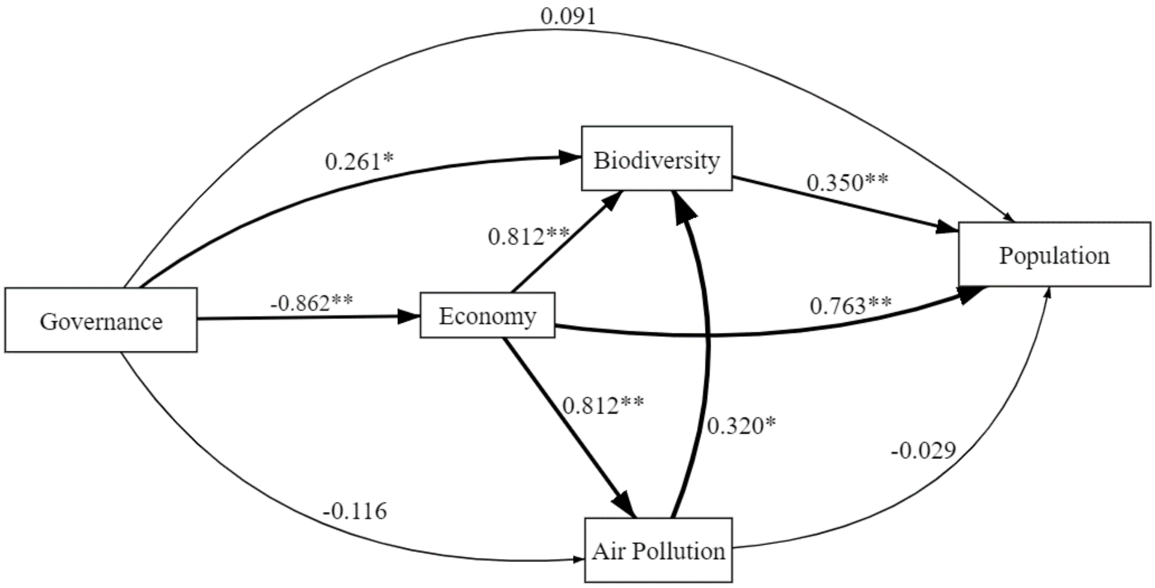
3.1. **Drivers of Population change**

For both SEM1 and SEM2, CFL =1.0 and RMSEA = 0.00, suggesting a good fit of our models to the data. Irrespective of the SEM considered, similar variables predict human population change: SEM1 (biodiversity and habitat, β_1=0.35±0.07, p<0.01; and economy, β_1=0.76±0.09, p<0.001; Table 1 and Figure 2) and SEM2 (biodiversity and habitat, β_2=-0.191±0.08, p=0.013; economy, β_2=1.024±0.11, p<0.001; Table 2 and Figure 3).

Table 1: *Regression coefficients in SEM1 where Air pollution = CH_4; Biodiversity and habitat = Species Protection Index; Economy = Gross Domestic Product; Governance = Control of Corruption (CCO). Pop = population.*

Drivers	Model Path	Estimate (β_1)	Standard error	z-value	P(>|z|)
Proximal drivers					
Air pollution (Air)	Air → Pop	-0.029	0.065	-0.451	0.652
Economy (Eco)	Eco → Pop	0.736	0.091	8.339	0.000*
Biodiversity (Bio)	Bio → Pop	0.350	0.069	5.045	0.000*
Governance (Gov)	Gov →Pop	0.091	0.053	1.717	0.086
Distal drivers					
Air pollution on Biodiversity	Air → Bio	0.320	0.161	1.984	0.047*
Governance on Biodiversity	Gov → Bio	0.261	0.131	1.994	0.046*
Economy on Biodiversity	Eco → Bio	0.850	0.184	4.615	0.000*
Governance on Economy	Gov →Eco	-0.862	0.092	-9.333	0.000*
Economy on Air pollution	Eco →Air	0.812	0.146	5.550	0.000*
Governance on Air pollution	Gov → Air	-0.116	0.146	-0.795	0.426

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2022 doi:10.20944/preprints202206.0011.v1



*Significant path ($p<0.05$)

Figure 2: Illustration of SEM1 where Air pollution = CH_4; Biodiversity and habitat = Species Protection Index; Economy = Gross Domestic Product; Governance = Control of Corruption (CCO).

Furthermore, a negative significant relationship was observed between governance and the economy: SEM1 (β_1=-0.86±0.09, $p<0.01$) and SEM2 (β_2=-0.86±0,1 $p<0.001$), and a positive relationship between the economy and air pollution: SEM1: (β_1=0.81±0.15, $p<0.01$) and SEM2 (β_2=1.00±0.14, $p<0.001$). Additionally, variations in biodiversity could be explained by air pollution: SEM1 (β_1=0.320±0.16, p=0.047) and SEM2 (β_2=0.641±0.19, p=0.002), and also governance (β_1=0.26±0.13, p=0.046), and the economy (β_1=0.85±0.18, $p<0.01$) but only in SEM1 (Tables 1&2; Figures 2&3).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2022 doi:10.20944/preprints202206.0011.v1

Table 2: Regression coefficients in SEM2 where Air pollution = CH_4; Biodiversity and habitat = Wetland Area; Economy = Gross Domestic Product; Governance = Government Effectiveness (GOE). Pop = population.

Drivers	Model Path	Estimate (β_2)	Standard error	z-value	P(>|z|)
Proximal drivers					
Air pollution (Air)	Air → Pop	0.160	0.096	1.664	0.096
Economy (Eco)	Eco → Pop	1.024	0.108	9.457	0.000*
Biodiversity (Bio)– Wetland area (size)	Bio → Pop	-0.191	0.077	-2.482	0.013*
Governance (Gov)	Gov →Pop	0.033	0.066	0.490	0.624
Distal drivers					
Air pollution on Biodiversity	Air → Bio	0.614	0.199	3.077	0.002*
Governance on Biodiversity	Gov → Bio	-0.059	0.157	-0.374	0.709
Economy on Biodiversity	Eco → Bio	0.251	0.253	0.990	0.322
Governance on Economy	Gov →Eco	-0.855	0.095	-9.020	0.000*
Economy on Air pollution	Eco →Air	1.000	0.143	6.994	0.000*
Governance on Air pollution	Gov → Air	0.102	0.143	0.715	0.474

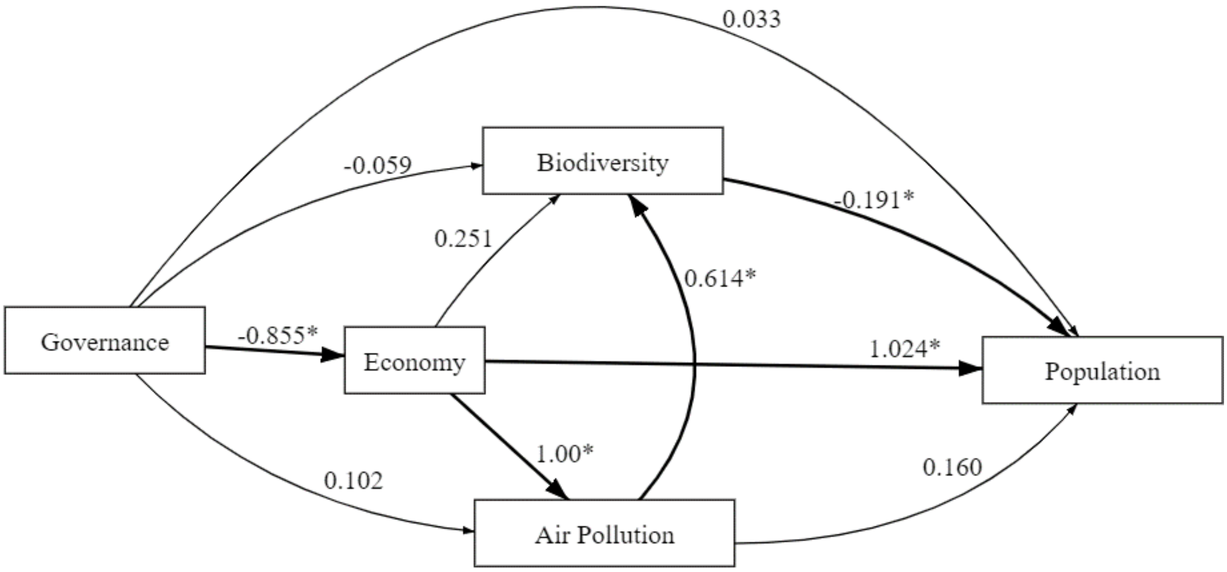


Figure 3: Illustration of SEM2 where Air pollution = CH_4; Biodiversity and habitat = Wetland Area; Economy = Gross Domestic Product; Governance = Government Effectiveness (GOE).

4. Discussion

4.1. Proximal drivers of population

Irrespective of how indicators of variables were selected, we found that biodiversity (species protection index or biodiversity habitat measured as wetland area) and economy (measured as GDP) correlate significantly with population. However, species protection index correlates positively with population while wetland area correlates negatively.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2022 doi:10.20944/preprints202206.0011.v1

Several studies also reported a positive co-variation between biodiversity (e.g., wildlife species richness [53-56] or plant diversity [57]) and human population. One explanation is that both biodiversity and population may simply co-vary with environmental parameters [57], thus justifying the structural equation model fitting approach used in the present study. Indeed, in their recent study, Davies et al. [57] demonstrated that environmental energy (measured as actual evapotranspiration) predicts human population density in southern Africa, but that biodiversity has a stronger predictive power for human population density in the same region, suggesting that there is more than a simple covariation of both biodiversity and population with environmental parameter in the relationship between biodiversity and human population. Our study complements that of ref. [57] suggesting that it is not just population density that correlates with biodiversity but also population growth too. Both studies therefore highlight how close is the link between biodiversity and human population.

Another explanation for the positive link between biodiversity and human population is that biodiversity provides to human a life support system through the provision of various ecosystem services, including regulating (e.g., carbon sequestration and clean air), provisioning (e.g., food and medicine) and cultural services [58,59]. Specifically, areas richer in biodiversity (e.g., phylogenetic plant diversity) correspond to areas with greater ecosystem services [57,60] that improve human well-being [60], and such areas match areas with high human population settlement in southern Africa [57]. Our finding suggests that biodiversity may drive population dynamic, mirroring the predictions of the Malthusian theory which indicates that resource availability (here biodiversity) would drive changes in population to a certain point in time where population would overtake resource growth, leading to the Malthusian crisis [61].

One of the manifestations of the Malthusian crisis is environmental degradation due to over-exploitation of natural resources grounded on exponential population growth [61]. It is therefore not surprising that we found a significant negative relationship between biodiversity habitat (here, wetland area) and human population in our study, reflecting the impacts of anthropogenic pressures on natural resources. Such pressures include demand for energy, demand of land for agriculture and demand for many more ecosystem services (e.g., water purification) that wetlands provide to human [62,63]. In search for these services, human eventually over-exploit wetlands (and natural habitats at large; [64], leading to the reduction of the extent of such sensitive ecosystem, thus justifying the negative relationships we found between wetland area and human population over the last 30 years. For example, 65% of South Africa's wetland ecosystems are at risk of collapse, and 22% of South Africa's natural terrestrial habitats are already lost, the most important loss occurring particularly in fynbos, grasslands, and Indian ocean costal belt [64] – the conservation conflict of Balmford et al. [53]. It is also reported elsewhere that population drives the loss of biodiversity (e.g., [57,65], and this loss may lead to uncalled-for consequences on human species itself [66], thus calling for actions to fix population growth.

What drives population growth? Apart from biodiversity as reported above, we also found that economic growth (GDP) is a significant and positive predictor of population change. The positive relationship between the two, i.e., the economy and population, is not unique to this study [15,19]. The impact of economic growth on population change can be explained by the economically sustained technological advancements. Such advancements improve healthcare and food security, which in turn lead to higher birth rate and lower mortality rates as well as increased food productivity that stimulates population growth as predicted in the Malthusian theory. As a support to this, ref. [20] found that well-off people who traditionally exhibit low fertility rate are now showing high fertility rate due to technological advancement. Other studies have also reported significant relationships between economic performance and different indicators of population such as child nutrition, infant mortality, and suicide rates [13,14,67].

 doi:10.20944/preprints202206.0011.v1

4.2. Distal drivers of population

4.2.1. *Economy, air pollution, and biodiversity*

We found a significant positive relationship between economic performance and air pollution. The energy fuelling South Africa's economy is heavily based on coal [68], which is a source of dirty energy. It is therefore not surprising that we found a positive and significant correlation between South Africa's economy and pollution. Our indicator of pollution is methane, a GHG linked to climate change [69]. As such, industrialisation coupled with over-reliance on conventional energy sources such as coal may be driving economic development, but this is not environmentally sustainable, calling for a progressive transition to green economy.

Several studies have observed similar patterns both at country and regional contexts [70-72]. However, there is an emerging dissociation of GDP from atmospheric pollution, which may be driven by increasing adoption of clean energy resources, especially in developed regions [73,74]. This pattern, however, cannot be expected in developing regions which are still in the early stages of economic development and with heavy reliance on fossil fuels such as coal and biomass [75]. These contrasting observations between developed and developing regions align to the Environmental Kuznets Curve (EKC) hypothesis which states that environmental pollution would proportionally increase in response to economic development until a critical point is reached [76]. This critical point, which is characterised by high income levels, would enable a transition towards the adoption of cleaner energy sources and less emission-intensive economy. This is supported by a recent study which shows that economic growth in South Africa is strongly linked to the emission of major air pollutants [77]. This then suggests that, unless moderating measures are instituted, the South African emissions levels will continue to rise in response to the need for economic growth until an optimal economic standard is achieved which will then enable the decoupling of atmospheric emissions from economic performance.

Furthermore, we also found that the economy is positively linked to biodiversity (measured as species protection index). Several authors have demonstrated the biodiversity-economy nexus [78-80]. Economic growth may promote species protection by making the resources necessary for biodiversity conservation available. Conversely, it can also hamper species protection by threatening the establishment and maintenance of protected areas [81]. In South Africa, some protected areas are largely dependent on financial support from the state, although few financially self-sustaining protected areas are also recorded in the country [82], supporting the relationship we found between biodiversity and economy. It is evident, however, that species protection is more complex and dependent on a myriad of factors which transverse economic, cultural, and political factors. Therefore, this presents an important opportunity for future research on the drivers of biodiversity protection in a country like South Africa that is rich in endemic biodiversity, and with a history of biodiversity-linked international relations, deep cultural values that are aligned to nature, and substantial economic reliance on ecotourism.

Finally, we found a significant positive relationship between air pollution and biodiversity. This is because, as showed above, both biodiversity and pollution co-vary with economy.

4.2.2. *Governance and its impact on the economy and biodiversity*

Governance, which is measured by the level of government effectiveness and control of corruption, was shown to significantly impact the economy and biodiversity. When considering the level of corruption as an indicator for governance, the negative link we found between governance and economic performance was expected as economic growth is reliant on good governance. As indicated by Dalyop [29], poor governance leads to increased uncertainty and risks which reduce investment and the overall economic performance. Surprisingly, government effectiveness, as another indicator for governance, was found to be negatively related to the economic performance. The potential reason for this observation may be related to the metric for measuring government effectiveness. The indicator for government effectiveness was derived from public perceptions which may not reflect the actual government performance driving economic growth. This is because public perception may be informed by factors that do not reflect the actual performance of a subject [83]. The issue of governance and economic performance is particularly more complex in South Africa, given its historical and contemporary political and socio-economic structures. Not only is it relevant for governance to influence economic performance, but economic performance may also impact government effectiveness and control of corruption. This is more important in a country that has high levels of social and economic inequality that resulted from decades of racial discrimination against majority ethnic groups. Consequently, the worsening economic conditions among previously marginalised groups have often resulted in violent public outbreaks and political riots [35,36].

The results of the current study also show that governance is positively related to biodiversity. This mirrors existing studies which explored the significance of government effectiveness in achieving biological conservation [84-86]. Good governance, as a function of government effectiveness and control of corruption, may positively influence species protection through the promulgation of conservation policies and economic regulations that promote species protection. A study by Chidakel et al. [86] found that a lack of accountability from key governance institutions may threaten the feasibility of protected areas in South Africa.

Overall, instead of the traditional correlation between economic growth and population change as predicted by the Malthusian theory, we showed in the present study that environmental factors, specifically biodiversity also predicts population growth. However, we also found evidence for conservation conflict since we found a negative correlation between wetland area and population growth, thus calling for the need to fix population growth for sustainability purpose or at least educate population on sustainability issues. However, the question is: can environmental education be successful when people's priority is elsewhere (e.g., food insecurity, job)? Such correlation was not found for any of the social factors we tested, calling for continued commitment to further investigate the social factors that may underlying population growth.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, **Figure S1:** Distribution and Pattern of Missing Data; **Figure S2**: Possible combinations of indicators selected following Method 2 (see subsection 'Selection of indicators to represent each of the 5 variables' in Method section). Each acronym represents an indicator of a given variable and the meaning of each acronym as well as the corresponding variable are in Table S1.; **Table S1**: Variables used in this study as well as their indicators and sources; **Table S2.1** Raw data collected; **Table S2.2** Scaled data; **Table S3**: The results of the stepwise regression with population as the response variable (Indicator Selection Method 1). *Indicators in red are selected as an indicator for each predictor variable; p-values highlighted in green are significant as per our chosen threshold ($p<0.05$); **Table S4**: The pairwise regression of indicators for each variable (Indicator Selection Method 2). The indicators highlighted in yellow were selected for further analysis using SEM, and the regression coefficients that are written in bold are considered to be strongly significant (coefficient ≥0.5); **Table S5:** AIC and BIC values for each of the 135 SEMs resulting from the selected indicator combinations in Figure S2. **R script:** R script used in this analysis.

Author Contributions: Conceptualization, K.Y.; methodology, B.P. and K.Y.; validation, K.Y.; formal analysis, B.P.; investigation, B.P. and K.Y.; resources, B.P. and K.Y.; data curation, B.P. and K.Y.; writing—original draft preparation, B.P.; writing—review and editing, K.Y.; supervision, K.Y.; project administration, K.Y. All authors have read and agreed to the published version of the manuscript.

Funding: K.Y. received funding from the National Research Foundation Incentive Funding for Rated Researchers grant # 146104P.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Johannesburg (ref, 2022-02-04/*Phogole_Yessoufou*).

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available as supplemental information.

Acknowledgments: We thank the National Research Foundation Incentive Funding for Rated Researchers grant # 146104P.

Conflicts of Interest: The authors declare no conflict of interest.

References

1- Bonggarts J. (2016) Slow down population growth. Nature 530, 409-412

2- Bongaarts, J. (2009). Human population growth and the demographic transition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1532): 2985-2990.

3- Lee, R. D. (2003). The demographic transition: Three centuries of fundamental change. *Journal of Economic Perspectives*, 17(4): 167–190.

4- Zimmer, A., Guido, Z., Tuholske, C., Pakalniskis, A., Lopus, S., Caylor, K. & Evans, T. (2020). Dynamics of population growth in secondary cities across southern Africa. *Landscape Ecology*, 35(11): 2501-2516.

5- Lima, M. & Abades, S. (2015). Malthusian Factors as Proximal Drivers of Human Population Crisis at Sub-Saharan Africa. *Frontiers in Ecology and Evolution*, 3: Article 130.

6- Nieves, J., Stevens, F., Gaughan, A., Linard, C., Sorichetta, A., Hornby, G., Patel, N. & Tatem, A. (2017). Examining the correlates and drivers of human population distributions across low- and middle-income countries. *Journal of The Royal Society Interface*, 14(137): Article 20170401.

7- Henderson, K. & Loreau, M. (2018). How ecological feedbacks between human population and land cover influence sustainability. *PLOS Computational Biology*, 14(8): Article e1006389.

8- UN DESA (United Nations Department of Economic and Social Affairs). (2021). Global population growth and sustainable development goals. Available at: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2022_global_population_growth.pdf

9- Roser, M., Ritchie, H. & Ortiz-Ospina, E. (2019). World Population Growth. Available at: https://ourworldindata.org/world-population-growth.

10- Bucci, A. (2015). Product proliferation, population, and economic growth. *Journal of Human Capital*, 9: 170-197.

11- Peterson, E. (2017). The Role of Population in Economic Growth. *SAGE Open*, 7(4): Article 215824401773609.

12- Hosen, A. (2019). The Stability of Population and GDP Growth: A Comparative Analysis Among Different Nations in the World. *International Journal of Business and Economics Research*, 8(4): Article 180.

13- Headey, D.D. (2013). Developmental drivers of nutritional change: a cross-country analysis. *World Development*, 42: 76–88

14- Coope, C., Gunnell, D., Hollingworth, W., Hawton, K., Kapur, N., Fearn, V., Wells, C. and Metcalfe, C. (2014). Suicide and the 2008 economic recession: Who is most at risk? Trends in suicide rates in England and Wales 2001–2011. *Social Science & Medicine*, 117: 76-85.

15- Degu, A. (2019). The Nexus Between Population and Economic Growth in Ethiopia: An Empirical Inquiry. *International Journal of Business and Economic Sciences Applied Research*, 12(3).

16- Bretschger L. 2020 Malthus in the light of climate change. European Economic Review 127, 103477

17- Malthus T. 1798. An Essay on the Principle of Population as it Affects the Future Improvement of Society. J. Johnson in St Paul's Churchyard, London.

18- Strydom, N. & Struweg, J. (2016). Malthus revisited: Long-term Trends in South African Population Growth and Agricultural Output. *Agrekon*, 55(1-2): 34-6.

19- Montano, B. & Garcia-Lopez, M. (2020). Malthusianism of the 21st century. *Environmental and Sustainability Indicators*, 6: Article 100032.
20- Myrskylä M., Kohler H-P, Billari FC 2009 Advances in Development Reverse Fertility Declines. *Nature* 460, 741-743.
21- Taagepera, R. (2014). A world population growth model: Interaction with Earth's carrying capacity and technology in limited space. *Technological Forecasting and Social Change*, 82: 34-41.
22- Lanz, B., Dietz, S. & Swanson, T. (2017). Global population growth, technology, and Malthusian constraints: a quantitative growth theoretic perspective. *International Economic Review*, 58(3): 973-1006.
23- Patnaik, R. (2018). Impact of Industrialization on Environment and Sustainable Solutions – Reflections from a South Indian Region. *IOP Conference Series: Earth and Environmental Science*, 120: Article 012016.
24- Nabi, A., Shahid, Z., Mubashir, K., Ali, A., Iqbal, A. & Zaman, K. (2020). Relationship between population growth, price level, poverty incidence, and carbon emissions in a panel of 98 countries. *Environmental Science and Pollution Research*, 27(25): 31778-31792.
25- Barbier, E. & Hochard, J. (2018). Land degradation and poverty. *Nature Sustainability*, 1(11): 623-631.
26- Temesgen, M., Getahun, A. & Lemma, B. (2019). Livelihood Functions of Capture Fisheries in Sub-Saharan Africa: Food Security, Nutritional, and Economic Implications. *Reviews in Fisheries Science & Aquaculture*, 27(2): 215-225.
27- Agbo, K., Walgraeve, C., Eze, J., Ugwoke, P., Ukoha, P. & Van Langenhove, H. (2021). A review on ambient and indoor air pollution status in Africa. *Atmospheric Pollution Research*, 12(2): 243-260.
28- Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N., Baldé, A.B., Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N., Chiles, T., Mahidol, C., Coll-Seck, A.M., Cropper, M.L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K.V., McTeer, M.A., Murray, C.J.L., Ndahimananjara, J.D., Perera, F., Potočnik, J., Preker, A.S., Ramesh, J., Rockström, J., Salinas, C., Samson, L.D., Sandilya, K., Sly, P.D., Smith, K.R., Steiner, A., Stewart, R.B., Suk, W.A., van Schayck, O.C.P., Yadama, G.N., Yumkella, K. & Zhong, M. (2018). The Lancet Commission on pollution and health. *Lancet*, 391: 462-512.
29- Dalyop, G.T. (2019). Political instability and economic growth in Africa. *International Journal of Economic Policy Studies*, 13: 217–257.
30- Lederman, D., Loayza, N.V. & Soares, R.R. (2005). Accountability and corruption: political institutions matter. *Economics and Politics*, 17(1): 1 – 35.
31- Shabbir, G., Anwar, M. & Adil. (2016). Corruption, political stability, and economic growth. *The Pakistan Development Review*, 55(4): 689 – 702.
32- Kesar, A., Kamaiah, B., Jena, P. K., & Yadav, M. P. (2022). The Asymmetric Relationship between Corruption, Political Stability and Economic Growth: New Evidence from BRICS Countries. *The Indian Economic Journal*, https://doi.org/10.1177/00194662221082204.
33- Zheng, Z. (2018). Reproductive behaviour and determinants in a low-fertility era in China. *Asian Population Studies*, 15(2): 127-130.
34- Alpermann, B. & Zhan, S. (2019) Population Planning after the One Child Policy: Shifting Modes of Political Steering in China. *Journal of Contemporary China*, 28(117): 348–366.
35- Cillier, J. & Aucion, C. (2016). Economics, governance and instability in South Africa. Institute for Security Studies. Available at: https://www.researchgate.net/publication/305034098_Economics_Governance_and_Instability_in_South_Africa.
36- Matshoba, A. (2022). July riots rob SA economy of above 5% growth. Available at https://www.moneyweb.co.za/news/economy/july-riots-rob-sa-economy-of-above-5-growth/.
37- RSA (Republic of South Africa). (2021). Geography and climate. Available at: https://www.gov.za/about-sa/geography-and-climate.

38- Seymore, R., Inglesi-Lotz, R. & Blignaut, J. (2014). A greenhouse gas emissions inventory for South Africa: A comparative analysis. *Renewable and Sustainable Energy Reviews*, 34: 371–379.

39- Stats SA (Statistics South Africa). (2021). Mid-year population estimates. Available at: http://www.statssa.gov.za/publications/P0302/P03022021.pdf

40- Turok, I. & Borel-Saladin, J. (2014). Is urbanisation in South Africa on a sustainable trajectory?, *Development Southern Africa*, 31(5): 675-691

41- Stats SA (Statistics South Africa). (2022). Quarterly Labour Force Survey (QLFS) – Q4:2021. Available at: http://www.statssa.gov.za/publications/P0211/Media%20release%20QLFS%20Q4%202021.pdf

42- Bruce, D. (2014). Addressing corruption in South Africa. *SA Crime Quarterly*, 48: 49 – 62.

43- Stats SA (Statistic South Africa). (2019). Inequality trends in South Africa: A multidimensional diagnostic of inequality. Available at: https://www.statssa.gov.za/publications/Report-03-10-19/Report-03-10-192017.pdf

44- Vhumbunu, C.H. (2021). The July 2021 Protests and Socio-Political Unrest in South Africa: Reflecting on the Causes, Consequences and Future Lessons. *Conflict trends*, 3: 3 – 13.

45- Wendling, Z.A., Emerson, J.W., de Sherbinin, A., Esty, D.C. (2020). 2020 Environmental Performance Index. Available at: https://epi.yale.edu/downloads/epi2020report20210112.pdf

46- R Development Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

47- Van Buuren, S. (2021). Package 'MICE'. Available at: https://cran.r-project.org/web/packages/mice/mice.pdf

48- Burgette, L.F. & Reiter, J.P. (2010). Multiple imputation for missing data via sequential regression trees. *American Journal of Epidemiology*, 172(9): 1070 – 1076.

49- Fan, Y., Chen, J., Shirkey, G., John, R., Wu, S., Park, H. & Shao, C. (2016). Applications of structural equation modeling (SEM) in ecological studies: an updated review. *Ecological Processes*, 5(1): DOI 10.1186/s13717-016-0063-3

50- Rosseel, Y. (2022). Package "Lavaan". Available at: https://cran.r-project.org/web/packages/lavaan/lavaan.pdf

51- Savalei, V. (2014) Understanding Robust Corrections in Structural Equation Modeling. *Structural Equation Modeling: A Multidisciplinary Journal*, 21(1): 149-160.

52- Capmourteres, V. & Anand, M. (2016). Assessing ecological integrity: A multi-scale structural and functional approach using Structural Equation Modeling. *Ecological Indicators*, 71: 258-269.

53- Balmford, A., Moore, J.L., Brooks, T., Burgess, N., Hansen, L.A., Williams, P. & Rahbek, C. (2001). Conservation conflicts across Africa. *Science*, 291: 2616–2619.

54- Chown, S.L., Van Rensburg, B.J., Gaston, K.J., Rodrigues, A.S.L. & Van Jaarsveld, A.S. (2003). Energy, species richness, and human population size: conservation implications at a national scale. *Ecological Applications*, 13: 1233–1241.

55- Evans, K.L., Van Rensburg, B.J., Gaston, K.J. & Chown, S.L. (2006). People, species richness and human population growth. *Global Ecology and Biogeography*, 15: 625–636.

56- Luck, G.W. (2007). A review of the relationships between human population density and biodiversity. *Biological Reviews*, 82: 607–645.

57- Davies, T.J., Maurin, O., Yessoufou, K., Daru, B.H., Bezeng, B.S., Schaefer, H., Thuiller, W. & Van der Bank, M. (2021). Tree phylogenetic diversity supports nature's contribution to people, but is at risk from human population growth. *bioRxiv*, preprint. Doi: https://doi.org/10.1101/2021.02.13.430985.

58- Daily, G.C. (Ed). (1997). *Nature's services*. Island Press, Washington, DC.

59- Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press, Washington DC.

60- Molina-Venegas, R. (2021). Conserving evolutionarily distinct species is critical to safeguard human well-being. *Scientific Reports*, 11: Article 24187.

61- Malthus, T.R. (1890). *An essay on the principle of population*. Ward, Lock and Co: London.

62- Verhoeven, J.T.A., Arheimer, B., Yin, C. & Hefting, M.M. (2006). Regional and global concerns over wetlands and water quality. *Trends in Ecology and Evolution*, 21(2): 96-103.
63- Nyman, J.A. (2011). Ecological Functions of Wetlands. In: LePage, B. (eds) *Wetlands*. Springer, Dordrecht. Available at: https://doi.org/10.1007/978-94-007-0551-7_6.
64- Skowno, A.L., Jewitt, D. & Slingsby, J.A. (2021). Rates and patterns of habitat loss across South Africa's vegetation biomes. *South African Journal of Science*. 117(1/2): Article 8182.
65- Mehring, M, Mehlhaus, N, Ott, E. & Hummel, D. (2020). A systematic review of biodiversity and demographic change: A misinterpreted relationship? *Ambio*, 49: 1297–1312
66- Pavoine S., Bonsall M.B., Davies T.J., Masi S. (2019). Mammal extinctions and the increasing isolation of humans on the tree of life. Ecology and Evolution 9, 914-924
67- Baird, S., Friedman, J. & Schady, N. (2011). Aggregate income shocks and infant mortality in the developing world. *The Review of Economics and Statistics*, 93(3): 847–856.
68- Stats SA (Statistic South Africa). (2015). The importance of coal. Available at: https://www.statssa.gov.za/?p=4820.
69- UNEP (United Nations Environmental Programme). (2021). Methane emissions are driving climate change. Here's how to reduce them. Available at: https://www.unep.org/news-and-stories/story/methane-emissions-are-driving-climate-change-heres-how-reduce-them#:~:text=Methane%20is%20also%20a%20powerful,keeping%20began%20in%20the%201980s.
70- Altieri, K. & Stone, A. (2016). Prospective air pollutant emissions inventory for the development and production of unconventional natural gas in the Karoo basin, South Africa. *Atmospheric Environment*, 129: 34-42.
71- Deshmukh, P., Kimbrough, S., Krabbe, S., Logan, R., Isakov, V. & Baldauf, R. (2020). Identifying air pollution source impacts in urban communities using mobile monitoring. *Science of The Total Environment*, 715: Article 136979.
72- Joshua, U., Bekun, F. & Sarkodie, S. (2020). New insight into the causal linkage between economic expansion, FDI, coal consumption, pollutant emissions and urbanization in South Africa. *Environmental Science and Pollution Research*, 27(15): 18013-18024.
73- Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., Mayer, A., Pichler, M., Schaffartzik, A., Sousa, T., Streeck, J. & Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. *Environmental Research Letters*, 15(6): Article 065003.
74- Ritchie, H. (2021). Many countries have decoupled economic growth from CO_2 emissions, even if we take offshored production into account. Available at: https://ourworldindata.org/co2-gdp-decoupling.
75- IEA (International Energy Agency). (2021). Global energy review: Coal. Available at: https://www.iea.org/reports/global-energy-review-2021/coal.
76- Wang, W. (2018). Region EKC for Air Pollution: Evidence from China. *Environment and Pollution*, 7(1):46 - 52.
77- Shikwambana, L., Mhangara, P. & Kganyago, M. (2021). Assessing the Relationship between Economic Growth and Emissions Levels in South Africa between 1994 and 2019. *Sustainability*, 13: Article 2645.
78- Waldron A., Mooers A.O., Miller D.C., Nibbelink N., Redding D., Kuhn T.S., Roberts J.T. & Gittleman J.L. (2013). Targeting global conservation funding to limit immediate biodiversity declines. *PNAS*, 110: 12144-12148.
79- Lindsey, P.A., Miller, J.R.B., Petracca, L.S. & Hunter, L.T.B. (2018). More than $1 billion needed annually to secure Africa's protected areas with lions. *PNAS*, 115(45): 10788-10796.
80- Kauano, É., Silva, J., Diniz Filho, J. & Michalski, F. (2020). Do protected areas hamper economic development of the Amazon region? An analysis of the relationship between protected areas and the economic growth of Brazilian Amazon municipalities. *Land Use Policy*, 92: Article 104473.
81- Bezeng S. B., Yessoufou K, Taylor PJ & Tesfamichael SG 2020. Expected spatial patterns of alien woody plants in South Africa's protected areas under current scenario of climate change

82- Welz, A. (2021). The pandemic has undone South Africa's national parks. Available at: https://www.theatlantic.com/science/archive/2021/06/covid-19-tourism-conservation-south-africa/619091/.
83- Lupyan, G. (2017). How Reliable Is Perception? *Philosophical Topics*, 45(1), 81–106.
84- Sowman, M., Hauck, M., van Sittert, L, & Sundae, J. (2011). Marine Protected Area Management in South Africa: New Policies, Old Paradigms. *Environmental Management*, 47: 573–583.
85- Niedziałkowski, K., Paavola, J. & Jędrzejewska, B. (2012). Participation and protected areas governance: The impact of changing influence of local authorities on the conservation of the Białowieża Primeval Forest, Poland. *Ecology and Society*, 17(1): Article 2.
86- Chidakel, A., Candice, E., Child, B., 2020. The comparative financial and economic performance of protected areas in the Greater Kruger National Park, South Africa: functional diversity and resilience in the socio-economics of a land-scape-scale reserve network. J. Sustain. Tour. 28, 1100–1119.